University of
Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Environmental Engineering	Spring semester, 2015 Open
Writer: Thale Wilson Losnedal	…………………………………………… (Writer's signature)

Faculty supervisor: Steinar Sanni

External supervisor(s): Emily Lyng

Thesis title:

"Evaluation of metal- and PAH toxicity of thermo treated oil-based drill cuttings by the use of DREAM sediment model"

Credits (ECTS):
30

Key words: - DREAM - $\mathrm{EIF}_{\mathrm{sediment}}$ - $\mathrm{EIF}_{\mathrm{water\text{-}column}}$ - TCC-treatement - Risk assessment - Toxic stressors: metal, PAHs - Non-toxic stressors	Pages: 153 + enclosure: 33 Stavanger, 28.06.2015 Date/year

Acknowledgements

In 2008 I was given 30-40% chance of survival. I spent two and a half years at the hospital. In 2010 “they” called me a “lost case”. The completion of this thesis means that I proved “them” wrong. And for that I will forever be proud.

On an academic and professional level I would like to thank;

- My supervisor, Steinar Sanni, for providing me this assignment, for giving me the opportunity to write my thesis at IRIS, and for all the help during the way
- Emily Lyng for the help, briefings and input
- IRIS, for providing me with an office (with a view!)
- Andrea Bagi! Thank you so much for the help with the lab-results.

On a more personal level, I would like to thank:

- Mum and dad, for not giving up on me!
- My sister, my inspiration
- My partner, for your patience
- Olaug and Eli… Thanks for saving my life!

Enough said.

Abstract

Dose-related Risk and Exposure Assessment Model (DREAM) is a risk assessment tool used for modulations of offshore waste discharges effects on the marine environment. The model was first developed in order to estimated the fate of produced water discharged in the water column. The model was further developed, through the joint industrial project ERMS (Environmental Risk Management System), enabling impact calculations for the sediment as well.

The objective of this study was to evaluate the DREAM model`s ability to estimate the EIF (Environmental Impact Factor) for a TCC treated discharge, specially considering the metals and particles content. The TCC unit pulverizes oil contaminated cuttings and remove the oil through vaporization. To be able to compare and decide the particles impact on EIF, different simulations was performed, thus both treated and untreated.

The different physical and chemical stressors contribution to risk are identified though a risk and hazard assessment. The PNEC values will be identified and several assumptions and simplifications will be necessary. The DREAM model will thus be able to calculate risk for the different scenarios.

Content

MASTER'S THESIS 1

Abstract 3

1. Introduction 15
- **1.1 Background** 15
- **1.2 Objectives** 16

2. Risk Assessment 18
- **2.1 Introduction** 18
- **2.2 History – Inclusion of drilling discharges** 18
- **2.3 Principles of risk assessment** 20
- **2.4 EIF for drilling discharges** 22
- **2.5 Summary** 23

3. Hazard assessment 25
- **3.1 Drilling waste** 25
- **3.2 Composition and discharge** 25
- **3.3 Toxic stressors in drilling discharges** 28
  - 3.3.1 Metals 30
  - 3.3.2 Natural Organic Compounds 33
  - 3.3.3 Added chemicals 34
- **3.4 Non-toxic stressors in drilling discharges** 35
  - 3.4.1 Burial of organisms 36
  - 3.4.2 Oxygen depletion (Hypoxia) 38
  - 3.4.3 Change in grain size 40
- **3.5 Summary** 42

4. Thermal cutting treatment 44
- **4.1 Thermomechanical Cuttings Cleaner (TCC)** 45
  - 4.1.1 Offshore discharge of Processed Cuttings 47

5. Exposure Assessment 49
- **5.1 DREAM** 49
- **5.2 ParTrack** 54

6. Effect Assessment 56
- **6.1 Environmental effects of OBM drilling discharges (general)** 56
- **6.2 Determination of PNEC values** 57
  - 6.2.1. Assessment factors 58
  - 6.2.2 Species Sensitivity Distribution (SSD) 60
  - 6.2.3 Equilibrium partitioning method 61
  - 6.2.4 Field monitoring data (F-PNEC) 63
- **6.3 PNEC for water column effects** 63
  - 6.3.1 Chemicals 63
  - 6.3.2 Suspended Particulate Matter (SPM) 65
- **6.4 PNEC for sediment effects** 68
  - 6.4.1 Burial 68
  - 6.4.2 Oxygen depletion (Hypoxia) 69
  - 6.4.3 Change in sediment structure (grain size) 70
  - 6.4.4 Chemicals 71

7. Methodology 74
- **7.1 Size distribution of particles found in thermally treated drill cuttings** 74
- **7.2 Model Setup** 80

8. Results 88
8.1 Simulation 1; Untreated drilling waste discharged in two batches. The PAH concentrations was excluded. 90
8.1.1 Sediment 90
8.1.2 Water Column 95
8.2 Simulation 2; Treated drilling waste discharged in two batches. The PAH concentrations was excluded. 99
8.2.1 Sediment 99
8.2.2 Water Column 104
8.3 Simulation 3; Drilling waste discharged in two batches. Particle size as for treated discharge and metal concentrations as for untreated discharge. PAH concentrations excluded. 108
8.3.1 Sediment 109
8.3.2 Water Column 114
8.4 Simulation 4; Treated drilling waste in two batches. PAH concentrations included. 119
8.4.1 Sediment 120
8.4.2 Water column 125
8.5 Simulation 5; Untreated drilling waste in two batches. PAH concentrations included. 130
8.5.1 Sediment 130
8.5.2 Water column 136
9. Discussion and conclusion 141
Refrences: 147
Appendix A 154
Appendix B 165
Appendix C 176

List of Figures

Figure 2.1: Overview of short and long-term disturbances caused by the discharges of drilling waste
Figure 2.2: Framework for the EIF_{DD}. The roman numbers indicate the different steps in the risk assessment process
Figure 3.1: Thickness of the sediment layer deposited due to discharges. The PEC value is the momentary layer thickness
Figure 3.2: Change in the integrated oxygen concentration over depth
Figure 3.3: Illustration of a new layer added on top of the original sediments. The new layer has a different particle size and may contain cuttings, barite and chemicals
Figure 3.4: Illustration of the vertical distribution of the median particle size in the sediment, some years after completion of the drilling program. Mixing in the sediment is caused by the action of bioturbation
Figure 4.1: Different thermal desorption technologies
Figure 4.2: TCC simplified process flow diagram
Figure 5.1: General schematic of the DREAM model
Figure 5.2: Layout for the model structure for calculations of potential impact
Figure 5.3: Vertical cross section of the near field plume and the deposition of particles on the sea floor
Figure 6.1: Assessment factors for deriving PNECs. Defined by the TGD for marine water column
Figure 6.2: Assessment factors for deriving PNECs. Defined by the TGD for the marine sediment, from short-term sediment toxicity tests
Figure 6.3: When PEC/PNEC = 1, the probability that a random species (PAF) is effected by the toxicant and the risk on adverse effects are both 5%
Figure 6.4: The probabilistic value at which 5% of the species are likely to be affected can be derived from this figure. SSD based on the absolute natural grain size window-of-occurrence of 300 North Sea, Norwegian Sea and Barents Sea species
Figure 7.1: Sample compartment components: A) Aperture tube, B) Aperture tube knob, C) Sample platform, D) Platform release, E) External Electrode, F) Stirrer, G) Particle trap, H) LED green, amber, and white status lights
Figure 7.2: Distribution of particle classes expressed in weight percentage of the four particle diameter ranges.

Figure 7.3: Distribution of particle classes expressed in weight percentages of the total treated cuttings, smaller than 100 μm.
Figure 7.4: Wellbore schematic
Figure 7.5: Default values for the particulate-size distribution for cuttings
Figure 8.1: The different colours might present in a DREAM risk map and their belonging EIF intervals
Figure 8.2: Sediment risk map estimated by the model for the untreated drilling waste. Attached metals were the only toxic stressor.
Figure 8.3: Overview of the different stressors weighted contribution to risk from untreated drilling waste in the sediment, represented by a pie chart. Attached metals were the only toxic stressor accounted for.
Figure 8.4: Pie chart showing the main metal contributors to the total environmental impact in the sediment from untreated drilling waste.
Figure 8.5: Time development showing the EIF variation in the sediment over time caused by untreated drilling waste. Low EIF values over a long period of time represents a chronic EIF.
Figure 8.6: Water column risk map estimated by the model for the untreated drilling waste. Attached metals were the only toxic stressor.
Figure 8.7: Overview of the different stressors in untreated drilling waste weighted contribution to risk in the water column, represented by a pie chart.
Figure 8.8: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge of untreated drilling waste.
Figure 8.9: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by untreated drilling discharge.
Figure 8.10: Sediment risk map estimated by the model for the treated drilling waste. Attached metals were the only toxic stressor.
Figure 8.11: Overview of the different stressors weighted contribution to risk caused by treated drilling waste in the sediment, represented by a pie chart. Attached metals were the only toxic stressors accounted for.
Figure 8.12: Pie chart showing the main metal contributors to the total environmental impact in the sediment from treated drilling waste.

Figure 8.13: Time development showing the EIF variation in the sediment over time caused by treated drilling waste. Low EIF values over a long period of time represents a chronic EIF.
Figure 8.14: Water column risk map estimated by the model for the treated drilling waste. Attached metals were the only toxic stressor.
Figure 8.15: Overview of the different stressors in treated drilling waste weighted contribution to risk in the water column, represented by a pie chart.
Figure 8.16: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge of treated drilling waste.
Figure 8.17: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by treated drilling discharge.
Figure 8.18: Sediment risk map estimated by the model for the discharge type in the third simulation. Attached metals were the only toxic stressor.
Figure 8.19: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. Attached metals were the only toxic stressors accounted for. Particles size distribution and metal concentrations as for treated and untreated discharge respectively.
Figure 8.20: Pie chart showing the main metal contributors to the total environmental impact in the sediment from the type of discharge mentioned in figure 8.18.
Figure 8.21: Time development showing the EIF variation in the sediment over time caused by the waste discharged. Low EIF values over a long period of time represents a chronic EIF.
Figure 8.22: Water column risk map estimated by the DREAM model for the drilling waste from the third simulation.
Figure 8.23: Overview of the different stressors weighted contribution to risk in the water column, represented by a pie chart. Metals were the only toxic stressor accounted for.
Figure 8.24: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge in the third simulation.
Figure 8.25: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the

second batch is discharged. Representing an acute EIF caused by the drilling discharge in the third simulation.
Figure 8.26: Sediment risk map estimated by the model for the treated discharge. Both PAH concentration and the metal concentrations are accounted for.
Figure 8.27: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. The PAH concentrations in the treated drilling waste was not significant enough to contribute to the total EIF (see table 8.7).
Figure 8.28: Pie chart showing the main metal contributors to the total environmental impact in the sediment from treated drilling waste.
Figure 8.29: Time development showing the EIF variation in the sediment over time caused by the treated drilling waste discharged. Low EIF values over a long period of time represents a chronic EIF.
Figure 8.30: Water column risk map estimated by the DREAM model for the treated drilling waste.
Table 8.31: Overview of the different stressors weighted contribution to risk from treated drilling waste in the water column, represented by a pie chart.
Figure 8.32: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by treated drilling waste discharge.
Figure 8.33: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by the treated drilling waste.
Figure 8.34: Sediment risk map estimated by the model for the untreated discharge. Both PAH concentration and the metal concentrations are accounted for.
Figure 8.35: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. The PAHs was the major risk contributors.
Figure 8.36: Pie chart showing the main metal contributors to the total environmental impact in the sediment from untreated drilling waste.
Figure 8.37: Time development showing the EIF variation in the sediment over time caused by the untreated drilling waste discharged. Relatively low EIF values over a long period of time represent a chronic EIF.
Figure 8.38: Water column risk map estimated by the DREAM model for the untreated drilling waste.

Figure 8.39: Overview of the different stressors weighted contribution to risk from untreated drilling waste in the water column, represented by a pie chart.
Figure 8.40: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by untreated drilling waste discharge.
Figure 8.41: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by the untreated drilling waste.

List of Tables

Table 3.1: Overview of base oils used fro drilling from a historical perspective
Table 3.2: Candidate chemicals for use in the risk calculations (EIF) for drilling discharges
Table 3.3: Heavy metal content in barite and in natural sediment on the NCS. The table shows the span of concentrations in barite between various mines/suppliers
Table 3.4: Selection of metals for inclusion in calculation of environmental risk of drilling discharges in the sediment compartment and water column. The metals selected are highlighted
Table 3.5: Functional groups of chemicals with use greater than 1000 tonnes and discharge greater than 100 tonnes on the NCS in 2004
Table 3.6 Threshold values for non-toxic stressors in the sediment.
Table 6.1: PNEC values and background concentrations derived by the use of the dutch MPC_{water} method. (NC_{water} is the Neglible Concentration for metals for marine surface waters)
Table 6.2: Derivation of PNECs for different weighting materials based on acute toxicity data and by using assessment factors
Table 6.3: overview of EC50 data for different weighting materials to construct the SSDs
Table 6.4: Overview of assessment factors applied to the HC_5 to derive the PNEC level
Table 6.5: PNET values for burial in both exotic and native sediments
Table 6.6: $\log K_d$ values derived through an empirical study done by Schaanning *et. al.* (2011). The recommended partition coefficient values are used in the DREAM model to estimate metal concentrations in sediments and interstitial waters.
Table 6.7: PNEC values for the dissolved heavy metals in pore water sediment. Water column toxicity for dissolved heavy metals is assumed valid for dissolved heavy metal toxicity in pore water as well.
Table 7.1: Initial weight and weight of the particles on top of each sieve.
Table 7.2: Summary of measurement results showing the distribution of cuttings particles in six size ranges, expressed as weight percentage (w/w%). S. D. stands for standard deviation.
Table 7.3: x w/w% of fraction 3 (smaller than 100 μm), particles are in the given size range.
Table 7.4: metal content in the drilling waste analysed (not accredited analysis)

Table 7.5: PAH content in the drilling waste analysed (not accredited analysis)
Table 7.6: Overview over the salinity and temperature profiles used in the simulations.
Table 8.1: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment. Attached metals were the only toxic stressor accounted for.
Table 8.2: Overview of the different stressors weighted contribution to risk and to the EIF value caused by untreated drilling waste in the water column.
Table 8.3: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by treated drilling waste. Attached metals were the only toxic stressor accounted for.
Table 8.4: Overview of the different stressors weighted contribution to risk and to the EIF value, caused by treated drilling waste in the water column.
Table 8.5: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by the drilling waste. Attached metals were the only toxic stressor accounted for. Particle size as for treated discharge and metal concentrations as for the untreated discharge.
Table 8.6: Overview of the different scenarios (1: untreated discharge, 2: TCC treated discharge, 3: TCC treated particle size, untreated metal concentration) and the different risk contributors given in per cent.
Table 8.7: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by the discharge in the third simulation
Table 8.8: Overview of the drifferent PAH groups.
Table 8.9: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by treated drilling waste.
Table 8.10: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by treated drilling waste.
Table 8.11: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by untreated drilling waste.
Table 8.12: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by untreated drilling waste.
Table 9.1: The EIF values variation and the main contributing stressors for the water column and for the sediment.

Abbrevations:

COV: Coefficient Of Variance
DD: Drilling Discharges
DREAM: Dose-related Risk and Effect Assessment Model
EIF: Environmental Impact Factor
EP: Escape Potential
ERMS: Environmental Risk Management System; A 3-year research program initiated by the oil industry to develop an environmental risk-based decision supporting tool, in order for the oil industry to establich cost-effective mitigation measures for reducing potential harmful discharges to the marine environment (SINTEF 2007)
EqP: Equilibrium Partitioning
EU-TGD: European Technical Guidance Document
F-PNEC: Field-Predicted No Effect Concentration
JIP: Joint Industry Project
LC: Lethal Concentration
Log K_{ow}/Log P_{ow}: Log Octanol-water partition coefficient. A constant which describe the tendency of a chemical to solve in an artificial biotic lipid (octanol) as compared to the solubility in water.
MPA: Maximum Permissible Addition
MPC: Maximum Permissible Concentration
NCS: Norwegian Continental Shelf
NOEC: No Observed Effects Concentration
OBM: Oil Based Mud
OSPAR: Oslo-Paris Convention
PAF: Potentially Affected Fraction
PAH: Polycyclic Aromatic Hydrocarbons
ParTrack: Particle Tracking for drilling discharges
PEC: Predicted Environmental Concentration
PET: Predicted Effect Threshold
PLONOR: List that describes chemicals that are considered to “Pose Little of No Risk”, when discharged to the marine environment
PNEC: Predicted No Effect Concentration

PNET: Predicted No Effect Threshold

PW: Produced Water

RCR: Risk Characterization Ratio

RPD: Redox Potential Discontinuity

SBM: Synthetic Based Mud

SSD: Species Sensitivity Distribution

TCC: Thermomechanical Cuttings Cleaner

THC: Total hydrocarbon concentration

TPH: Total Petroleum Hydrocarbon

UKCS: UK`s Continental Shelf

WBM: Water Based Mud

1. Introduction

1.1 Background

Norwegian authorities established in 1997 the goal of zero environmentally harmful discharges to sea from the oil and petroleum industry by the end of 2005 (Norwegian Petroleum Directorate 2011). To achieve this goal the operating companies on the Norwegian Shelf, together with external consultants, initiated the development of the DREAM (Dose-related Risk and Effect Assessment Model) model and the Environmental Impact Factor for produced water (EIF_{PW}) (Smit *et al., 2006 (*ERMS report no. 3)). The EIF_{PW} was focusing on the produced water discharges and the environmental impact in the water column, based on toxicity as the only stressor (Smit *et al., 2006 (*ERMS report no. 3)). The drilling discharges and the impact on the sediments was not taken into consideration. As a follow up of the EIF_{PW}, an EIF for drilling discharges was developed (EIF_{DD}).

The EIF_{PW} is predicted by the DREAM model based on information about local oceanographic conditions and volumes and compositions of the produced water discharges. The EIF for drilling discharges also takes into account risk in the sediment compartment by estimation of the area of sea floor that contains high enough concentrations of drilling chemicals to exceed pre-determined toxicity threshold values (Frost *et. al.*, 2006 (ERMS report no. 4)). EIF_{DD} do additionally cover other parameters than toxicity due to the sinking of cuttings to the seafloor. Burial, oxygen depletion, changes in grain size in the sediments and disturbances due to the presence of suspended particulate matter in the water column are the nontoxic stressors accounted for (Frost *et. al.*, 2006 (ERMS report no. 4)).

Most of the mass of drilling discharges is composed of solids that settle rapidly from the water column, down-current from the point of discharge. DREAM can predict the extent of deposition of solids on the sea floor, and the concentrations of the drilling chemicals of concern, e.g. heavy metals, hydrocarbons and PAHs (Polycyclic Aromatic Hydrocarbons). These data is then used to predict the area of sea floor where toxicity threshold concentrations of the drilling chemicals in sediments exceed predetermined toxicity thresholds (Frost *et. al.*, 2006 (ERMS report no. 4)). DREAM also predicts the effects of the drilling discharges in the water column regarding concentrations of dissolved chemicals.

Oil-based mud (OBM) drilling discharges is prohibited on the Norwegian Continental Shelf (NCS). Particles with Total Hydrocarbon Concentration (THC)/PAHs/heavy metals will either stay in the water column or sink down to the seabed and could thereby influence organisms in both the sediments and the water column (Blytt *et. al.,* 2014). The impact on the environment is potentially huge if the drill cuttings are not treated properly. In Norway today, the OBM cuttings and waste products are transported to shore for further treatment and disposal. Enabling waste treatment offshore would be more environmental friendly and cost-effective compared to the emissions and expenses related to transportation by boats and/or re-injection.

Thermomechanical Cuttings Cleaner (TCC) is a relatively new cleaning method for oily waste. The oil and water will evaporate due to the heat created by the friction generated when crushing the rocks. The oil and water vapours are then fed through the TCC condensing system and recovered (Halliburton). The environmental regulations are becoming stricter in many oil-producing territories. The TCC is able to efficiently separate the oil from the solids, enabling the oil to be commercialized, and ensuring the solids to become non-hazardous to the environment (Thermtech AS).

1.2 Objectives

The scope of this thesis is divided into three objectives, all of them linked together in the following specific order:

1) First of all, is the DREAM tool a suitable method for estimation of EIF values for drilling discharges treated offshore by TCC? How should these EIF values be interpreted according to relevance?
2) Secondly, based on the first objective, the model should be evaluated regarding the particle content, metal concentration and PAH concentration in the discharge.

3) If the results from 1) and 2) seem to be reasonable, can it be used to anticipate environmental positive or negative risks? If not, what improvements need to be done?

Literature review will be performed in order to search for toxicological data and information that fulfil the recommendations in the EU Technical Guidance Document on Risk Assessment (EU-TGD) for calculation on predicted no effect concentrations for relevant substances. The major contributing model factors will be identified in order to understand which factors are important to consider.

2. Risk Assessment

2.1 Introduction

The ratio of exposure and sensitivity gives an indication of the likelihood of adverse effects to occur as a result of the anticipated exposure. This is a universal methodology where they comprise a comparison of the exposure of the ecosystem to a chemical with the sensitivity of the ecosystem for this chemical. The exposure is often represented by the PEC and the sensitivity is often expressed in a PNEC (Smit et. al., 2005 (ERMS report no. 10)). The PEC/PNEC ratio is also known as RCR – Risk Characterization Ratio. This is only used to indicate whether or not a risk is present, and it do not provide a quantification of the environmental risk

2.2 History – Inclusion of drilling discharges

Exploration and production companies active on the NCS initiated the development of a risk assessment tool for environmental management of produced water discharges. Following the Norwegian authorities' requirements in 1997 of "zero discharges to sea by the end on 2005", the DREAM project was embodied in 1998. From this project the EIF_{PW} was developed. EIF_{PW} is an indicator of environmental risk whose purpose is to aid the industry in the development of a "zero harm" strategy and selection of cost-benefit based solutions (Singsaas *et. al.,* 2007). 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.

In order to enlarge the "toolbox" for environmental risk assessment further, the Environmental Risk Management System (ERMS) Joint Industry Project (JIP) was established to develop an EIF for drilling discharges (Singsaas *et. al.,* 2007) comparable to the EIF_{PW}. Both EIFs would form an integrated system enable the oil companies to perform risk calculations for different discharge scenarios during different operations (production and drilling). The objective of the ERMS program was to develop an environmental risk-based decision-supporting tool in order to establish cost-effective mitigation measures for reducing potential harmful discharges to the marine environment. The environmental impact factor for drilling discharges was developed as a tool to identify and quantify the environmental risks associated with disposal of drilling discharges. As an initial step in this work the main categories of substances associated with drilling discharges and assumed to contribute to toxic and nontoxic stress were identified, and further evaluated for inclusion in the risk assessment (Altin & Frost & Nilssen, 2007). 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 accounted for.

Hazard identification has indicated several important stressors related to drilling discharges (Smit *et al.,* 2006 (ERMS report no. 3)):

- Water column:
  - Toxicity of chemicals
  - Physical effects of suspended matter

- Sediments:
  - Toxicity of chemicals (organic chemicals and heavy metals)
  - Change in sediment structure – grain size
  - Oxygen depletion
  - Burial of organisms

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 the water column. The DREAM model is explained in greater detail in a later section. Figure 2.1 gives a presentation of the fates of drilling discharges (Singsaas *et. al.,* 2007).

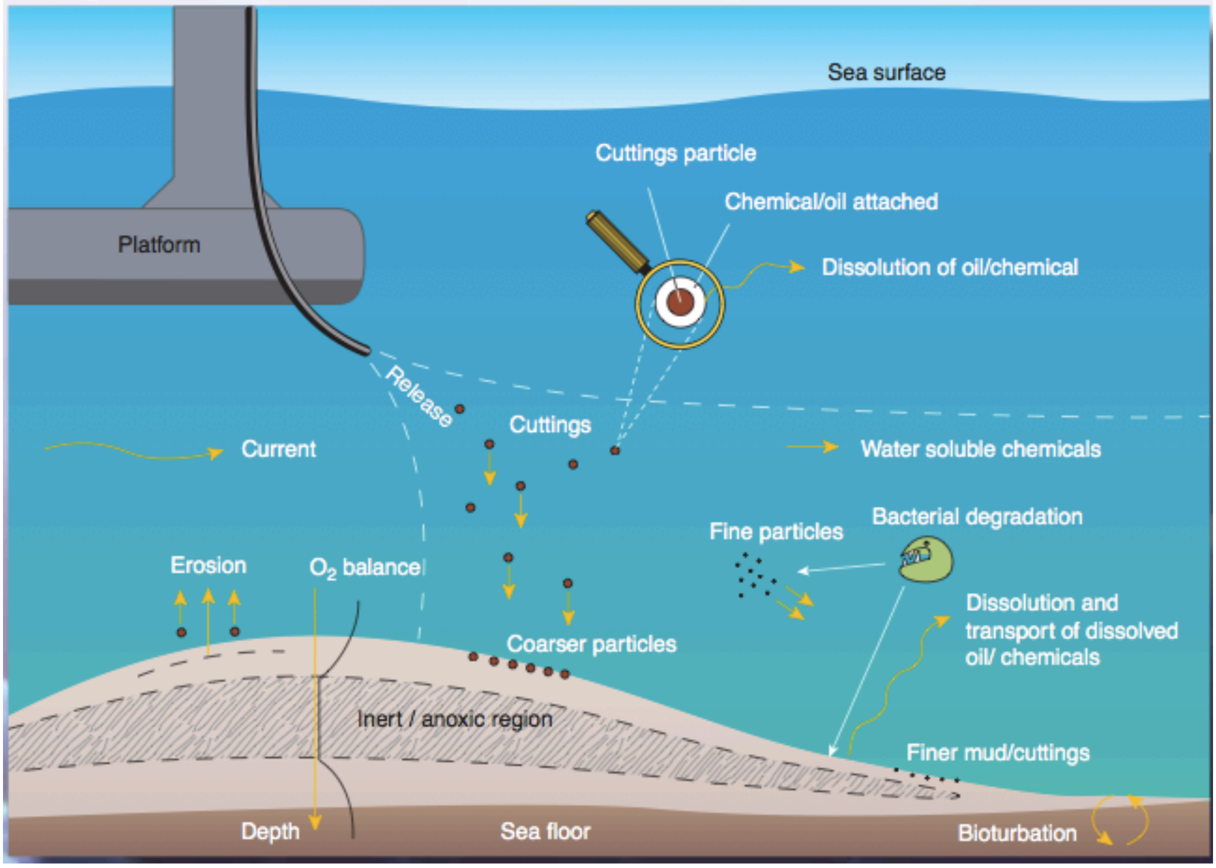


Figure 2.1: Overview of short and long-term disturbances caused by the discharges of drilling waste (Singsaas *et. al.,* 2007).

2.3 Principles of risk assessment

EU-TGD require that an environmental risk assessment should be carried out on notified new substances, on priority existing substances and active substances, and substances of concern in biocidal products (EC 2003). This risk assessment should proceed in the following sequence (also see figure 2.2) (EC 2003):

- Hazard identification
- Dose (concentration) – response (effect) assessment
- Exposure assessment
- Risk characterisation/Risk assessment

According to the EU-TGD (2003) environmental risks for chemicals may be estimated by calculating the ratio between the PEC and the PNEC for the chemicals in the same compartment (quantitative risk characterisation). The PEC is an estimate of the concentration of a chemical to which the biota will be exposed during and after discharge of the chemical (Altin & Frost & Nilssen, 2007). These values can be based on analytical data or they can be derived from model calculations (exposure assessment). The PNEC is the concentration of the chemical in the environment below which it is unlikely that adverse effects on the biota inhabiting a particular environmental compartment will occur (Frost *et. al.*, 2006 (ERMS report no. 4)). The PNEC values are usually determined on the basis of results from controlled laboratory experiments taking adequate assessment factors into account (Altin & Frost & Nilssen, 2007). The likelihood of occurrence of adverse effects from drilling discharge chemicals in the water column and in the sediments is indicated by the ratio of the PEC to the PNEC. Implementation on the approach helps to identify acceptable or unacceptable risks, providing the basis of environmental management or regulatory decisions.

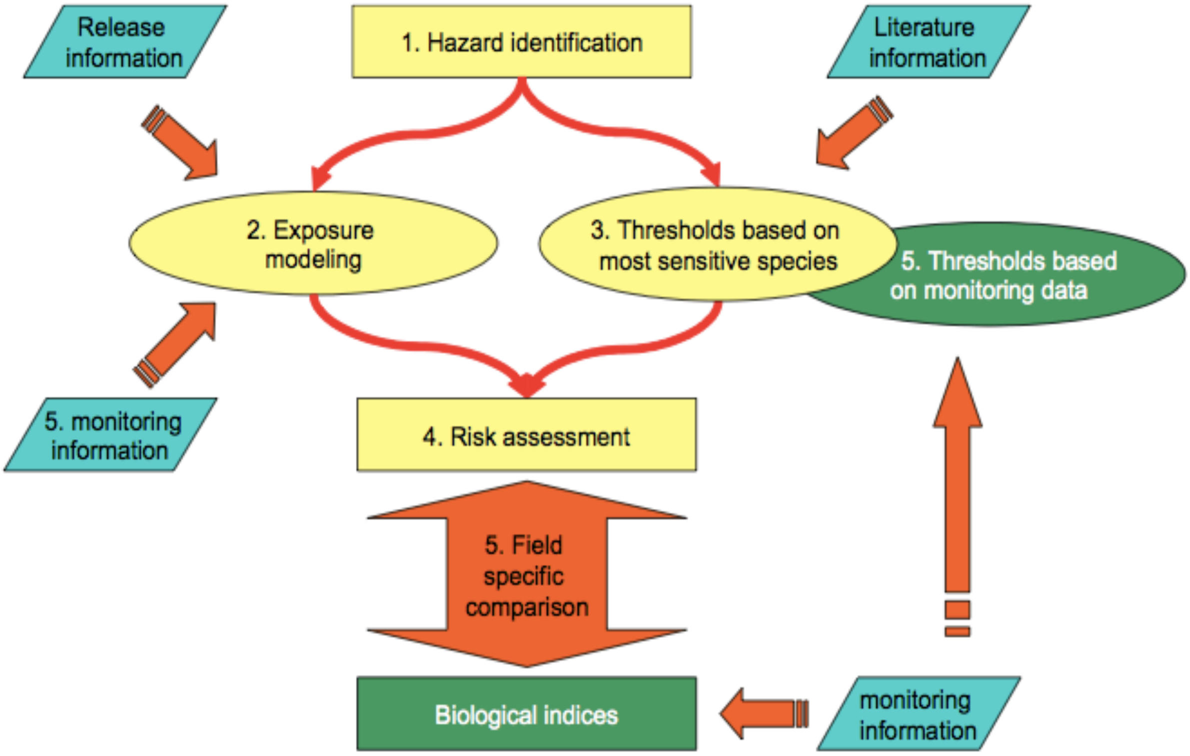


Figure 2.2: Framework for the EIF_{DD}. The numbers indicate the different steps in the risk assessment process (Smit *et al.,* 2006 *(*ERMS report no. 3)).

In general, the risk assessment phase (see figure 2.2) is carried out along the following steps (EC 2003):

- Determine the PEC/PNEC ratios for the different compartments

Dependent on these PEC/PNEC ratios:

- Determine whether further information/testing may lead to a revision of these ratios;
- Ask for further information/testing
- Refine the PEC/PNEC ratio.

→ This process should be continued until a final conclusion regarding the environmental risks can be reached.

Presuming that the relevant data are available, a direct comparison of the PEC and PNEC values is carried out. If the PEC/PNEC ratio is greater than one, the substance is "of concern" and further action has to be taken. The competent authority should consult industry in order to see if additional data on exposure and/or ecotoxicity can be obtained in order to refine assessment (EC 2003).

2.4 EIF for drilling discharges

The discharge of drilling muds and cuttings will influence two compartments; i) the water column and ii) the sediments. As mentioned above the stressors identified for the two different compartments was suspended matter and chemical concentrations in the water column, and burial, change in grain size, oxygen depletion, and chemical concentrations in the sediment. The potential impacts on the two compartments have different time frames (Smit *et al.,* 2006 *(*ERMS report no. 3)). During discharges and shortly after, exposure levels are present in the water column thus risks on adverse effects could be present as long as these exposure levels exists. The duration of water column exposure varies in the order of minutes to several days. During and long after the drilling discharges, exposure levels will be significant at the sediment surface (Smit *et al.,* 2006 *(*ERMS report no. 3)). The duration of possible exposure through the sediment is much longer compared to the one for water column, in order of months and years. The water column risks are generally referred to as acute, while the sediment risks are chronic. The total EIF_{DD} is thus an expression of two separate EIF values; $EIF_{water\ column}$ and $EIF_{sediments}$. It is an integrated measure of the overall probability of damage caused by the different stressors. This implies that different kinds of stress (toxic and physical) are combined (Smith *et al*., 2006 (ERMS report no. 9)).

The EIF_{DD} is finally calculated in the risk assessment phase (figure 2.2). Environmental risks for all stressors in the two marine compartments are estimated by calculation on PEC/PNEC ratios. In order to combine and compare the contribution of different stressors to the overall risk, Species Sensitivity Distribution (SSD) can be applied. Based on modelled 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 spatial extent, volume or area, over which the combined PAF value exceeds 5%, is taken as a basic value for the EIF_{DD} in the water column as well as in the sediment (Smit *et. al.,* 2006 (ERMS report no. 3)).

2.5 Summary

EIF_{DD} consists, as described above, of two parts: A water volume in which the joint risk probability for exposure to toxicants and suspended matter exceeds a 5% level. And, the sediment surface area where the joint risk probability for exposure to toxicants, oxygen depletion, burial, and changes in grain size exceeds the 5% level (Smit *et al.,* 2006 *(*ERMS report no. 3)).

Environmental management for offshore practices is constantly working towards a reduction of the EIF_{DD}. The two values constituting the total EIF are related to acute effects (water column) and to chronic effects (sediments). As long as this is the case, a way of weighing the two values should be defined. Focus should be on a reduction of both the time scale as well as value of the EIF.

To reduce the acute EIF for the water column the drilling waste could be discharged close to the sediment floor. This may result in a high chronic EIF for the sediment compartment. Vice versa, discharging close to the water surface would reduce the EIF for the sediment, but increase the EIF for the water column. This dilemma indicates that both EIFs should be compared in a quantitative way.

It is, however, unclear how the EIFs should be compared. A complication is that the EIFs differ in their expression (volume vs. area), and time-scale (acute/short-term (days) vs. chronic/long-term (years)). Experience with the behaviour of both EIF values needs to be gained. Procedures for a sound comparison of EIFs need to be developed (Smit *et al.,* 2006 *(*ERMS report no. 3)).

3. Hazard assessment

3.1 Drilling waste

There are three types of drilling fluids: water based mud (WBM), synthetic based mud (SBM) and oil based mud (OBM) (Frost *et. al.*, 2006 (ERMS report no. 4)). Cuttings containing small amounts of WBM, SBM, or some times OBM may be permitted for discharge to sea, depending on environmental regulations for different coastal and offshore areas of the world. Discharge of OBM cuttings to the sea have been prohibited on the Norwegian Continental Shelf (NCS) since 1993 due to its toxicity and potential harmful effects on the environment (Akvaplan-Niva AS 2010).

3.2 Composition and discharge

Environmental monitoring of discharges from the petroleum industry has been conducted since 1973. The monitoring covered mainly the area close to the offshore installations and included primarily the total hydrocarbon level (THC), PAHs and heavy metals (mercury, lead, zinc, copper, cadmium, chromium) in the sediments (Akvaplan-Niva AS 2010).

The largest-volume solid waste generated during drilling of wells offshore is drilling muds and cuttings. The cuttings vary in size, shape and texture, ranging from fine sand to gravel, depending on the rock type and drill bit used (About the industry: Drill cuttings 2009). To meet the required mud design criteria, drilling weight materials, comprising up to 90% of the mud, are used as small particles. The barite and ilmenite (weight materials) used are grained into small particles of specific grain sizes, ranging from 0.0007-0.05 mm, with a typical diameter 15-20 micrometres (Kjeilen-Eilertsen & Westerlund, 2004 (ERMS report no. 4A)). The mud is needed to keep hydrostatic overbalance in the hole, to prevent the cuttings to clog the borehole, the drill string from getting stuck and the bit from getting to warm. The fluid has different kinds of properties depending on the section being drilled. It should be able to carry the cuttings to the surface, keep the cuttings in suspension (in case of e.g. stop in the drilling procedure), lubricate the drill string, work as a cooling agent and keep the pressure in the well under control. The different well sections demand different mud densities and chemical combinations. Some of them have no effect on the environment what so ever while others can cause harmful reactions.

Drilling muds are specially formulated mixtures. The major components are a liquid (water, oil, or another organic fluid) and a weighting agent (typically barite, $BaSO_4$) (Bakke & Klungsøyr & Sanni 2013). To improve the technical performance of the mud, various additives are used. Among these are viscosifiers, emulsifiers, pH and scale control agents, and deflocculants. The amounts of the different components added depend on the desirable properties of the mud. Due to the strict regulations on discharge of OBM and SBM, most drilling of offshore oil and gas wells is achieved with WBM (Frost *et. al.*, 2006 (ERMS report no. 4)). OBM and SBM are used when lubrication and stabilization in the borehole needs to be improved, e.g. in the deepest sections of the well and during directional drilling operations.

Drilling discharges did constitute 82% of the total discharges of chemicals from the offshore petroleum activity on the NCS in 2004. Weighting agents and inorganic salts are the ingredients used and discharged in the largest amounts. The chemicals used as additives in the drill muds today are mostly classified as PLONOR (OSPAR List of Substances/Preparations Used and Discharged Offshore which Are Considered to Pose Little of No Risk to the Environment) (Frost *et. al.*, 2006 (ERMS report no. 4)). Ideally all added chemicals shall be included from a risk assessment prospective if used in considerable amounts. For inclusion of substances in EIF drilling discharges calculations, the main criteria are the total amount of chemicals used/discharged to the sea and the potential for accumulation in the water column or in the sediments to levels that may cause toxic or nontoxic stress to biota (Altin & Frost & Nilssen, 2007)

The particle content parts of the discharge will normally sink to the sea floor due to higher densities. Once on the sea floor, processes like bioturbation and degradation will change the quality and structure of the sediment (in order to assess the exposure also undistributed sediment processes have to be incorporated in the DREAM model). The depositions on the sea floor are caused by different contributions (Singsaas *et. al.,* 2007 (ERMS report no 24)):

- The cuttings particles sink to the sea floor in accordance with their sinking velocity
- The particles in the weighting material are also assumed to sink to the sea floor in accordance with the sinking velocity of the particles
- The chemicals in the discharge with a log octanol-water partition coefficient (log K_{ow}, log P_{ow}) higher than 3. These are assumed to primarily deposit on the sea floor as attached to the cuttings particles or as agglomerates.
- The heavy metals in the barite are assumed to be attached to the barite particles and will thus move along with the barite

Drilling discharges spread over large areas an tend to stay in the water column for a prolonged time, thus the potential impacts are considerable given the volumes and suit of components being discharged (Kjeilen-Eilertsen & Westerlund, 2004 (ERMS report no. 4A)). Cutting piles will be affected by storms (down to a 100 meters depth) and by erosion leading to re-suspension and spreading in the water column. Hence, both pelagic and benthic organisms can be repeatedly exposed, both by “primary” exposure as the material settle through the water column and as “secondary” exposure due to resuspension and repeated settling of particulate matter (Kjeilen-Eilertsen & Westerlund, 2004 (ERMS report no. 4A)).

Oil-based systems were developed and introduced in the 1960s to help address, as mentioned above, several drilling problems:

- Formation clays that react, swell, or slough after exposure to WBMs
- Increasing down-hole temperatures
- Stuck pipe and torque and drag

Until 1984, discharges of cuttings with diesel OBM were discharged extensively from North Sea drilling operations (Bakke & Klungsøyr & Sanni 2013). Over time base oils have changed considerably. See table 3.1. A big influence on this development is the requirements for human health and the natural environment.

Description	**Specification**	**Year**
Diesel oil	High content of aromatics High volatility Dries out and irritates the skin	Pre- 1984
Mineral oil	HDF 200 Relatively high volatility Lower aromatic content	1995
Mineral oil	EDC 95/11 or equivalent oils Zero aromatics Low volatility	1998
Low-viscosity oils	Sipdrill 2.0 (paraffin) EDC 99 (mineral-oil based) Zero aromatics High volatility	2002

Table 3.1: Overview of base oils used fro drilling from a historical perspective (Blytt *et.al.,* 2014, cited in Aarrestad, 2013).

3.3 Toxic stressors in drilling discharges

Drilling muds contains a wide range of added chemicals with different functions in the drilling process and maintenance of the well, as previously described. Three categories of chemicals associated with drilling waste discharges have been selected for prediction of the possible harm of drilling discharges to the marine environment (Frost *et. al.*, 2006 (ERMS report no. 4)):

- Metals (as ingredients of added chemicals or cuttings)
- Natural organic compounds
- Added chemicals (both non-PLONOR and PLONOR chemicals)

In table 3.2 the chemicals included in these three categories are summarized. Many chemicals are included in each of the categories, but most drilling muds and drill cuttings do not contain environmentally significant amounts of all these chemicals (Smit *et al., 2006 (*ERMS report no. 3)).

A limited number of chemicals were selected from table 3.2 for inclusion in the risk calculation for drilling discharges, based on the following criteria (Smit *et al., 2006 (*ERMS report no. 3)):

- The total amount of each chemical used and discharged to the sea from drilling discharges
- The chemicals potential to accumulate in either the water column (soluble chemicals) or in the sediments (low-soluble chemicals) in concentrations that could be toxic and/or cause other disturbances (burial, oxygen depletion etc.) to marine organisms.

Metals (as ingredients of added chemicals or as part of the barite)	Arsenic (Ar), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn)
Natural Organic Compounds	BTEX (Benzene, Toluene, Ethylbenzene, Xylenes), Naphthalenes and other 2-3-Ring PAH, ≥ 4-Ring PAH and Aliphatic Hydrocarbons, and Phenols
Added chemicals (Green/PLONOR chemicals)	Barite, Carboxymethyl cellulose, Bentonite, Portland cement class G, Quartz, Xanthan gum
Added chemicals (Other than PLONOR chemicals)	Categorized by the use of colour codes other than green. Yellow substances should be evaluated; black or red substances will be evaluated if use is proved to be necessary from a safety or a technical point of view.

Table 3.2: Candidate chemicals for use in the risk calculations (EIF) for drilling discharges (Frost *et. al.*, 2006 (ERMS report no. 4)).

The toxic compounds represented in drilling discharges should be included in the risk calculations both for the water column and for the sediments due to the different fate processes (dilution, dispersion, degradation, bioaccumulation, biodegradation etc.).

3.3.1 Metals

Metals that exist on the sea floor and in the sediments at higher concentrations than the background concentration are most likely originated from human or geological activity. This can cause a disturbance in the steady internal metal levels (homeostasis) of the animal/organism and further lead to more or less severe toxic effects in the biota (Frost *et. al.*, 2006 (ERMS report no. 4)). The metals of concern, based on their abundance in drilling discharges and their potential toxicity to marine organisms, include arsenic, barium, chromium, cadmium, copper, iron, lead, mercury, nickel and zinc (table 3.2), also referred to as heavy metals. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations.

Most metals associated with drilling discharges originate from trace impurities in mud ingredients as barite, ilmenite, and clay as well as formation rock in the drill cuttings and from added chemicals (Altin & Frost & Nilssen, 2007). The heavy metals, mainly from barite, are assumed to be attached to the barite particles and will thus follow the particles until sedimentation on the sea floor. Furthermore, they may become remobilized and available for uptake in biota. Bioavailability is the portion of a contaminant (e.g. metal) that can be taken up by an organism and thus subsequently transported, distributed and metabolized. Both uptake and bioavailability of metals are important measures in assessing environmental (and other) impacts. Metals adsorbed to barite particles can become available within the body of filter feeding organisms (*Daphnia*), which again might lead to unexpected high tissue concentrations. For suspension feeders such as mussels and copepods, uptake of metals from the dissolved phase and food ingestion can be equally important to metal accumulation.

Barite (and other heavy metals) also occurs naturally in sediments (Rye & Ditlevsen, 2013). Table 3.3 shows the average concentrations of some heavy metals in sediment samples collected from the NCS..

Heavy metal considered	**Heavy metal content in barite, low value ppm (mg/l)**	**Heavy metal content in barite, high value ppm (mg/l)**	**Average content of heavy metal in sediment on the NCS ppm (mg/l)**
Cadmium, Cd	0.05	7	0.037
Chromium, Cr	6.5	40	14.6
Copper, Cu	86	189	4.1
Mercury, Hg	0.05	6.7	0.021
Lead, Pb	18	1370	10.7
Nickel, Ni	Not used in sediment		
Zinc, Zn	35	2030	20.7

Table 3.3: Heavy metal content in barite and in natural sediment on the NCS. The table shows the span of concentrations in barite between various mines/suppliers (Rye & Ditlevsen, 2013).

Barium is the most abundant metal in most drilling muds due to the high consumption of barite ($BASO_4$). Barite has a low solubility in the seawater caused by the natural high concentration of sulphate in the ocean, which again leads to a low bioavailability and toxicity to marine organisms (Frost *et. al.*, 2006 (ERMS report no. 4)). Although barite is a PLONOR chemical, it should be included in the risk calculations of drilling discharges. Barite is used in such great quantities, thus the physical disturbance potential in the sediments (burial, change in grain size etc.) is high.

Other metals abundant in barite, in addition to barium, are lead, zinc, iron and in some cases chromium (Frost *et. al.*, 2006 (ERMS report no. 4)). Iron is not regarded as a concern even though it is normally present in the drilling muds at high concentrations. Because iron primarily exists as insoluble oxides or in the matrix of clay particles at concentrations similar to or lower than the background concentrations, iron will not be necessary to include as a toxicity stressor (Frost *et. al.*, 2006 (ERMS report no. 4)).

Due to the following criteria: “The potential for the chemical to accumulate in the water column (soluble chemicals) or sediments (low-solubility chemicals) in forms and concentrations that could be toxic (and/or cause other disturbances (burial, oxygen depletion, etc)) to marine organisms" (Frost *et. al.*, 2006 (ERMS report no. 4)), metals that will be necessary to include in the risk calculations for drilling discharges and that exist in the mud at higher concentrations than in the sediments are; cadmium, chromium, copper, mercury, lead and zinc (summarized in table 3.4) (Altin & Frost & Nilssen, 2007).

The concentrations of nickel in drilling discharges usually are about 10 times below concentrations in natural sediments and are therefore regarded of no concern for toxicity in the sediments. Although, it should be included for risk assessment calculation in the water column. Metals for risk assessment in the water column include all the metals selected for the sediment, except chromium (Altin & Frost & Nilssen, 2007). Chromium is not relevant for risk calculations in the water column due to either very low concentration in the drilling discharges, or the chromium is in a reduced and insoluble form.

Metal	Abundant in mud/cuttings?	Potentially bioavailable?	Aquatic toxicity data adequate?	Include in EIF$_{sediment}$?	Include in EIF$_{water}$?
Arsenic	No	No	Yes	No	No
Barium	Yes	No	Non-toxic	No	No
Cadmium	**Sometimes**	**Yes**	**Yes**	**Yes**	**Yes**
Chromium	**Yes**	**Yes**	**Yes**	**Yes**	No
Copper	**Sometimes**	**Doubtful**	**Yes**	**Yes**	**Yes**
Lead	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Mercury	**Sometimes**	**Doubtful**	**Yes**	**Yes**	**Yes**
Nickel	**No**	**Doubtful**	**Yes**	No	**Yes**
Zinc	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Table 3.4: Selection of metals for inclusion in calculation of environmental risk of drilling discharges in the sediment compartment and water column. The metals selected are highlighted (Frost *et. al.,* 2006 (ERMS report no. 4)).

Three aspects are of particular relevance in assessing the impacts caused by metal contamination in drilling discharges (Kjeilen-Eilertsen & Westerlund, 2004 (ERMS report no. 4A)):

- metals leaching
- metals bioavailability
- effects from metals to biota

3.3.2 Natural Organic Compounds

Natural organic compounds in drilling discharges include both intentionally added ingredients (categorized as ”added chemicals”) in drilling muds/drilling fluid (particularly OBM), and drilling mud contaminated with formation hydrocarbons when drilling hydrocarbon bearing structures (Frost *et. al.,* 2006 (ERMS report no. 4)).

The natural organic chemicals of particular interest and concern, and hence important to evaluate for inclusion in the risk assessment are PAHs, aliphatic hydrocarbons, BTEX, and alkylated phenols. BTEX was found to not be included in the risk calculations. This group is highly soluble and easily biodegradable and is therefore not likely to be present in elevated concentrations at toxic levels for a prolonged time to cause toxic stress. The aliphatic hydrocarbons are both volatile and easy biodegradable, and not likely to cause toxic stress. However, aliphatic hydrocarbons with high molecular weights have water solubilities below their acute toxic concentrations and are readily biodegraded. This may result in non-toxic stress to benthic ecosystems by physically altering the sediments or cause oxygen depletion by organic enrichment, and are therefore included in the risk calculations for the sediments (Altin & Frost & Nilssen, 2007).

PAHs are hydrocarbons that are composed of multiple aromatic rings (benzene rings). They are non-ionic, highly hydrophobic chemicals with low aqueous solubility and a high affinity for adsorption to solid, organic-rich particles. When the drilling waste is discharged the PAHs will adsorb to the suspended particles and accumulate at the sea-floor sediments. There are three dominant sources of PAHs (Frost *et. al.,* 2006 (ERMS report no. 4)):

- Petrogenic PAHs: formed from transformation of fossil organic matter to peat, coal and petroleum
- Pyrogenic PAHs: formed by combustion of organic matter
- Biogenic PAHs: formed in the sediments under anoxic conditions

PAHs are toxic and persistent in the marine environment and may contribute to toxic stress when present at higher concentrations than the background concentrations in the sediments. Nearly all sediments, even the sediments in the deep sea, contain some PAHs. This common scenario is due to the many sources of PAHs in the ocean and their slow degradation. The organisms living in the sediment tolerate these background concentrations. The sediments near the offshore oil and gas installations on the other hand, may contain elevated levels of PAHs, mainly from drilling discharges, which can be toxic to the bottom dwelling communities and also the consumers of the benthic fauna like fish and shellfish (Frost *et. al.,* 2006 (ERMS report no. 4)). PAHs should thus be included in the risk assessment calculations.

3.3.3 Added chemicals

Drilling muds contains a vide range of chemicals. The chemicals are added due to their different properties and functions in well drilling and maintenance. Most of the drilling chemicals are PLONOR. These substances are typically salts, cellulose and weak acids that are expected to pose little or no risk of harm to the environment (Frost *et. al.,* 2006 (ERMS report no.4)). Table 3.5 shows an example of chemicals used and discharged from drilling operations on the NCS in 2004.

Function	Use (tonnes)	Discharge (tonnes)
Lost circulation chemicals	12141	1193
Scale inhibitor	2778	893
Completion chemicals/fluids	19644	3273
Clay stabiliser	6080	4089
Cementing chemicals	26175	1845
pH regulating chemicals	2617	340
Weighting agents and inorganic chemicals	178226	53976
Viscosity reducing chemicals	6554	3714

Table 3.5: Functional groups of chemicals with use greater than 1000 tonnes and discharge greater than 100 tonnes on the NCS in 2004 (Frost *et. al.*, 2006 (ERMS report no.4)).

3.4 Non-toxic stressors in drilling discharges

Comparable to the risk assessment for toxic substances, the risk assessment of these disturbances is based on a comparison of the exposure to the selected stressor and a defined threshold for adverse effects derived for this stressor (Smit *et. al.*, 2006 (ERMS report no. 9)). The SSD (explained in section 6.2.2) for the stressor is used to derive an exposure to risk function.

The risk assessment guidelines for toxicity described in the EU-TGD served as a basis, as no formal evaluation procedures exist for non-toxic stressors. To be able to compare and integrate the different disturbances caused by drilling discharges they should all be based on the same principles. The PEC/PNEC approach was therefore proposed as an applied method for non-toxic stressors as well.

Deviation from the TGD guidelines became necessary due to the nature of the non-toxic stressors data and their studied effects. There is no regulatory framework available for other disturbances than toxicity (Smith *et. al.,* 2006 (ERMS report no. 9)) and thus the terms PEC and PNEC should not be used for non-toxic stressors, as these terms refer to a certain concentration. Instead, the terms could be replaced by exposure, level or change and threshold. The change is the deviation from the original situation (undisturbed) (Smith *et. al.,* 2006 (ERMS report no. 9)). For consistency reasons, however, the term PEC and PNEC will be used for the non-toxic stressors as well.

Based on the collected information the threshold levels for burial, grain size changes and oxygen depletion as presented in table 3.6 were defined:

Stressor	**Value**
Burial	0.65 cm deposited layer
Grain size change	52.7 μm change in median grain size
Oxygen depletion	20% reduction of integrated oxygen content

Table 3.6 Threshold values for non-toxic stressors in the sediment (Smith *et. al.,* 2006 (ERMS report no. 9)).

In the next sub-sections the impact of settling particles, initially covering the sediment and resulting in burial of organisms, oxygen depletion and change in grain size will be described. The methods applied for determination of the different threshold levels will be explained in section 6.

3.4.1 Burial of organisms

The following factors determine the effect of burial on different species (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)):

- Depth of burial
- Tolerance of species
- Burial time
- Nature of material (grain size different from native sediment)
- Temperature

According to Kjeilen-Eilertsen *et. al.,* (2004), the effect data describing the specific impacts related to the factors above is not available, and therefore assumptions have to be made to predict scientifically sound threshold for burial effects.

In general, the effect of burial mainly depends on the mobility of organisms in the benthic sediment and on the settling rate of particles. The most sensitive species are the organisms which have no or very limited abilities to move (Smith *et. al.,* 2006 (ERMS report no. 9)). Effects can be both short-term or long term, depending on affections on individual levels or on whole populations respectively. Such effects are; mortality, reduced growth of some species, reduced larval settlement and change in fauna composition (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)).

Based on the available literature data and the discussions made in Kjeilen-Eilertsen *et. al.* (2004), the following aspects must be considered to be the most relevant when considering burial as part of drilling discharge impacts:

- Depth of deposition
- Rate of deposition.

The fraction of the suspended matter that settles will, together with the settled cuttings, form a deposition layer/piles on the seafloor. If this layer is formed quickly, the sediment biota can be buried and therefore pose a risk due to the reasons mentioned above. Both the rate and depth of deposition determine the final risk of burial.

Burial is defined as the total thickness of the added layer caused by deposition (Singsaas *et. al.* 2007 (ERMS report no. 24). This build-up is caused by the particles in the discharges. Figure 3.1 below presents a schematic overview of the increasing layer thickness in a sediment surface grid cell over time. The thickness is calculated from the following equation (Smith *et. al.,* 2006 (ERMS Report no. 3)):

$$\text{Burial} = \frac{1}{1-\varphi}\sum_i \frac{M_i}{\rho_i} \qquad \text{Equation 3.1}$$

φ = porosity,

M_i = the mass of particle component *i* deposited pr. m^2 of the sediment area,

ρ_I = the density of the particles of class *i*.

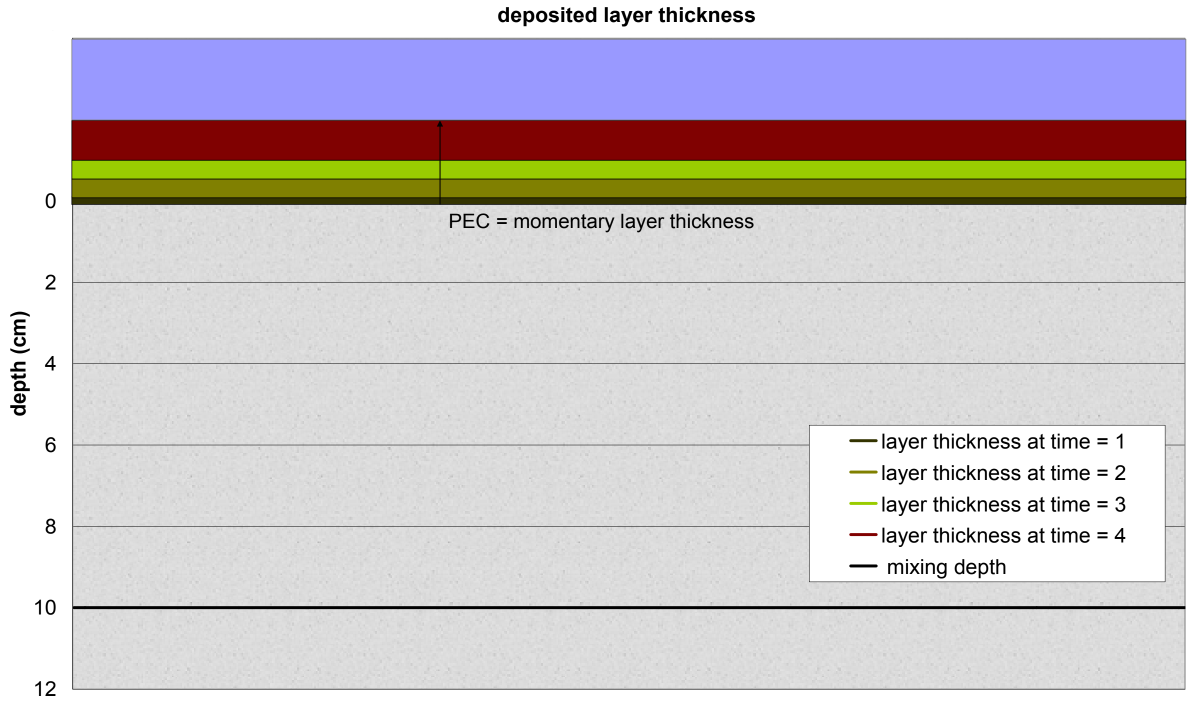


Figure 3.1: Thickness of the sediment layer deposited due to discharges. The PEC value is the momentary layer thickness (Smith *et. al.,* 2006 (ERMS Report no. 3)).

3.4.2 Oxygen depletion (Hypoxia)

Hypoxia degrades bottom habitat through a wide suite of mechanisms. Under conditions of limited oxygen at the bottom, rates of nitrogen and phosphors remineralisation and sulphate reduction increase. The resulting production of sulphide in combination with low oxygen can prove lethal to benthic organisms (Buzzelli *et. al.,* 2002). Organisms and populations may also experience sub-lethal effects as growth, survival, moult, capture success, feeding, developing, hatching, motion, respiration and settlement of individual benthic organisms (Smit *et. al.,* 2006 (ERMS report no. 9)).

The processes that determine the oxygen content in bottom water are (Smit *et. al.,* 2006 (ERMS report no. 9)):

- The consumption of oxygen due to degradation of organic materials in the bottom water and sediments

- Consumption by in faunal organisms
- The oxygen supply from vertical mixing and horizontal transport processes.

The DREAM model expresses the thickness of the oxygenated sediment layer as the integrated oxygen concentration over depth, or the total amount of oxygen in the RDP-layer (RPD – Redox Potential Discontinuity). The sediment can be divided into oxic, suboxic and anoxic layers. Each layer is associated with its respective oxidation-reduction potential.

The oxygen depletion is calculated by comparison of the new free oxygen profile after discharge with that in the undisturbed sediment (Singsaas *et. al.,* 2006 (ERMS report no. 24)). In addition to the natural biodegradation (present in the sediment layer before discharge), the biodegradation from added chemicals in the new sediment layer must be included as well. A reduction of the free oxygen content in the pore water of the sediment layer may be the result. Figure 3.2 shows the change in the integrated oxygen concentration over depth.

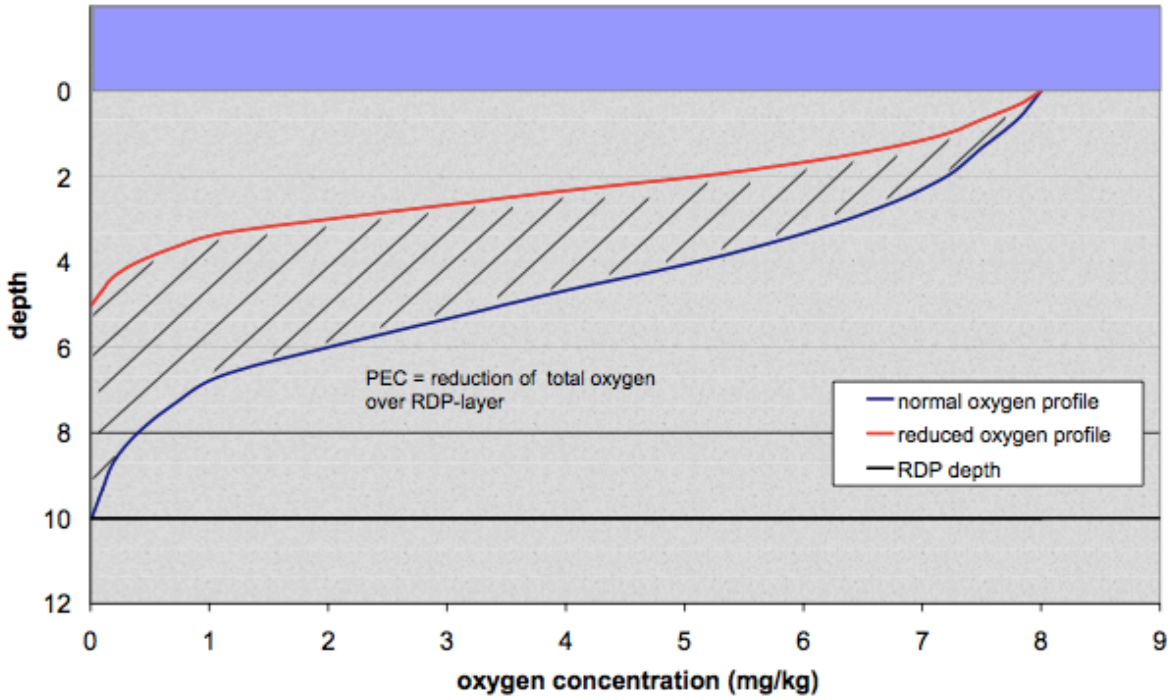


Figure 3.2: Change in the integrated oxygen concentration over depth (Smith *et. al.,* 2006 (ERMS Report no. 3)).

3.4.3 Change in grain size

As sediment biota has a preference for specific sediments, the presence of specific species can be related to specific ranges of the median grain size (Smit *et. al.,* 2006 (ERMS report no. 9)). These ranges of median grain sizes are used to derive the sensitivity of species to changes in median grain sizes. The observed range of median grain size per specie if defined as “the grain size window-of-occurrence”. This window-of-occurrence is described by an average value and variation for the median grain size (Smit *et. al.,* 2006 (ERMS report no. 9)). This variation is expressed as the range including 95 per cent of the observations of these species.

The change in grain size happens due to the introduction of exotic sediment. Figure 3.3 shows a new layer with another median grain size added on top of the original sediment layer. The native sediment layer and the exotic sediment layer may start to mix due to bioturbation, caused by the living organisms in the sediment, and will thus produce a new gradient with respect to the original median grain size. Figure 3.4 shows the vertical distribution of the median particles size in the sediment some time after the completion of the drilling program.

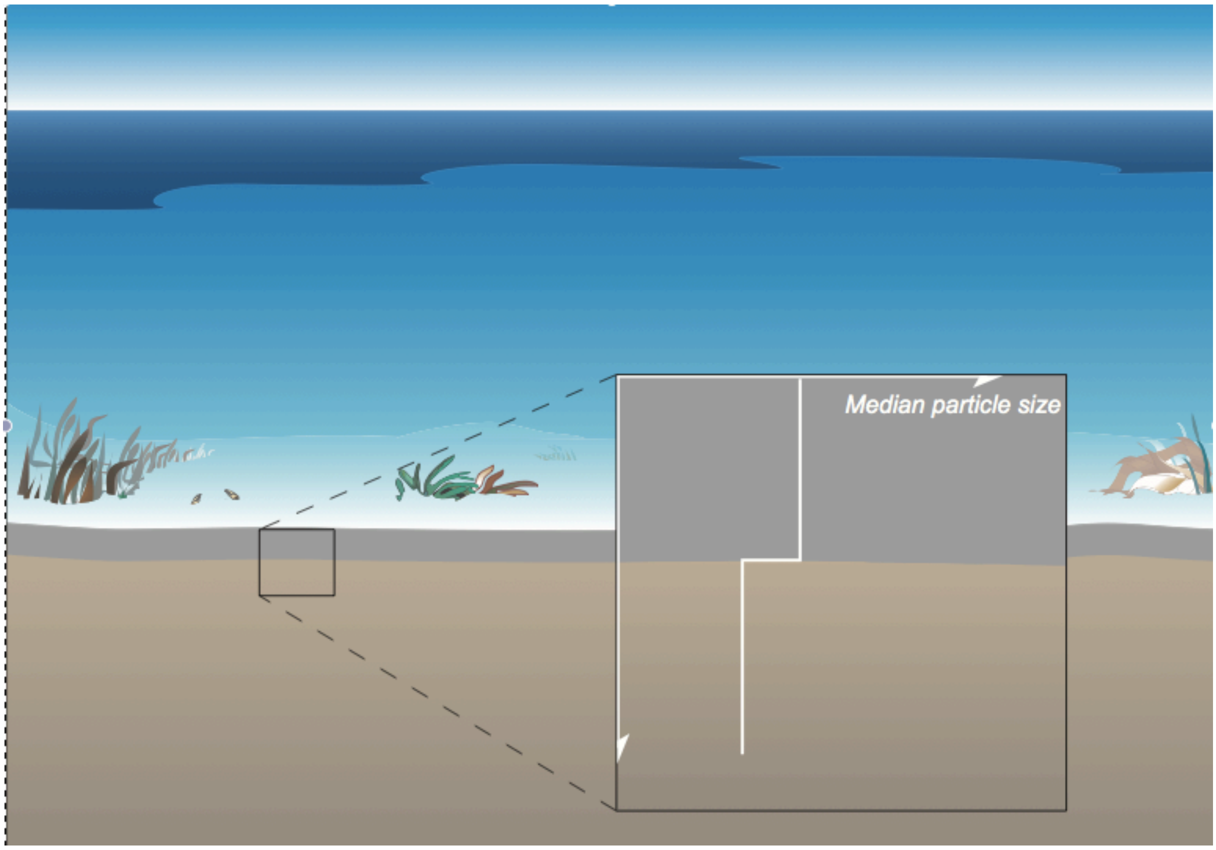


Figure 3.3: Illustration of a new layer added on top of the original sediments. The new layer has a different particle size and may contain cuttings, barite and chemicals (Rye *et. al.,* 2006 (ERMS report no. 18)).

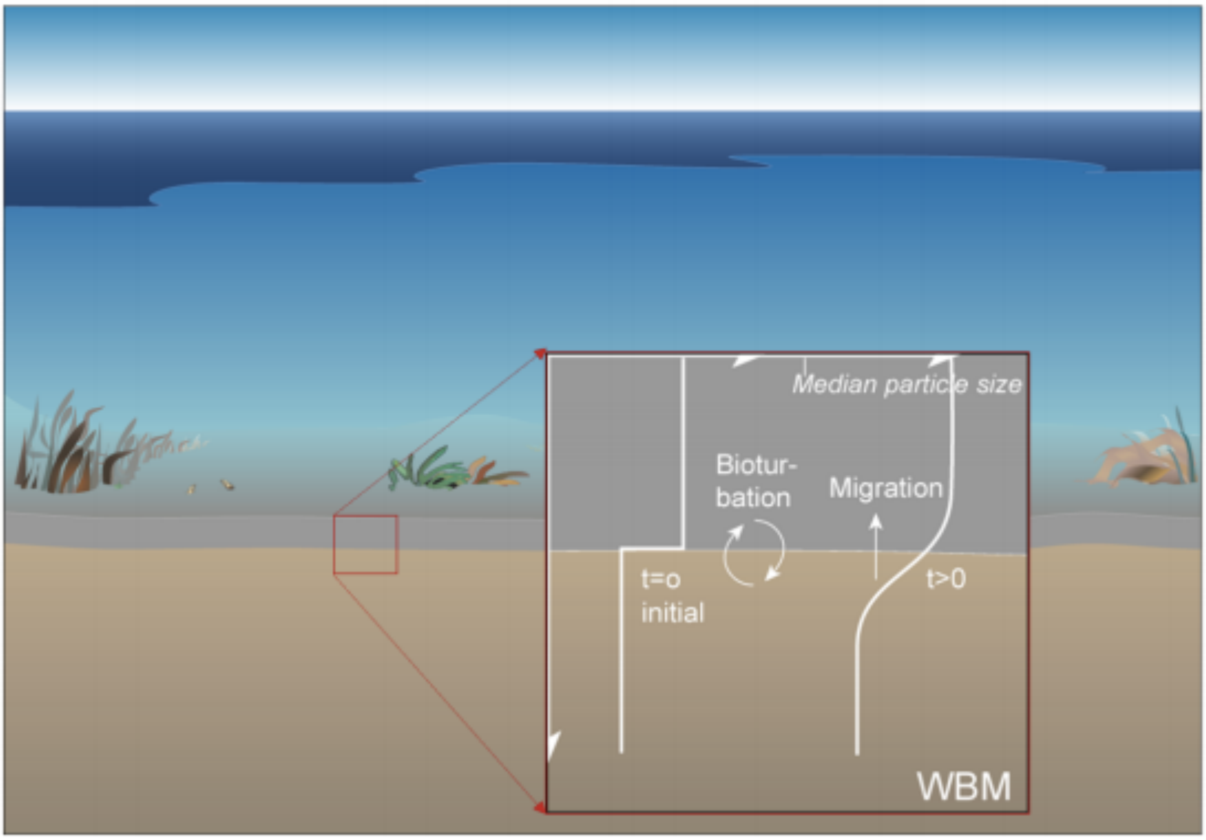


Figure 3.4: Illustration of the vertical distribution of the median particle size in the sediment, some years after completion of the drilling program. Mixing in the sediment is caused by the action of bioturbation (Rye & Ditlevsen, 2013).

3.5 Summary

The relation between the potential stressors in the sediments needs to be emphasised, as it is evident that they are linked to each other (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)). All parameters (toxicity, burial, oxygen depletion, change in grain size) co-vary in a cuttings pile (see figure 2.1), so field studies do not provide a clear indication of which parameters are contributing most to adverse biological effects in the benthos (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)). The sum risk (joint risk probability) for all stressors (toxic and non-toxic) is calculated assuming independent action (Smith *et. al.,* 2006 (ERMS Report no. 3)).

As described earlier, the EIF_{DD} consists of two parts; the water column and the sediment compartment. As long as there exists two values for the EIF (one for the water which is related to acute effects and one to the sediment which is related to chronic effects) a way of weighing the two values should be defined. According to Smith *et. al.,* (2006) the focus should be on a reduction of both the time scale as well as values of the EIF.

4. Thermal cutting treatment

Various types of thermal treatment technology are available for cuttings. The process uses heat energy to separate contaminants from solids in order to allow for safe re-use/re-cycling/disposal of all phases. The contaminated solids are heated inside a sealed treatment chamber to the point where the hydrocarbon contaminants are vaporized. Further, hydrocarbon and water vapours are removed from the treatment chamber, condensed and recovered. The dry and clean solids are discharged from the treatment chamber with Total Petroleum Hydrocarbon (TPH) content less than 0.5% (Andino & Moyano, 2013). Figure 4.1 shows an overview of different thermal desorption technologies.

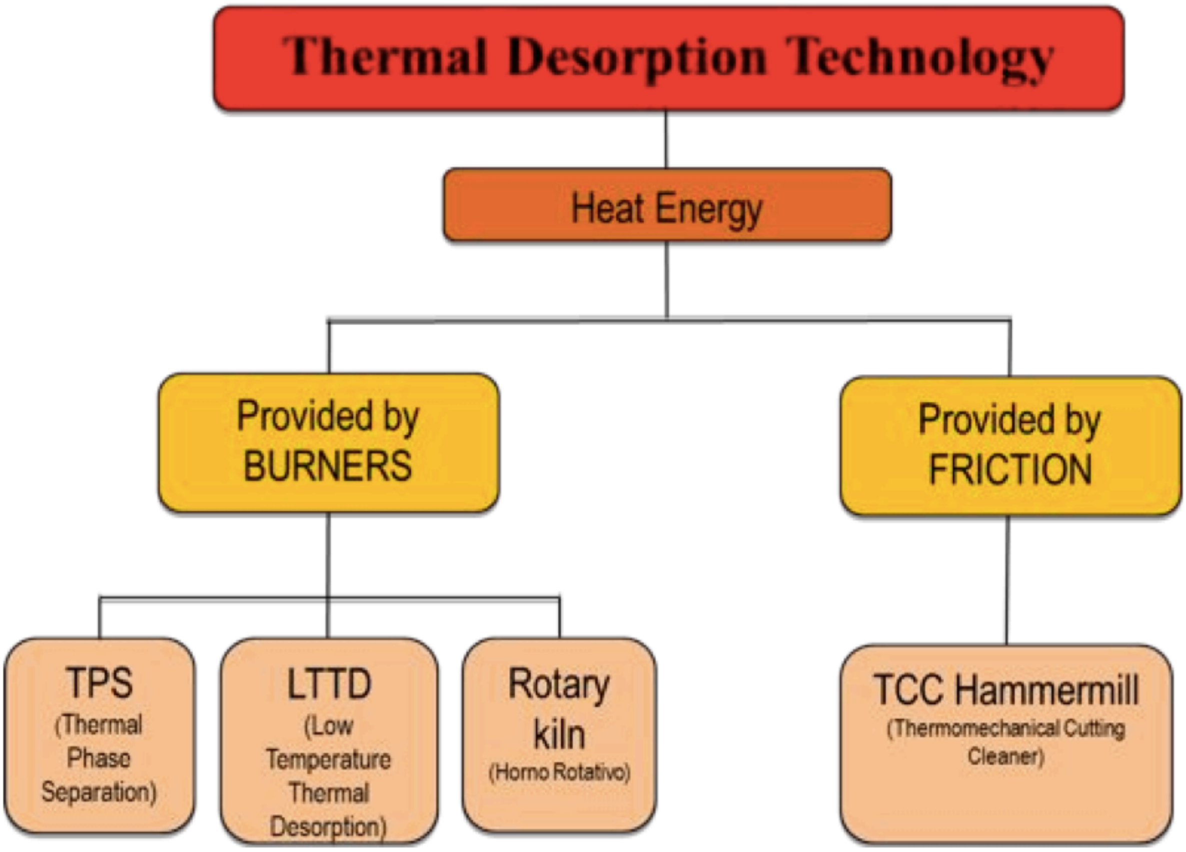


Figure 4.1: Different thermal desorption technologies (Andino & Moyano, 2013).

4.1 Thermomechanical Cuttings Cleaner (TCC)

On the drilling rig the mud and the cuttings are separated. The mud is recycled to be used again and the cuttings are either; discharged to the seabed, re-injected or taken ashore for treatment and disposal (About the industry: Drill cuttings 2009).

Normal practice in Norway when OBM is used is to transport the discharges to shore for cleaning and disposal. The transportation process is time consuming and associated with high risk. Enabling cleaning and disposal offshore would eliminate the transportation costs and emissions, minimize the crane lifts and reduce excessive manual handling. This will also improve HSE benefits (Halliburton).

Thermomechanical cuttings cleaner (TCC) is based on the principle of thermal separation. Thermtech AS, a Norwegian technology and knowledge company, is the developer. TCC has a small footprint and easy mobility, which makes it advantageous, compared to other thermal treatment methods. TCCs are currently operated both offshore and onshore, but from a zero discharge point of view, there is a pull of having a complete treatment facility on board drilling vessels despite the low oil on cuttings ratio (<1%) (Halliburton).

The Norwegian Environment Agency has reported that Total will now have the opportunity to use TCC-technology, in conjunction with the drilling of seven wells at the Martin Linge field. This technology has not been used offshore in Norway before but it is well known from the UK`s continental shelf (UKCS) (Taraldsen, 2014). The authorization includes requirements according to constant monitoring and concentration measuring of oil on the cuttings. If the oil on cuttings ratio exceeds 0,05 per cent, the discharge is not permitted.

As mentioned above, the drill cuttings are the largest waste streams generated while drilling for hydrocarbons. The amount of drill cuttings generated and the value of the drilling fluids continue to grow as a consequence of the more sophisticated drilling technologies and deeper boreholes. If the cuttings are not treated properly the environmental impact can potentially be huge (Thermtech AS).

The principle with the TCC technology is to convert kinetic energy to thermal energy in a thermal desorption process that efficiently separates and recovers the components of drilling waste whilst preserving the original quality of the components prior to treatment. The highest temperature in the mill is found within the actual particles as a result of the frictional heat. Sand is added until a sufficiently high temperature has been reached. When the temperature is high enough, the cuttings to be treated are added. The liquid phase vaporizes/condenses and is separated into dedicated tanks for water and oil (Blytt *et. al.,* 2014). Typical temperatures lie between 250-300°C. Higher temperatures should be avoided due to loss of quality of the recovered base oil. This makes it possible to re-use the recovered base oil in new OBM or as fuel for diesel engines. If the oil on cuttings ratio is low enough relative to the regulations, the cuttings can be discharged to the sea or it could have other industrial uses, such as a substitute for chalk in asphalt (Thermtech AS). Figure 4.2 shows a simplified process flow diagram for the TCC.

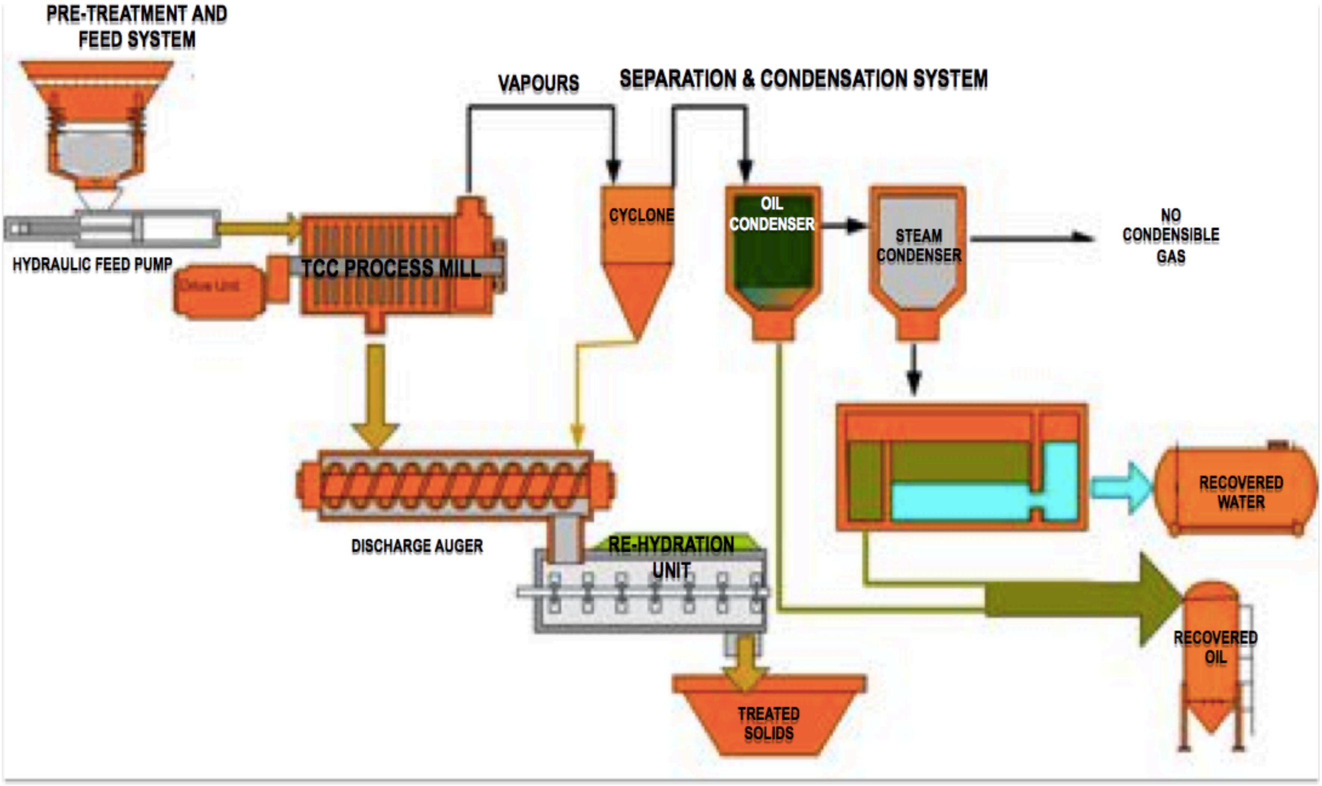


Figure 4.2: TCC simplified process flow diagram (Andino & Moyano, 2013).

4.1.1 Offshore discharge of Processed Cuttings

The TCC technology is field proven, but not yet qualified for use on the NCS. The Norwegian Oil and gas Association took the initiative to implement a project to enlighten on environmental issues related to offshore thermal treatment of drill cuttings contaminated with OBM. The objective of this project was to secure data on the physical-chemical and environmental-toxicological properties of such cuttings after treatment. The data was collated and used in assessing the environmental consequences of discharging thermal treated OBM cuttings offshore (Blytt *et. al.,* 2014).

The environmental harm caused by discharge of treated OBM cuttings can be due to increased particle content in the water column and thus bigger particle surface areas, sedimentation on the seafloor or by leaching oil, PAH and heavy metals to the water column or sediment pore water to which living organisms will be exposed.

Blytt *et. al.* (2013) did evaluate the influence of oil, PAH and heavy metals on organisms by the use of leaching tests. Because of the dilution of oil, PAH and heavy metals which are discharged to the seawater, there was no harmful environmental effects expected.

Based on sampling, analyses and environmental risk assessment of offshore discharges for heat-treated OBM cuttings to the sea, Blytt *et. al.* (2013) did draw the following conclusions:

- Environmental risk associated with discharges of thermal treated OBM cuttings will correspond to that seen with discharges of WBM cuttings.
- The concentrations of oil, PAH and heavy metals in treated OBM cuttings are expected to be similar to those in WBM cuttings
- The only environmental-related footprints that might be identified through monitoring relate to particles and smothering with sludge in areas with the highest sedimentation rate of cuttings.
- Because particles of thermal treated cuttings are somewhat smaller than for WBM cuttings, smothering with sludge on the seabed is expected to be less.

Based on the conclusion drawn by Blytt *et. al.* (2013) and the objectives of this thesis, the results of the DREAM model simulations can somewhat be expected to reflect that OBM cuttings treated with TCC do not cause any crucial environmental impact.

5. Exposure Assessment

5.1 DREAM

DREAM is a three-dimensional, time-dependent numerical model that computes transport, exposure, dose, and effects in the marine environment. The model makes it possible to simulate complex mixtures of chemicals. DREAM can account simultaneously for up to 200 chemical components, with different release profiles for 50 or more different sources. A set of physical, chemical and toxicological parameters describes each chemical component in the effluent mixture (DREAM – Dose-related Risk and Effects Assessment Model 2014). Calculation of the environmental concentration (PEC) is the basis for risk assessment. In DREAM, PEC values are calculated by modelling the fates of pollutants in the environment.

The DREAM was developed through a JIP in the period 1997-2000 and was further implemented for produced water management in the Norwegian sector of the North Sea as a part of the ”Zero discharge work”, 2000-2005 (Johnsen & Frost, 2011). The model is based on a generalized transport equation, accounting for advection, dissolution, sedimentation and biodegradation. It was primarily developed for produced water discharges, but to be able to perform risk calculations for different discharge scenarios during different operations, both production and drilling, DREAM needed to be further developed. The new version should be able to estimate ecological risks arising from intended drilling discharges and integrate it with the EIF for produced water. As drilling discharges are likely to pose a risk to biota in both the water column and in the sediment compartment, the environmental compartment seabed needed to be included in the model framework of DREAM.

The model is using particles to compute transport, behaviour, and effects of pollutants released to the environment. The particles are divided into two groups depending on their nature; those representing dissolved substances and those representing oil droplets or particles with non-neutral buoyancy. The latter particle group is “pseudo-Lagrangian”, in that their motion is subject to a vertical rising or settling velocity superimposed on the advective and turbulent motions of the water around them (Reed *et. al.,* 2011).

DREAM is a software tool designed to support rational management of environmental risks associated with operational discharges of complex mixtures (Reed & Rye, 2011). The model helps visualization and analysis of releases occurring over extended time periods and large water volumes. Some tasks suitable for DREAM include (Reed *et. al.,* 2011):

- Analysis of impacts on the environment from releases of produced water
- Time-varying exposure of representative individual organisms
- Acute and chronic effect calculations
- Risk assessment
- EIF calculations
- Decision-making and approval of planned releases

The ParTrack extension license builds on the DREAM model to include releases of drill muds and cuttings. This can be used to calculate fates, effects, and risk in bottom sediments as well as the suspended particle effects in the water column (Reed *et. al.,* 2011). The figures 5.1 and 5.2 present a general schematic and layout of the DREAM model.

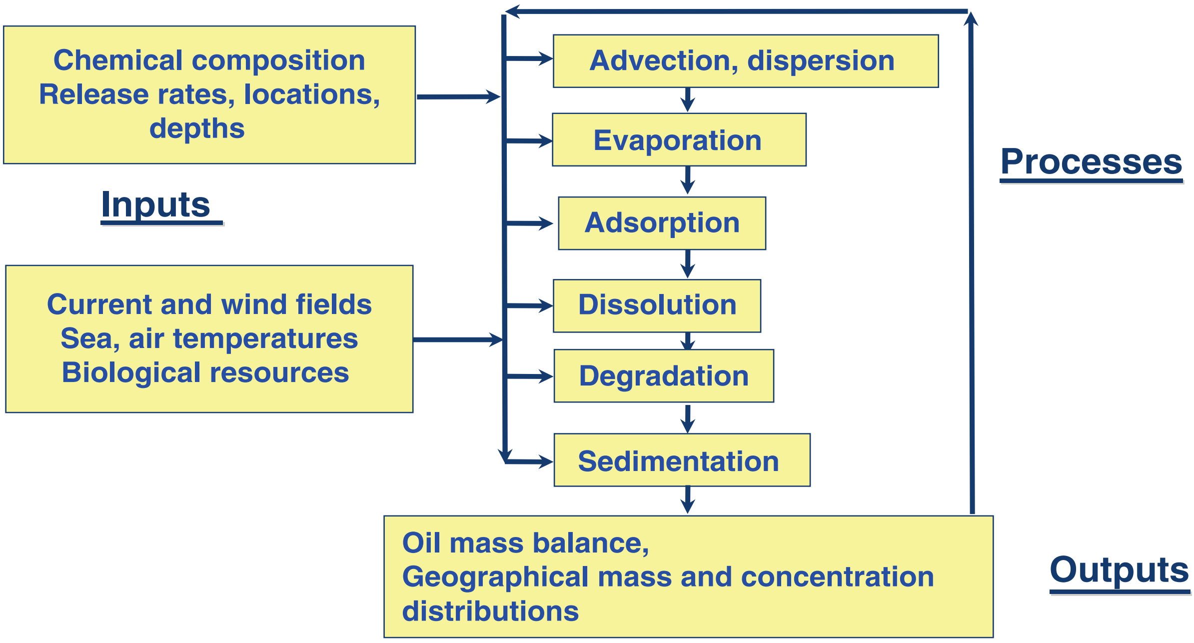


Figure 5.1: General schematic of the DREAM model (Reed & Rye, 2011).

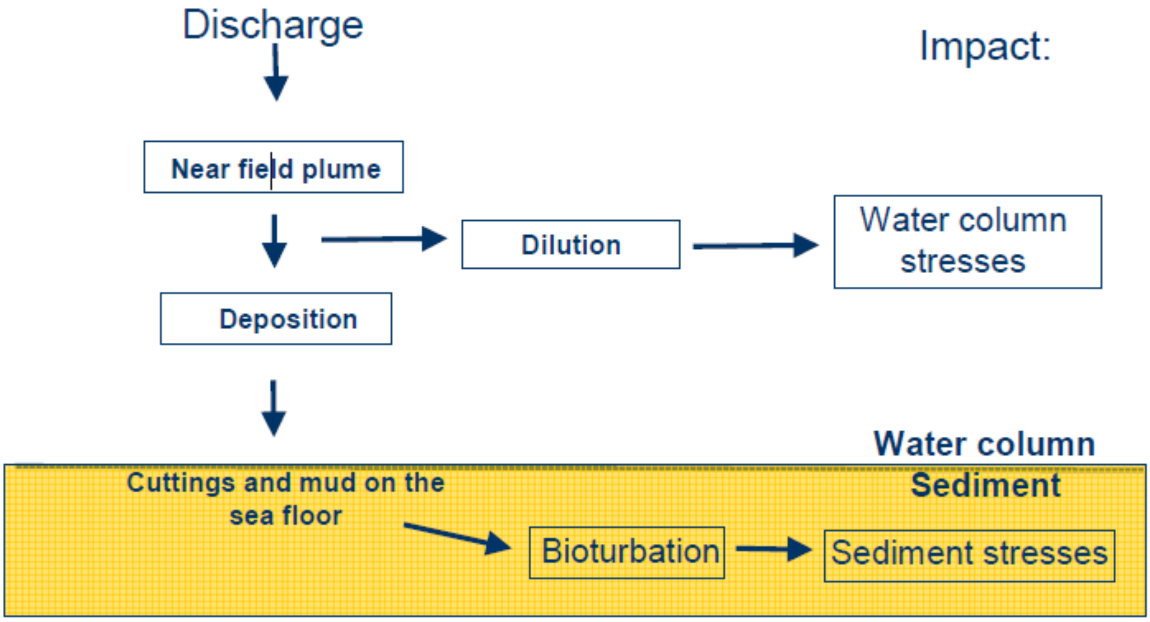


Figure 5.2: Layout for the model structure for calculations of potential impact (Singsaas *et. al.*, 2007 (ERMS report no. 24)).

The deposition of the matter on the sea floor

As part of the Environmental Risk Management System (ERMS) project, the DREAM model was extended to include (Rye *et. al.,* 2006 (ERMS report no. 18)):

- Inclusion of the near field plume for the descent of the discharge
- Inclusion of solid particles to sink down through the water column
- Inclusion of solid particle size distributions for various particle types

The inclusion of a three-dimensional and time variable ocean current field will cause a spread of the discharge in the water column. This spread is resulting into a deposition that is varying with the horizontal co-ordinates x and y (Rye *et. al.,* 2006). The DREAM model generates a grid on the sea floor, with a water depth associated with each cell. Each of the grid cells distributed on the sea floor then contains the amount of drill cuttings and mud deposited on the sea floor within that cell (Rye *et. al.,* 2006).

Near field plume:

The model activates the near-field module for register release depths greater than zero (i.e. subsurface) (Reed *et. al.,* 2011). Drilling discharges contain drill cuttings and mud thus, have densities that are significantly higher than the ambient water. The module computes for this density formation in order to account for the descent of the plume. The plume is subjected to the oceanic conditions such as current velocities, salinity and temperatures. The combination of these factors causes the plume to level out at some depth or sink down on the sea floor and level out there. The near-field module in the model has been made available to specify the specific conditions and the vertical distribution of the temperature and salinity (stratifications) (Rye *et. al.,* 2006 (ERMS report no. 18)). The module can calculate for releases both that are operational in nature (e.g. produced water or drilling fluids), or underwater blowouts on the deep or shallow water (Reed *et. al.,* 2011). Figure 5.3 shows a vertical cross section of an underwater plume on the downstream side of the release calculated with the revised DREAM model (Rye *et. al.,* 2006). One part of the discharge appears to spread horizontally at the depth of trapping due to negligible sinking velocities (small particles). The other part of the discharge appears to sink down on the sea floor due to coarser particles.

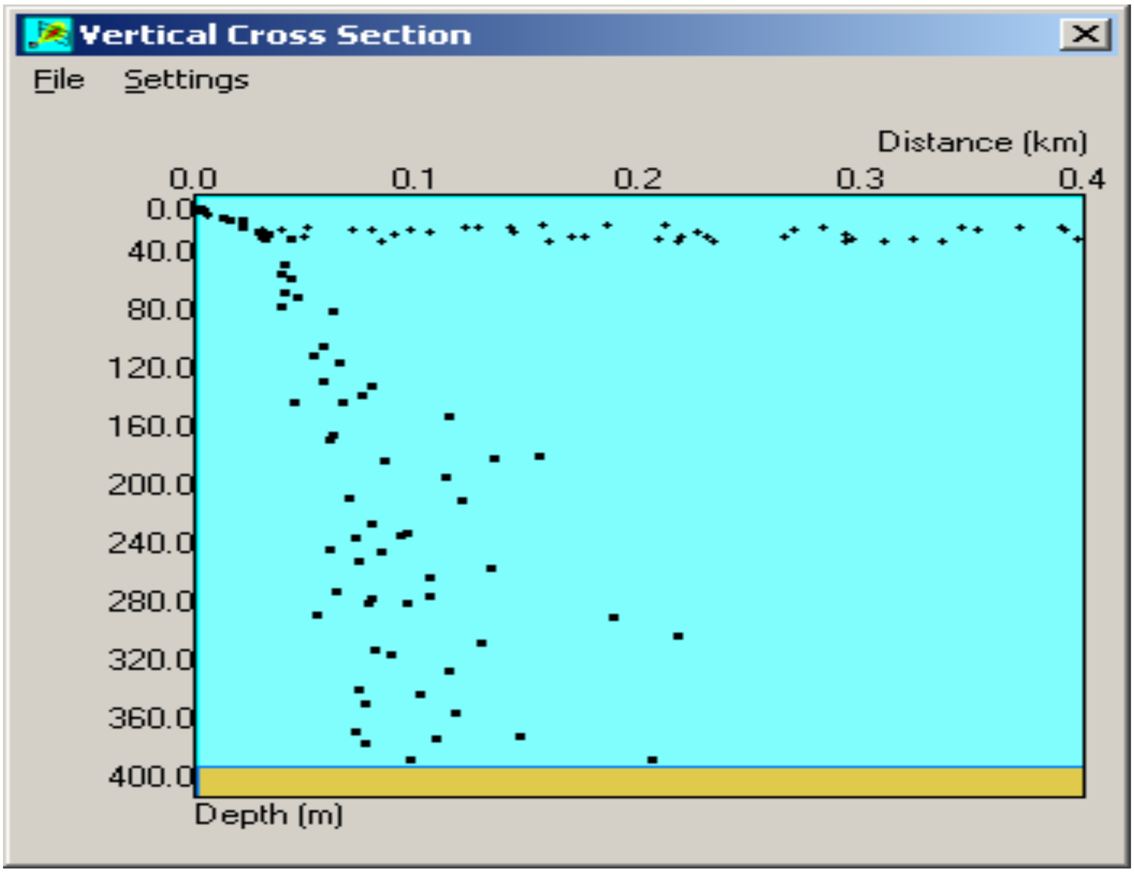


Figure 5.3: Vertical cross section of the near field plume and the deposition of particles on the sea floor (Rye *et. al.,* 2006).

Inclusions of a near field plume is recommended because drilling discharges can be relatively heavy and sink down (Reed *et. al.,* 2011).

Deposition:

The impact caused by deposition to the sea floor is generally of limited geographical extent. In the model, the “DEPOSITION” factor represents the spreading of the discharge in the ambient, transport by the currents, the sinking down and deposition of the particles (including chemicals) on the sea floor (Rye *et. al.,* 2006 (ERMS report no. 18)). The model also includes the possibilities that particles may agglomerate. Biodegradation or other processes is not accounted for in the deposition calculations due to the short period of time these processes are assumed to take. Chemicals may start to biodegrade as soon as they are deposited on the sea floor (Rye *et. al.,* 2006 (ERMS report no. 18)).

5.2 ParTrack

As mentioned above, the ParTrack extension builds on the DREAM model to include releases of drilling muds and cuttings. Additional environmental risk calculations for bottom sediments and particle stress in the water column are available here.

The stressors to be calculated for in the sediment layer comes in addition to the stressors already defined for the water column – toxicity and suspended particles (Rye *et. al.,* 2006 (ERMS report no. 18)) (see section 2.2).

Four sediment effects are modulated in the revised DREAM model (Singsaas *et. al.,* 2007 (ERMS report no. 24)). (See also section 3.4)

- **Burial.** Thickness of the deposited layer of the suspended matter and cuttings settled on the seafloor (calculated from the deposition of the discharged compounds only (not including natural deposition)).
- **Toxicity.** The toxicity is calculated form the content (concentration) of the chemical(s) in the added sediment.
- **Free oxygen depletion.** Calculated by comparison of the free oxygen profile before and after the discharge.
- **Change in grain size.** The new grain size profile is estimated by allowing the new-formed layer to mix with the natural sediment.

Model requirements

The sediment model requires that processes that involve free oxygen balance and effects from sediment mixing/bioturbation must be included, thus free oxygen content of the sediment before and after the discharge must be contained (Rye *et. al.,* 2006 (ERMS report no. 18)).

Restitution time of the sediment is required, meaning that the time development of the sediment impact must be included as well. The model must also simulate the time development of the different stressors with time and as a function of the sediment depth (z).

The deposits are spread out over some geographical area (x,y), thus the model needs to be fully three-dimensional (x,y,z).

The processes are all described by means of differential (diagenetic) equations for free oxygen, organic matter and particle matter. These equations are solved in a fixed grid system. The formulation of these equations and the necessary assumptions made, are explained in greater detail in the ERMS report no. 18 by Rye *et. al.,* (2006).

6. Effect Assessment

In order to obtain an indication of the potential effects of drilling discharges, the exposures to the selected stressors will be compared to the levels at which they might cause effects (Smith *et. al.,* 2006 (ERMS Report no. 3)). Toxicity effect levels are mainly obtained from laboratory studies and available in different databases. For the non-toxic stressors, the disturbance-effect relationships and the variation in species sensitivity is not easy to obtain. Due to all the assumptions made when determining threshold values and sensitivity distributions for non-toxic stressors, inherent uncertainties will be attached (Smith *et. al.,* 2006 (ERMS Report no. 3)).

6.1 Environmental effects of OBM drilling discharges (general)

Oil-based mud may be selected for special applications. They are resistant to contaminants such as anhydrite, salt, and CO_2 and H_2S acid gases; they are effective against corrosion and have superior lubricating properties.

Cost can be one of the concerns when selecting OBM, the cost of containment, hauling and disposal can greatly increase the cost of using oil-based fluids. However, because OBM can be reconditioned and reused, the costs may be comparable to using WBMs. Today, with increasing environmental concerns, the use of OBM is either prohibited or severely restricted in many countries, Norway included (Amani & Al-Jubouri & Shadravan, 2012).

Discharges of cuttings from both WBMs and OBMs drilling operations can have an adverse effect on the seabed biological habitat in the immediate vicinity of the platform, and this is mainly due to physical burial of the natural sediment. The spread of cuttings particles is greatly influenced by their particle size in the prevailing current regime. However, it is believed that cuttings, particularly from OBM drilling operations, fall more directly to the seabed as a result of agglomeration (Amani & Al-Jubouri & Shadravan, 2012). The bottom sediment model must therefore be able to calculate the impacts on the original sediment layer caused by the parts of the discharge that deposit on the sea floor.

Beyond the area of physical smothering, the effects of OBM cuttings may be due to enrichment of the sediment and/or toxicity of certain fractions of the oils used (e.g. PAHs).

6.2 Determination of PNEC values

The strategy for determination of the PNEC for the marine environment was to follow the principles of TGD (Frost *et. al.,* 2006 (ERMS report no. 4), EC, 2003). According to Frost *et. al.,* (2006) some deviations from the risk principles described by TGD was occasionally found appropriate.

The PNEC values traditionally are determined on the basis of available toxicity data from single species laboratory tests taking into account adequate assessment factors (Frost *et. al.,* 2006 (ERMS report no. 4)). TGD recommend the use of both freshwater and marine data for PNEC derivation and the most sensitive species as endpoint, determined from the available toxicity data and divided by an assessment factor. In general, the same strategy is applied for PNECs based on aquatic toxicity data and for PNECs based on sediment data.

PNECs for the sediment compartment should be calculated for substances that have potential for either directly depositing on the seafloor or sorbing to sedimenting particles. PNECs for the water column are based on toxicity data on at least three selected trophic levels (Frost *et. al.,* 2006 (ERMS report no. 4)).

In the following sections, different methods for PNEC estimations are presented. Further the values found to be representative for organic substances, metals, drilling fluid chemicals and for the non-toxic stressors associated with the drilling waste for the water column and the sediment are recognized.

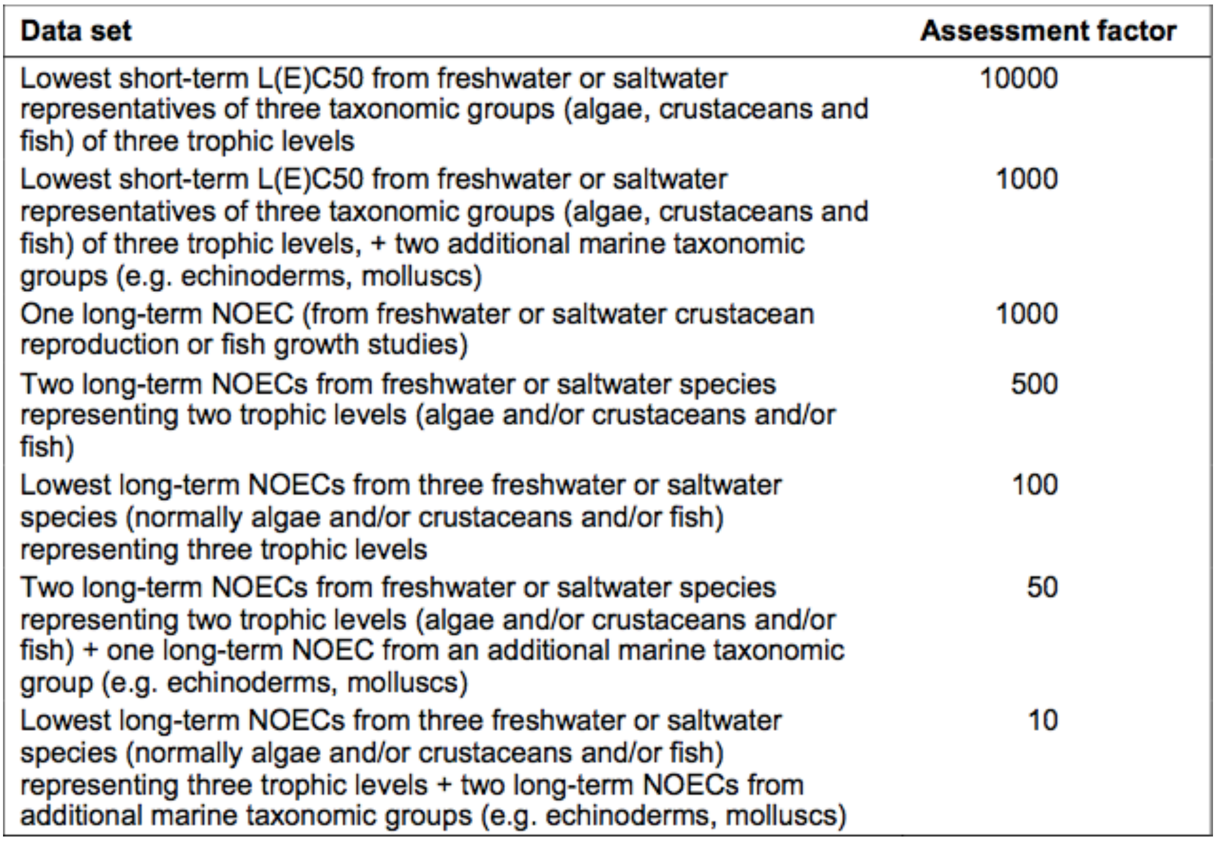
6.2.1. Assessment factors

The use of assessment factors is the most common method for derivation of PNEC values. Normally, data from one single species toxicity effect data generated from laboratory experiments are used (Bjørgsæter, 2006 (ERMS report no. 15)). In principle, the PNECs should be derived from the most sensitive endpoint regardless of the medium, and preferably, the toxicity data on at least three selected taxonomic or trophic levels are required.

It is assumed that the marine environment has broader species sensitivity than the freshwater environment, thus higher assessment factors are applied for the marine environment (Smith *et. al.,* 2006 (ERMS Report no. 3)). Higher assessment factors reflect higher uncertainties, addresses lacking toxicity data. In applying such factors, the intention is to predict a concentration below that an unacceptable effect will most likely not occur.

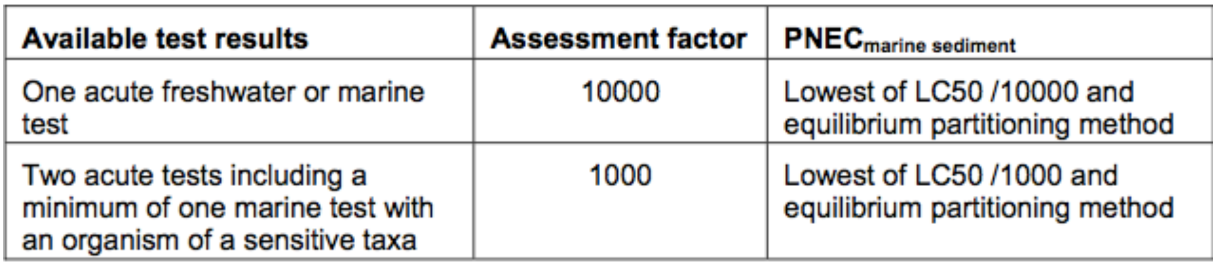
To determine the PNEC for a specific compound, L(E)C50 (median Lethal (Effect) Concentrations) values or NOEC (No Observed Effects Concentration) values (depending on short-term acute studies or long-term chronic studies, respectively) are divided by the assessment factor based on the amount of information provided (Smith *et. al.,* 2006 (ERMS Report no. 3)).

The assessment factors presented in figure 6.1 and figure 6.2 should be considered as general factors that under certain circumstances may be changed (EC, 2003).



Data set	Assessment factor
Lowest short-term L(E)C50 from freshwater or saltwater representatives of three taxonomic groups (algae, crustaceans and fish) of three trophic levels	10000
Lowest short-term L(E)C50 from freshwater or saltwater representatives of three taxonomic groups (algae, crustaceans and fish) of three trophic levels, + two additional marine taxonomic groups (e.g. echinoderms, molluscs)	1000
One long-term NOEC (from freshwater or saltwater crustacean reproduction or fish growth studies)	1000
Two long-term NOECs from freshwater or saltwater species representing two trophic levels (algae and/or crustaceans and/or fish)	500
Lowest long-term NOECs from three freshwater or saltwater species (normally algae and/or crustaceans and/or fish) representing three trophic levels	100
Two long-term NOECs from freshwater or saltwater species representing two trophic levels (algae and/or crustaceans and/or fish) + one long-term NOEC from an additional marine taxonomic group (e.g. echinoderms, molluscs)	50
Lowest long-term NOECs from three freshwater or saltwater species (normally algae and/or crustaceans and/or fish) representing three trophic levels + two long-term NOECs from additional marine taxonomic groups (e.g. echinoderms, molluscs)	10

Figure 6.1: Assessment factors for deriving PNECs. Defined by the TGD for marine water column (Smith *et. al.,* 2006 (ERMS Report no. 3), EC, 2003).



Available test results	Assessment factor	PNEC$_{\text{marine sediment}}$
One acute freshwater or marine test	10000	Lowest of LC50 /10000 and equilibrium partitioning method
Two acute tests including a minimum of one marine test with an organism of a sensitive taxa	1000	Lowest of LC50 /1000 and equilibrium partitioning method

Figure 6.2: Assessment factors for deriving PNECs. Defined by the TGD for the marine sediment, from short-term sediment toxicity tests (Smith *et. al.,* 2006 (ERMS Report no. 3), EC, 2003).

A disadvantage using assessment factors is that it discards a lot of information since it only uses the most sensitive species. When using different methods for PNEC derivations, the lowest PNEC derived should be used for the risk calculation.

6.2.2 Species Sensitivity Distribution (SSD)

The SSD approach is based on the fact that there is often a significant variation between the susceptibility of different species tested for a given toxicant (van Straalen, 2002). In ecological/environmental risk assessment the ”concentration versus effect” data usually comes from single-species toxicity tests measuring effects to individuals even though it is the populations, communities and ecosystems that are the entities to be protected. Single-species test data are combined to predict concentrations affecting only certain percentage of species in a community. If a large set of single-species data of good quality (either LC_{50} values or NOEC values) is available, a distribution can be drawn by log-transforming the toxicity data. This makes it possible to identify a hazardous concentration at which a certain percentage of all species are assumed to be affected (Newman *et. al.,* 2000). This is done in such a way that the percentile is sufficiently low as to cause no harm to the majority of the community. The corresponding concentration is designated as HC_p, “hazardous concentration for p percent of the species” (van Straalen, 2002).

For pragmatic reasons it has been decided that the concentration corresponding with the point in the SSD profile below which 5 % of the species occur, should be derived as an intermediate value in the determination of a PNEC/ HC_5 (Smit *et. al.,* 2005 (ERMS report no. 10)). In other words, at the 5 % point at the distribution curve the hazardous concentration can be identified (see figure 6.3). This method is only reliable if it exist at least 10 NOEC/LC_{50} values in the database for different species covering 8 or more taxonomic groups (e.g. BTEX, PAHs, heavy metals etc) (Smit *et. al.,* 2005 (ERMS report no. 10))

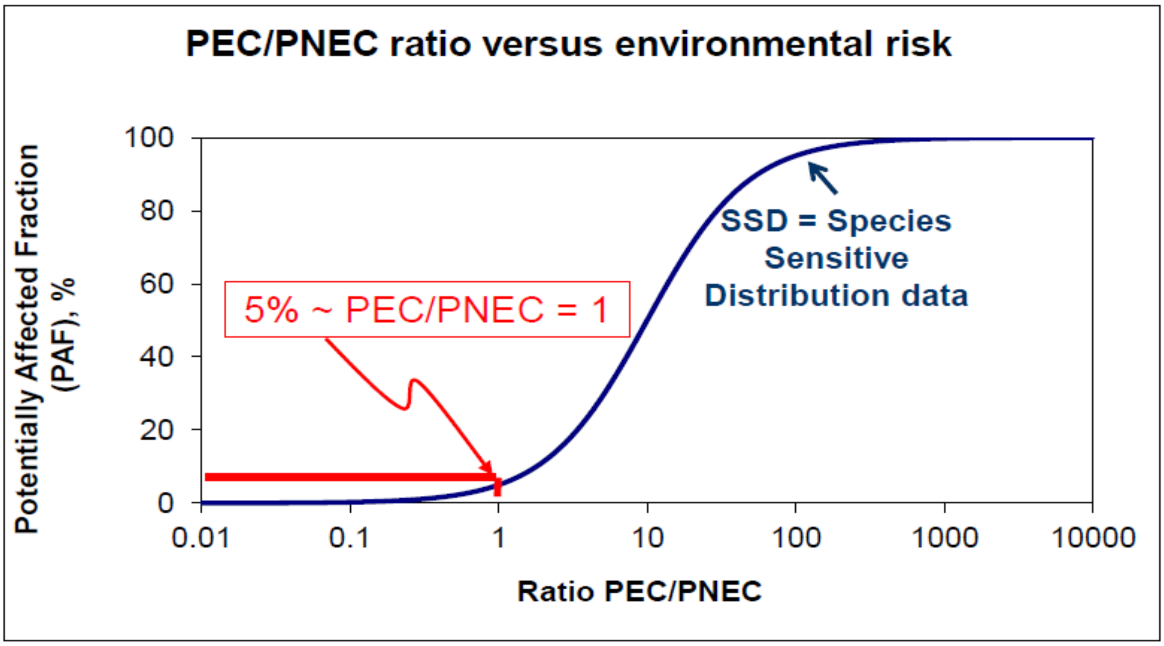


Figure 6.3: When PEC/PNEC = 1, the probability that a random species (PAF) is effected by the toxicant and the risk on adverse effects are both 5% (Reed & Rye, 2011).

When the PEC/PNEC = 1 the probability that a random species is effected by the toxicant and the risk on adverse effects are both equal to 5 %. At any other level of exposure the probability that a species is affected by the toxicant is equal to the respective frequency in the SSD (Smit *et. al.,* 2005 (ERMS report no. 10)). This probability is defined as the risk at that level of exposure. The SSD methodology makes it possible to compare and combine the contribution of the single components to the overall risk of the mixture. By doing so, the main contributor to the overall risk can be identified and make the risk “reducement” as effective as possible.

6.2.3 Equilibrium partitioning method

Due to the absence of any ecotoxicological data for sediment-dwelling organisms, the PNEC values for the sediments may be provisionally calculated using the equilibrium partitioning method (EC, 2003).

The main underlying assumptions of using partitioning methods are (EC, 2003):

- Benthos and planktons organisms are equally sensitive for the given substance

- The given substance are in thermodynamic equilibrium in organisms, sediments and pore water
- Sediment/water partition coefficients can either be measured or derived on the basis of a generic partition method from separately measurable characteristics of the sediment and the properties of the chemical.

According to the TGD, the equilibrium partitioning method should be used for PNEC determination when only acute toxicity data with benthic organisms are available (Smith *et. al.,* 2006 (ERMS Report no. 3).

After a literature survey done by Rye & Ditlevsen (2013) related to partitioning of heavy metals in the sediment, new knowledge was revealed. The values presently used in the DREAM model are partly based on a publication by Neff, J.M. (2008), and suffers from the fact that the laboratory experiments that form the basis for the partition coefficients used do not account for the effects from the natural sediment present. The native sediment tends to adsorb an essential portion of the heavy metals dissolved from the particle ingredients in the mud. These effects will cause the "efficient" partition coefficients between the sediment (including barite) and pore water to increase substantially due to the reduction on the amount of the heavy metals dissolved in the pore water (Rye & Ditlevsen, 2013).

The conclusion from the literature survey was a new recommendation based on an other experimental setup done by Schaanning *et. al.* (2011) which appears to include all ingredients present (mud particle metal barite, metals in natural sediment and from dissolved metals in barite, even contributions from the presence of biota) (Rye & Ditlevsen, 2013). Therefore, the Schanning values for the partition coefficients for heavy metals in sediment are recommended to be used in the DREAM sediment impact model. Table 6.6 and table 6.7 provides an overview of these values.

6.2.4 Field monitoring data (F-PNEC)

The definition of the threshold values is based on generic guidelines assuming that most sensitive species should be protected. These literature based thresholds are compared to levels in the field where (no)effects of the specific stressor has been observed.

As an alternative of deriving PNECs from laboratory eco-toxicity data, the possibility to derive F-PNECs from field data of benthic macro benthos living in a gradient of contaminants were investigated (Bjørgsæter, 2006 (ERMS report no. 15)). This method requires large datasets with chemical and biota information for sediment samples. Single species are plotted as a function of their abundance against the natural contamination concentrations and thus EC50s are estimated using regression technique. The EC50s are presently used to construct F-SSDs (Field Species Sensitivity Distributions), from which F-PNECs are derived.

The different methods used (assessment factors, equilibrium partitioning etc.) for derivation of PNEC values, are summarized in Frost *et. al.* (2006) for metals, organic compounds and other PLONOR/non-PLONOR chemicals.

6.3 PNEC for water column effects

6.3.1 Chemicals

As mentioned in section 3.3 toxic stressors related to drilling discharges in the water column are divided into three classes:

- Metals in drilling mud
- Natural organic compounds
- Added chemicals (both PLONOR and non-PLONOR)

Weighting agents and clay are the main source of heavy metals in drilling discharges to the marine environment. If the natural organic substances are discharged, they are assumed to associate to cuttings and mud particles and sink down to the sea floor. The contribution to the dissolved concentrations in the water column is assumed to be limited (Smith *et. al.,* 2006 (ERMS Report no. 3).

PNEC values for a specific toxicant are highly dependant on the availability of data. The use of assessment factors and statistical extrapolation can be applied to the data to assess the PNEC, as described in the EU-TGD (EC, 2003)

Metals

The main source of heavy metals in drilling discharges is, as mentioned, weighting agents used in different drilling muds. Hence both pelagic and benthic organism can be repeatedly exposed, both by “primary” exposure as the material settle through the water column and as “secondary” exposure due to resuspension and repeated settling of particulate matter (Kjeilen-Eilertsen & Westerlund, 2004 (ERMS report no. 4A)).

The Maximum Permissible Concentration (MPC_{water}) is the concentration above which the risk for the ecosystem is considered unacceptable (Smith *et. al.,* 2006 (ERMS Report no. 3). This parameter was prepared by the Dutch National Institute of Public Health and the Environment, and evaluated as “PNEC” values for metals.

The MPC_{water} is calculated from the Maximum Permissible Addition (MPA_{water}) derived from laboratory toxicity data. The MPA_{water} can be used as the concentration of a metal in a specific compartment that may originate from anthropogenic sources, and that can be regarded as acceptable when added to the background concentration (Cb_{water}) (Frost *et. al.,* 2006 (ERMS report no. 4)). The MPC_{water} is defined as the sum of the MPA_{water} and the background concentration.

MPC_{water} values are calculated by the use of either fixed assessment factors, by the equilibrium partitioning method or by SSD. However, in order to be able to use extrapolation methods (e.g. SSD), a 95 % protection level is chosen as a cut-off value. Table 6.1 represents values determined based on conditions in the Netherlands. The MPA_{water} concentrations are based on statistical extrapolation of combined sets of toxicity data (NOEC) from both fresh- and seawater species (Frost *et. al.,* 2006 (ERMS report no. 4)):

Metal	**MPA_{water} (µg/l) ($PNEC_{water}$)**	**$Cb_{marine\ water}$ (µg/l)**	**MPC_{water} (µg/l)**	**NC_{water} (µg/l)**
Cadmium	**0.34**	0.025	0.37	0.028
Copper	**1.1**	0.25	1.4	0.26
Lead	**11**	0.02	11	0.13
Inorganic mercury	**0.23**	0.0025	0.23	0.0048
Methyl-mercury	**0.01**	0.0025	0.013	0.0026
Nickel	**1.8**			
Zinc	**6.6**	0.35	7	0.42

Table 6.1: PNEC values and background concentrations derived by the use of the dutch MPC_{water} method. (NC_{water} is the Neglible Concentration for metals for marine surface waters) (Frost *et. al.,* 2006 (ERMS report no. 4)).

6.3.2 Suspended Particulate Matter (SPM)

When discharging drilling muds and cuttings the concentrations of suspended particulate matter (SPM) in the water column will increase. The smallest particles tend to stay in the water column over longer periods of time and thus may cause impact on water column organisms.

According to Smith *et. al.,* (2006) a literature review was performed in order to collect information that could contribute to establish a PNEC for weighting agents in analogy to the PNECs derived for the toxic substances.

Protocolised laboratory tests for suspended matter are lacking, thus the quality of data is highly variable. This has resulted in low quality information regarding effects from SPM. The effect data on weighting agents include several types of particles and several types of end-points. Due to lack of information in the literature, the PNEC values has been based on acute effect data (L(E)C50) for at least three taxonomic groups (algae, crustaceans and fish). When only short-term toxicity data are available, an assessment factor of 10 000 should be applied on the lowest L(E)C50 of the relevant available toxicity data. Table 6.2 provides an overview of the amount of data and the resulting PNEC, applying the assessment factor approach (Smith *et. al.,* 2006 (ERMS Report no. 3).

Type of weighting material	**Barite**	**bentonite**	**attapulgite**	**WBMs**
Number of effect data	30	17	10	82
Number of L(E)C_{50} data	15	12	7	63
Number of tax. groups	5	5	1	4
Lowest effect value (mg/l)	0.5	2.0	25	5
Lowest L(E)C_{50} (mg/l)	32	9.6	2470	2.6
PNEC (mg/l) using assessment factor of 1000	0.032	0.0096	2.5	0.0026

Table 6.2: Derivation of PNECs for different weighting materials based on acute toxicity data and by using assessment factors (Smith *et. al.,* 2006 (ERMS Report no. 3).

As a second approach SSDs were based on EC50 values for barite, bentonite, attapulgite and WBMs. In table 6.3 below, and overview of the data used to construct the SSDs are presented. For attapulgite only fish data was available, thus SSD cannot be considered as representative for general marine biota.

Type of weighting material	**barite**	**bentonite**	**attapulgite**	**WBMs**
Number of EC_{50} values	20	12	8	63
Number of species with 1 or more EC_{50} values	15	12	7	13
Xm	8.01	7.51	9.22	8.81
Sm	3.05	3.25	2.70	1.05
HC_5	20.0	8.8	1800	79.6
95% confidence interval around HC_5	1.2-100	0.25-58.1	287-3841	5.01-364

Table 6.3: overview of EC50 data for different weighting materials to construct the SSDs (Smith *et. al.,* 2006 (ERMS Report no. 3).

A SSD approach was further used to determine PNEC values for barite, bentonite, attapulgite and WBMs. The results showed to be less conservative and more in line with observed effect levels in the field and in field-relevant exposures (see table 6.4):

Type of weighting material	**barite**	**bentonite**	**attapulgite**	**WBMs**
HC_5 (mg/l)	20.0	8.8	1800	79.6
Proposed assessment factors:				
EC_{50} to NOEC level	10	10	10	10
Lab to field & acute to chronic translation	10	10	10	10
Lack of data on different taxa	-	-	10	-
PNEC (mg/l)	**0.20**	**0.088**	**1.8**	**0.8**

Table 6.4: Overview of assessment factors applied to the HC_5 to derive the PNEC level (Smith *et. al.,* 2006 (ERMS Report no. 3).

6.4 PNEC for sediment effects

As mentioned earlier, the PEC and PNEC values are based on chemical concentrations. Thus, only toxicity is of relevance. The non-toxic stressors on the other hand are based on assumptions and the terms could be replaced by exposure, level or change and threshold. The PEC/PNEC ratio could, as an example, be redefined to PET/PNET (Predicted effect threshold/Predicted no effect threshold) (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)) where the PET represents the exposure and the PNET represents the threshold value for adverse effects. The ParTrack/DREAM model can estimate the PET values.

According to the TGD, the same strategy applied for calculation of PNEC based on aquatic toxicity data also should be applied to sediment data (EC, 2003). If results from whole-sediment tests with benthic organisms are available, the PNEC values for sediment should be derived using assessment factors; only long-term tests studying sub-lethal endpoints are considered applicable to marine risk assessment (Frost *et. al.,* 2006 (ERMS report no. 4)).

6.4.1 Burial

A number of earlier studies of burial have examined the effects from short-term discharges of natural special sediments (such as dredged material). These kinds of discharge rates are not realistic in the form of drilling discharges due to the more constant discharge process during drilling operations. This is therefore of limited relevance for the derivation of a PNEC for burial. In deriving PNEC values, the best information available/best assumptions that can be made have been used (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)). The PNEC represents the threshold value for adverse effects caused by burial, and should therefore be selected as the “lowest threshold” value. PNEC values for both native and exotic sediment can be derived from SSD curves. The threshold data is derived from the effect data reported in Kjeilen-Eilertsen *et. al.,* (2004). Some important assumptions and adaptations was made in the same report:

- When the threshold value is described as "less than" a certain value, half of the value is taken as input for the SSD.
- For some species have threshold values of 0 because they could not escape burial of 1 cm depth. A threshold level of 0 cannot be used as an input value so threshold values of 0.5 cm have been set.
- In case two, or more, threshold values are reported for only one species, the average value for that species is taken as the input for the SSD.

Table 6.5 below shows the PNEC values calculated based on the above assumptions

PNEC burial – exotic sediment	0.96 cm
PNEC burial – native sediment	0.65 cm

Table 6.5: PNEC values for burial in both exotic and native sediments (Kjeilen-Eilertsen *et. al.,* 2004 (ERMS report no. 9B)).

Table 6.5 indicate that species are more sensitive to burial by exotic sediment than native sediment.

6.4.2 Oxygen depletion (Hypoxia)

Hypoxia is defined as dissolved oxygen in seawater of less than 2.8 mg O_2/l and below saturation (Smit *et. al.,* 2006 (ERMS report no. 9)). The most realistic way to present the stress of reduced oxygen ("PNEC") in the sediment would be the reduction of the total oxygen content in the upper sediment layer. The oxygen profile is estimated by calculating the natural oxygen concentration before and after deposition, thus the PNEC value for oxygen depletion is based on a theoretical risk curve. Assuming that the RDP mimics the oxygen profile, the PNEC for oxygen can be set to the same value as the maximum change in RDP where no effects on the benthic community were observed (Smit *et. al.,* 2006 (ERMS report no. 9)). Based on the assumption above, the maximum allowable oxygen reduction used as PNEC is set to 20% (Smit *et. al.,* 2006 (ERMS report no. 9)).

6.4.3 Change in sediment structure (grain size)

These PNEC values are calculated based on the SSD and on a review of benthic surveys in the Dutch sector of the North Sea (Trannum 2004 (ERMS Report no. 9A)). The mathematical base for the PNEC derivation can shortly be described by the cumulative distribution of the species sensitivity plotted against the coefficient of variance (COV) (standard deviation divided by the average grain size) for the grain size. COV is used as an indicator of the percentage of change that will be tolerated by a species (Trannum 2004 (ERMS Report no. 9A)). Given that the true data show a good fit to a normal distribution curve, plotted in the same plot, the value were 5 % of the species are likely to be affected, can be calculated (see figure 6.4).

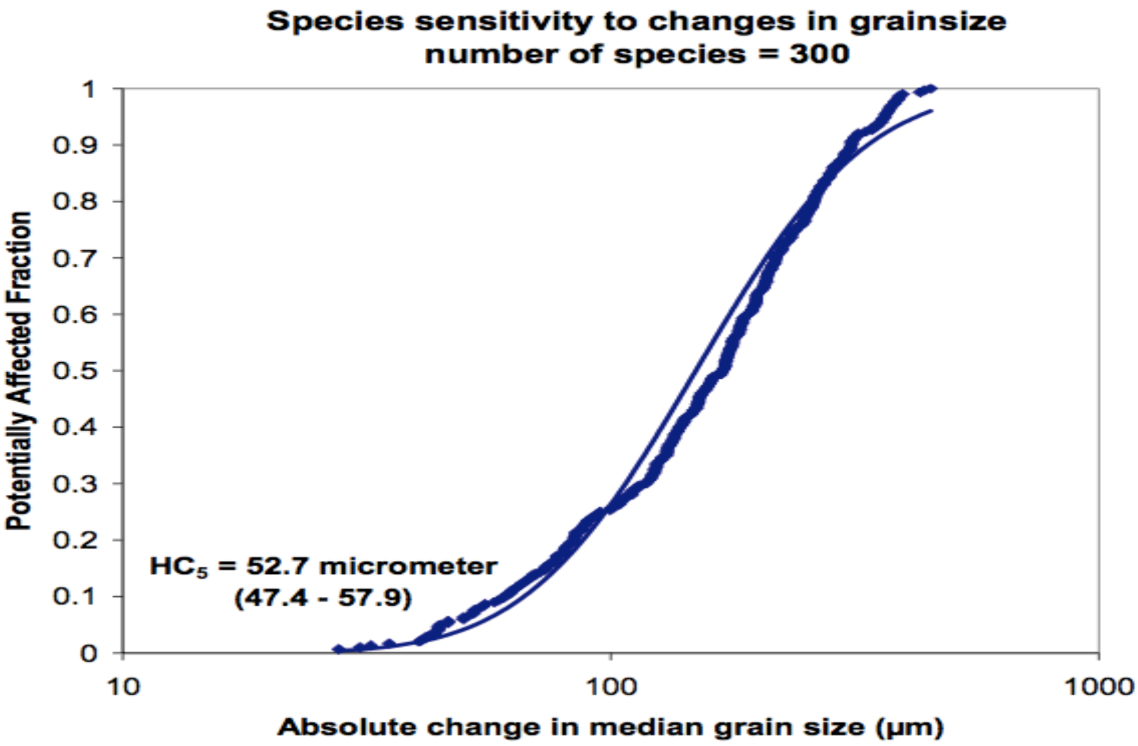


Figure 6.4: The probabilistic value at which 5% of the species are likely to be affected can be derived from this figure. SSD based on the absolute natural grain size window-of-occurrence of 300 North Sea, Norwegian Sea and Barents Sea species (Smit *et. al.,* 2006 (ERMS report no.3), Trannum 2004 (ERMS report no. 9A)).

6.4.4 Chemicals

The sediments may act as a permanent sink for highly hydrophobic or insoluble substances that can accumulate in sediments to high concentrations (Smith *et. al.,* 2006 (ERMS Report no. 3).

As mentioned above, PNEC for the sediment compartment should be calculated for substances that have potential for either directly depositing on the seafloor or sorbing to sedimenting particles. Organic substances with log K_{oc} or log $K_{ow} \geq 3$ are considered to accumulate in sediments and are therefore included in the risk assessment of the sediment compartment (Frost *et. al.,* 2006 (ERMS report no. 4)).

Metals

Heavy metal toxicity from barite cuttings deposited on the sea floor is calculated from the dissolution of the metal in barite into the pore water. The bioavailability of heavy metals increases in the dissolved state, thus only the pore water content of dissolved metals is considered toxic (Rye & Ditlevsen, 2013).

Heavy metals in cuttings are assumed to contain the same concentrations as the background concentrations at the site prior to the discharges, thus these are not included in the calculations for added risk (Rye, H. & Ditlevsen, M.K., 2013). Further, an assumption that it is the dissolved metals in the pore water that are representing the toxicity of metals in the sediment can be drawn. To arrive at the concentrations of dissolved metals in pore water, a partition coefficient between the pore water and the sediment concentrations is applied. This method was deemed more appropriate, compared to the assessment factor approach due to the small amount of available toxicity data from long-term studies. Eq. 6.1 shows the equation used for the calculations of the pore water concentrations for dissolved heavy metals (Rye & Ditlevsen, 2013).

Calculation of local pore water concentration $PEC_{porewater}$ for barite metals (ERMS approach) (Rye & Ditlevsen, 2013):

$$PEC_{porewater} = \frac{PEC_{metal}}{Kd_{metal-porewater}} \qquad \text{Equation 6.1}$$

in which:

$PEC_{porewater}$ = concentration of dissolved metal in pore water (mg/kg)
PEC_{metal} = concentration of metal in the sediment (mg/kg)
$Kd_{metal\text{-}porewater}$ = barite metal-pore water partitioning coefficient (l/kg)

Equation 6.1 is valid for the PNEC concentration level as well. Note the established link between the PNEC for the sediment and the PNEC for the pore water concentration in the sediment (Kd). Thus, the toxicity of heavy metals deposited in sediment is dependent on both the partition coefficient and the PNEC level of the heavy metals in the dissolved state.

The DREAM model applies partition coefficients for estimating heavy-metal concentrations in sediment (C_{sed}) and interstitial waters (C_{PW}) from which toxic impacts are derived. The “barite metal-pore water partitioning coefficient” depend on properties of both the particulate phase and the solute and consequently on local environmental conditions (Schaanning *et. al.,* 2011).

Often, the concentration of metals in the discharged cuttings is known or easily determined. The concentration of the corresponding metals in the interstitial water can then be calculated ($C_{PW} = C_{sed}/K_d$) and the toxicity assessed from the ratio of the PEC to the PNEC below which there is no risk for toxic effects (Schaanning *et. al.,* 2011). The study done by Schaanning *et. al.* (2011) provided different Kd values ($Kd = C_{sed}/C_{PW}$) derived through an empirical study performed in a mecosome. These values are considered relevant for modelling interstitial water concentrations and toxicity in offshore cuttings deposits (table 6.6).

Metal	**Range logK$_d$**	**Recommended logK$_d$**
Pb	3.8-4.8	4.8
Ni	3.8-4.2	3.9
Zn	3.2-4.2	4.2
Cd	3.3-4.0	3.4
Hg	3.3-5.1	3.3
Cr	3.9-5.7	5.7
Cu	3.7-4.0	4.0

Table 6.6: logK$_d$ values derived through an empirical study done by Schaanning *et. al.* (2011). The recommended partition coefficient values are used in the DREAM model to estimate metal concentrations in sediments and interstitial waters.

PNEC for dissolved metals	**Old DREAM values ppb (μg/l)**	**OSPAR (2012) ppb (μg/l)**
Cadmium, Cd	0.028	0.21 + background
Chromium, Cr	8.5 (not used for pw)	0.6 + background
Copper, Cu	0.02	2.6
Mercury, Hg	0.008	0.047 + background
Lead, Pb	0.182	1.3
Nickel, Ni	1.22	8.6
Zinc, Zn	0.46	3 + background

Table 6.7: PNEC values for the dissolved heavy metals in pore water sediment. Water column toxicity for dissolved heavy metals is assumed valid for dissolved heavy metal toxicity in pore water as well. The Old DREAM values are taken from Frost *et. al.*, 2006, table 5.18, ERMS report no.4. (Rye & Ditlevsen, 2013).

7. Methodology

To estimate the particle size distribution for TCC treated drill cuttings a Multisizer analysis was performed. The toxicity data used as input in the DREAM model and the drill cuttings analysed are not from the same cuttings samples. It seems, although, reasonable to assume that the results from the Multisizer are representative for the toxicity-tested sample due to the use of TCC for both samples and the visual resemblance.

7.1 Size distribution of particles found in thermally treated drill cuttings

Sieving and sampling for Multisizer analysis

Approximately 1.5-2.0 g cuttings were suspended in 200 ml of an electrolyte mixture made from isotone and glycerol. The suspension was vigorously shaken for 1 minute. Afterwards, this suspension was poured through a sieve with 1.0 mm mesh size. To wash out particles from the bottle and to rinse remaining particles on top of the sieve, distilled water was used. The amount of water used was recorded for calculations. The particles left on top of the sieve was left to dry and then measured on an analytical scale. The rest of the suspension, which passed through the sieve, was used for sampling for particle analysis and for further sieving. For particle analysis, each time, 50 ml of suspension was pipetted into the Multisizer beaker and 150 ml electrolyte was added to reach a total volume of 200 ml.

The remaining suspension was poured through the next sieve with 500 μm mesh size and the same procedure was carried out as for the first sieving step. The remaining suspension was then used for a final sieving step through a 100 μm mesh size sieve and the same procedures were carried out again. Figure 7.1 gives an overview of the sample compartment components.

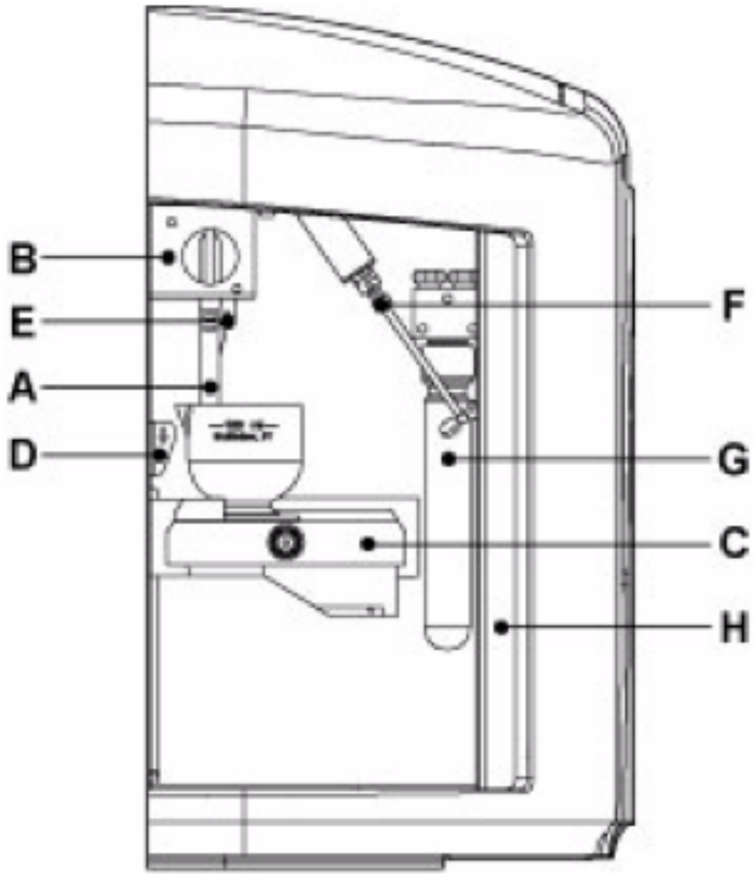


Figure 7.1: Sample compartment components: A) Aperture tube, B) Aperture tube knob, C) Sample platform, D) Platform release, E) External Electrode, F) Stirrer, G) Particle trap, H) LED green, amber, and white status lights (User's manual – Multisizer™ 4, Particle Analyzer, 2010).

Multisizer analysis procedure

For all particle characterization measurements a Multisizer 4 was used. The instrument was turned on 1 hour prior to any analysis. Two different aperture tubes were used; a 1000 μm and a 200 μm tube with measuring ranges of 40 – 600 μm and 4 – 160 μm, respectively. When the largest tube was used, the composition of the electrolyte was 60 % isoton I. and 40 % glycerol (volume percentage). For the small aperture tube, regular isoton I. was used as electrolyte. For all samples, three replicate runs were done and pure electrolyte samples were measured as blank controls for each aperture tube.

As indicated in the previous section, a four times diluted suspension was used when measuring fractions after the first and the second sieve. In case of the third fraction a 64 times dilution was necessary.

The first two fractions (< 1.0 mm and < 500 μm) were analysed using the 1000 μm aperture tube and run conditions were as follows: control mode was set to time (10 s), stirring with a speed of 35 was used and 112 bins were monitored in the range of 40 – 600 μm. In order to determine the volume of suspension analysed during each run, the Mutisizer beaker was weighed before and after each analysis, and a density of 1.123 g/ml was used to convert masses into volumes.

The third fraction (<100 μm) was analysed using the 200 μm aperture tube and run conditions were as follows: control mode of volume (2000 μl) was selected, stirring with a speed of 25 was used and 116 bins were monitored on the size range of 4 – 120 μm.

The Multisizer results fro the three different fractions are presented in appendix A, B and C respectively.

Results

Initial weight and weight of the particles remaining on top of each sieve has been summarized in table 7.1.

	Sample 1	Sample 2	Sample 3
Initial weight of cuttings (g)	1.9986	1.7830	1.6832
On top of 1.0 mm sieve (g)	0.0501	0.0861	0.0752
On top of 500 μm sieve (g)	0.0389	0.0248	0.0668
On top of 100 μm sieve (g)	0.1088	0.122	0.0921

Table 7.1: Initial weight and weight of the particles on top of each sieve.

Results of the calculations from the raw data on the weighing of sieved particles are summarized in table 7.2. (Therein, results should be read, as for example, in a 100 g cuttings sample there were on average 84.33 g particles smaller than 100 μm.)

Particle size range	w/w % of cuttings particles				
	Sample 1	Sample 2	Sample 3	Average	S.D.
> 1.0 mm	2.51	4.83	4.47	3.93	1.2
< 1.0 mm	97.49	95.17	95.53	96.07	1.2
1.0 mm > 500 μm	2.35	1.60	4.92	2.96	1.7
< 500 μm	95.14	93.57	90.61	93.11	2.3
500 μm > 100 μm	8.2616	9.111	8.968	8.78	0.5
< 100 μm	86.88	84.46	81.64	84.33	2.6

Table 7.2: Summary of measurement results showing the distribution of cuttings particles in six size ranges, expressed as weight percentage (w/w%). S. D. stands for standard deviation.

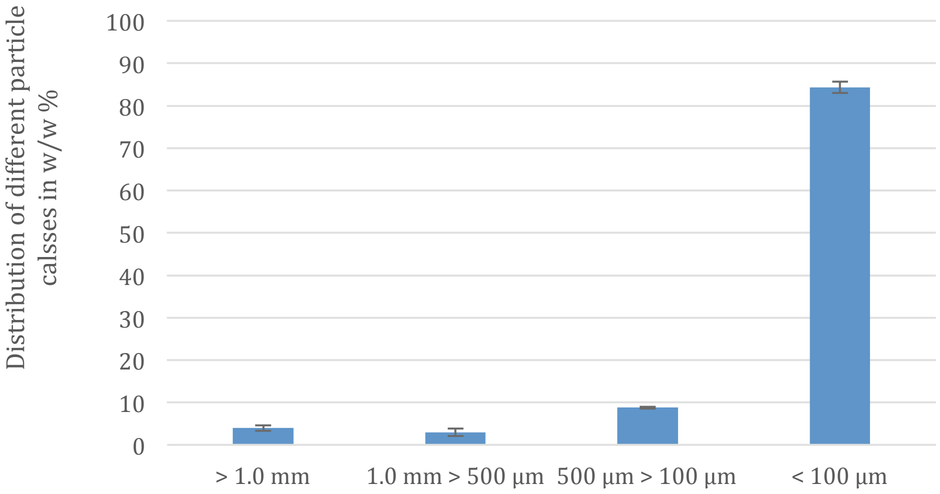


Figure 7.2: Distribution of particle classes expressed in weight percentage of the four particle diameter ranges.

Thus, for the particles smaller than 100 μm (fraction 3), the following distribution was calculated:

Particle size range	w/w % of cuttings particles				
	Sample 1	Sample 2	Sample 3	Average	S.D.
5-10 µm (1)	19,49	19,20	19,20	19,29	0.17
10-15 µm (2)	9,05	8,42	8,42	8,63	0.36
15-20 µm (3)	7,08	6,00	6,00	6,36	0.60
20-25 µm (4)	6,45	5,00	5,00	5,49	0.80
25-30 µm (5)	5,41	4,53	4,53	4,83	0.49
30-35 µm (6)	4,03	3,92	3,92	3,96	0.06
35-40 µm (7)	4,12	3,47	3,47	3,68	0.36
40-45 µm (8)	3,01	2,65	2,65	2,77	0.20
45-50 µm (9)	3,19	2,84	2,84	2,96	0.19
50-60 µm (10)	7,34	5,13	5,13	5,87	1.23
60-70 µm (11)	6,52	5,66	5,66	5,94	0.48
70-80 µm (12)	4,50	3,21	3,21	3,64	0.73
80-90 µm (13)	2,37	6,11	6,11	4,86	2.10
90-100 µm (14)	1,76	3,44	3,44	2,88	0.93
100-110 µm (15)	0,00	2,08	2,08	1,39	1.16
110-120 µm (16)	0,00	2,68	2,68	1,79	1.50

Table 7.3: x w/w% of fraction 3 (smaller than 100 µm), particles are in the given size range.

The numbers in brackets behind the particle size range (in table 7.3) represents the numbers on the x-axis on the graph below (figure 7.3). In the graph, the y-axis represents the percentage (w/w%) of the total number of particles in the treated drill cuttings in that specific size range.

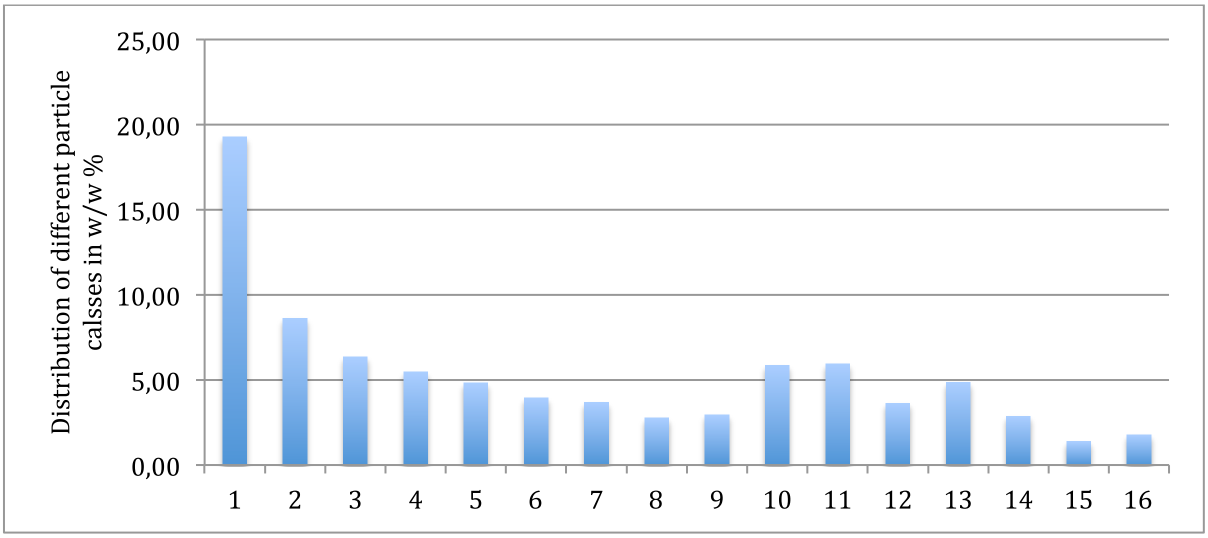


Figure 7.3: Distribution of particle classes expressed in weight percentages of the total treated cuttings, smaller than 100 μm.

7.2 Model Setup

The choice of model input values are based on the results from the Multisizer analysis, from the toxological analysis done by Intertek (2014), the DREAM user manual and reasonable assumptions.

Environmental parameters

The drilling location was kept constant in all simulations, thus the same wind and current profiles. The wind profile represents the conditions at "Ekofisk" and the current profile is derived from May 1990. These are standard wind and current inputs in DREAM.

Model parameters

These parameters are used to control the numerical setting of the DREAM model. The choices here govern the performance of the model (Rye 2012).

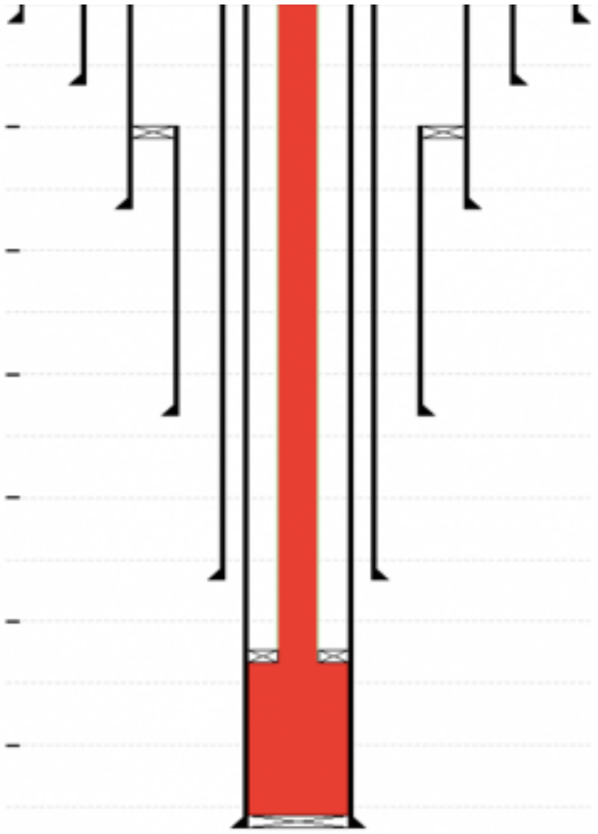
- Liquid/solid/dissolved particles: The number of model particles used to represent the discharge and estimate the fates. More particles yield a higher resolution, but also increase the modelling time.
- Concentration grid dimension: Determination of the number of cells and the volume (x, y and z) of each cell where the EIF is calculated.
- Surface grid dimensions: not applicable for this scenario.
- Concentration grid depth: Specifies the depth interval where the concentration in the water column is to be visualized. The interval should be chosen to reflect the depth interval where the discharge is expected to impact on the water column. In other words, how deep the model should calculate the EIF for.
- Lower concentration limit (ppb): The lowest concentration the model uses to calculate EIF for. 0.001 is used as a default.
- Surface film thickness: Does not apply to drilling discharges.
- Output interval: The frequency of exporting results to file for presenting results. To high output interval might lead to bypassing critical results.

- Time step: This should reflect the duration of the discharge, shorter time steps when the duration of discharge is short and vice versa. Too small time steps may give large computer times. A high time step might lead to bypassing critical results.

Sediment model parameters

The “Sediment Model” menu is used to control the sediment impact calculations. The numbers that are already filled in does no need to be changed for ordinary use of the model for drilling discharge calculations, except for one parameter (see “grain size of the natural sediment” below).

The standard time duration of the sediment model calculations is 10 years. The reason for the big time range, compared to duration of a discharge in the water column, is that the processes in the sediment are relatively slow. Thus, the potential impacts in the sediment after the termination of the discharge will also be accounted for (Rye 2012).



Drilling scenario

A standard well is assumed drilled to reflect a relatively simple drilling procedure:

- Section 1: 36″, 60 m
- Section 2: 26″, 530 m
- Section 3: 17 1/2″, 690 m
- Section 4: 12 1/4″, 1200 m
- Section 5: 8 1/2″, 980 m

Total depth: 3460 m

Figure 7.4: Wellbore schematic (IPT Global)

Seawater is used for the two top sections and is discharged at the seafloor. The third section is drilled with WBM while in section 4 and 5 OBM is assumed used. The TCC will only be used for the sections drilled with OBM. The penetration rate is 25 m/h for both sections considered. Treated OBM cuttings are assumed in this modelling to be released 11 m below sea-surface facing downwards (180°). This discharge will sink in the water column, and an underwater cloud of small particles could form. The larger particles will sediment. At some point, the particle "cloud" will disperse in the same way as water-soluble substances.

Due to the TCC treatment, the effluent will contain very small amount of oily compounds. It is assumed that the oil on cuttings ratio will not exceed 0.05 percent (500 ppm) according to the requirements from the Norwegian Environment Agency. Cuttings and barite are the main part of the effluent.

The drill cuttings analysis performed by Intertek (2014) resulted in the following metals and PAH concentrations before and after treatment (table 7.4 and table 7.5):

Component (unit: mg/kg DM)	**Untreated drilling waste**	**TCC treated drilling waste**
Mercury, Hg	0.37	0.049
Cadmium, Cd	0.22	0.35
Chromium, Cr	22	26
Copper, Cr	74	78
Nickel, Ni	22	36
Lead, Pb	64	70
Zinc, Zn	100	120

Table 7.4: metal content in the drilling waste analysed (not accredited analysis) (Intertek West Lab, 2014)

Component (unit: mg/kg DM))	**Untreated drilling waste**	**TCC treated drilling waste**
Napthtalene	5.0	0.043
Acenaphtylene	1.7	<0.05
Acenaphtene	3.3	<0.01
Fluorene	2.0	0.038
Phenanthrene	2.1	0.13
Anthracene	0.37	0.014
Fluoranthene	0.26	0.021
Pyrene	1.2	0.061
Benzo(a)anthracene	0.26	0.028
Chrycene	0.30	0.046
Benzo(b)fluoranthene	0.15	0.041
Benzo(k)fluoranthene	0.017	<0.01
Benzo(a)pyrene	0.12	0.031
Indeno(1,2,3-cd)pyrene	0.037	0.022
Dibenzo(ah)anthracene	0.031	0.015
Benzo(ghi)perylene	0.16	0.098
Total PAH_{16}	17	0.59

Table 7.5: PAH content in the drilling waste analysed (not accredited analysis) (Intertek West Lab, 2014).

The information given in table 7.4 and table 7.5 will be used as input values for the present components.

To be able to compare and evaluate how good the DREAM model reflects the impacts from metals and PAHs discharged to sea, the following simulations was found necessary:

1) Untreated drilling waste discharged in two batches (1 batch per section). The PAH concentrations was excluded.
2) TCC treated drilling waste discharged in two batches. The PAH concentrations was excluded.

3) Drilling waste discharged in two batches. Particle size as for the TCC treated discharge and metal concentrations as for untreated discharge. PAH concentrations excluded.
4) TCC treated drilling waste in two batches. PAH concentrations included.
5) Untreated drilling waste in two batches. PAH concentrations included.

The total amount of discharge will be the same for all simulations. A 1000 tons of discharge, divided into two batches.

Grain size of the natural sediment

The sediment texture is regarded as one of the most important factors for the structuring of benthic communities, by both direct and indirect mechanisms. Thus, the sediment texture has strong influence on the partitioning of contaminants (Trannum & Brakstad & Neff, 2006 (ERMS report no. 12)).

The model calculates the stresses caused by the deposition of grains that have sizes that are different from the natural grain sizes at the actual location (Rye & Ditlevsen, 2013), and therefore the median grain size on the natural sediment should be known. The number specified here forms the basis for calculating the grain size change stressor. The number to be filled in is preferentially based on results from field surveillance of the sediment usually carried out on the drilling site prior to the drilling operations. A median grain size equal to 0.15 mm will be used in these calculations (default value) (Reed *et. al.,* 2011).

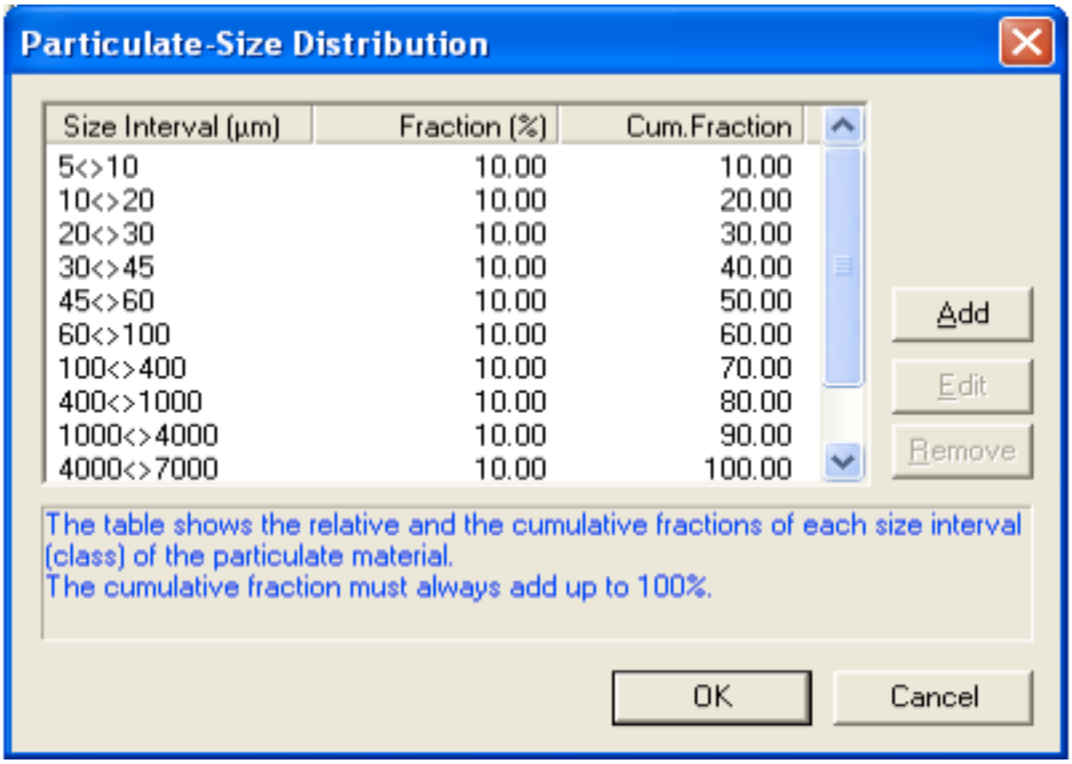
Discharge distribution

Treated discharge:
The main particle fractions are cuttings and weight material (barite, ilmenite, bentonite). It is assumed, in these calculations that the fractions are mixed into one single fraction due to the TCC treatment. For simplicity reasons that fraction will be represented by cuttings as the only particles present, thus the metals and PAHs will be attached to cuttings only. The density of the cuttings (the default value in the model, 2.6

tons/m^3) will be increased considered the barite originally in the mixture. When the Multisizer analysis was performed, a density of the treated cuttings was found to be 6.8 tons/m^3. The size distribution of the cuttings used as input is the results from the same analysis.

Untreated discharge:

It is assumed that cuttings represent all the particles. The increased density from above will stay constant to compensate for the excluded barite. The default values defined by the model are used as size distribution for the cuttings. Figure 7.5 represents the size distribution and the related fraction of each size interval used by the model.



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%.

Figure 7.5: Default values for the particulate-size distribution for cuttings (Rye & Ditlevsen, 2013).

Time duration of the discharge

When an exploration well is to be drilled, the duration is expected to last for two to three months. The drilling (and discharge) will not be continuous due to other activities. The drilling waste needs to be transported to the topside of the platform for treatment. Due to the time consuming and capacity restricted TCC treatment, the discharge is assumed to happen batch-wise. The duration per batch is set to 10 hours with a 48 hours repeat interval.

Stratification

The ambient water data input are according to the summer stratification in the North Sea, and used to evaluate the effects from introducing a thermocline and a pycnocline. The data can either be turned on average or user specified (profile). An overview of the temperatures and salinity used as input is given in table 7.6. The writer assumes the values represented in the table.

Depth (m)	Salinity (ppt)	Temperature (°C)
10	33.0	10
20	33.5	9.8
30	34.0	8.7
40	34.5	8.3
50	35.0	7
75	35.0	6.8
100	35.0	6.6
150	35.0	6.2

Table 7.6: Overview over the salinity and temperature profiles used in the simulations.

Currently used PNEC values for non-toxic stressors

- Cuttings: 10 mg/l particle content
- Barite: 0.2 mg/l particle content
- Burial: 6.5 mm
- Change in 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

(Rye, H. 2012).

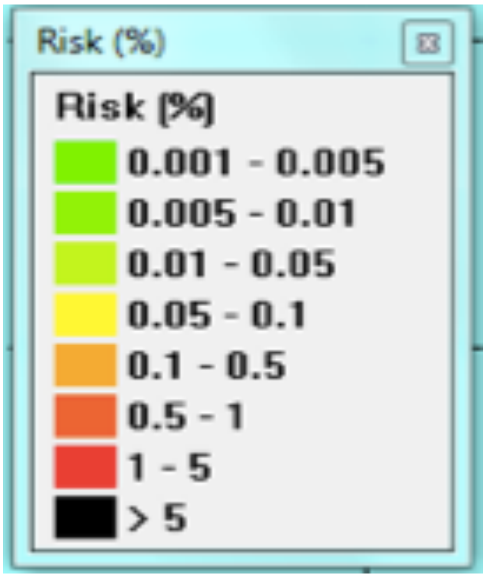
8. Results

As described in the introduction, cuttings discharged to the sea from offshore installations could affect the marine environment through (Blytt *et. al.,* 2014):

- Particles with THC/PAH/heavy metals staying in the water column or seabed sediments and thereby influencing organisms in both the sediment and the water column
- Oil (THC), PAH and heavy metals being discharged to the sea and potentially affecting organisms in the water column and sediment.

All simulations were performed with the set-up described in section 7.2. The EIF and risk results are based on instantaneous values from the time where the risk is at its maximum. The model also calculates the time required to restitute the natural state of the environment when the discharge has ceased to occur. For the water column, this happens shortly after termination of the drilling period. However, for the sediment layer, the restitution time (the restitution time is the time taken until the risk is below 5 %) may extend over several years (default value of 10 years is used in the model) (Rye *et. al.,* 2007).

All scenarios will be represented by a risk map, a pie chart showing the different stressors weighted contribution to risk, a pie chart showing the main contributing metals, a table showing the stressors and their contributions to the risk and EIF values and a time development chart. The different colours present in the risk map represent the severity of the EIF value. Figure 8.1 shows an overview of the different intervals and the belonging colour codes. The scenarios are all divided into one sediment section and one water column section.



Risk (%)

🟩 0.001 - 0.005
🟩 0.005 - 0.01
🟩 0.01 - 0.05
🟨 0.05 - 0.1
🟧 0.1 - 0.5
🟧 0.5 - 1
🟥 1 - 5
⬛ > 5

Figure 8.1: The different colours might present in a DREAM risk map and their belonging EIF intervals

8.1 Simulation 1; Untreated drilling waste discharged in two batches. The PAH concentrations was excluded.

The purpose of the first simulation was to see how the untreated particle size would affect the sediments and how the toxicity of the metals would be distributed between the present components. The interpretation of the results are important to be able to draw conclusions regarding the models ability to estimate the impact on the environment from especially the metals content, but also how the particle size distribution occurrence will contribute to the total EIF.

The following figures (figure 8.2 – figure 8.9) and tables (8.1 and 8.2) are representing the results from the first simulation in both the sediment and in the water column.

8.1.1 Sediment

The metal concentrations in the untreated waste sample were lower than in the TCC treated cuttings sample. The visual results from the DREAM simulation can be seen in figure 8.2. The black area represents the sediment area with an EIF value above 5%. This area covers the total risk in the sediment, including all of the physical and chemical stressors. The area covers a relatively small area due to the high sinking velocities. The reason for this is partly due to formation of larger particles when the discharge mud has “sticky” properties (as for OBM in this case), and partly because a near-field plume is formed with a density larger than the ambient water (Rye, H., 2005).

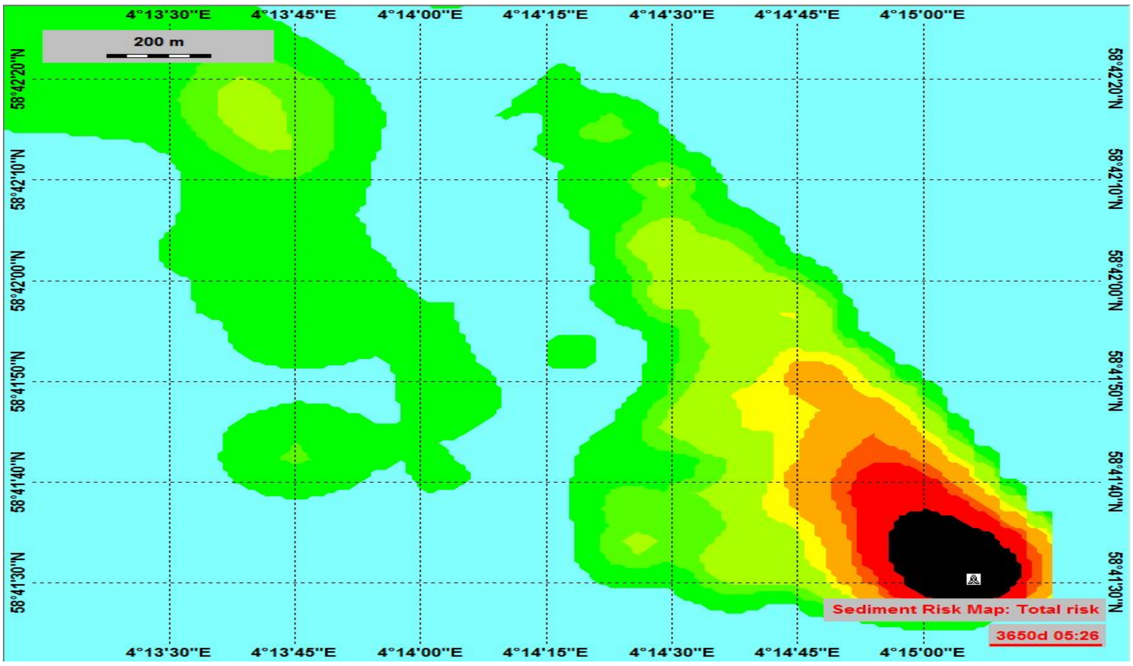


Figure 8.2: Sediment risk map estimated by the model for the untreated drilling waste. Attached metals were the only toxic stressor.

The pie charts given in figures 8.3 and 8.4 are estimated from the numerical output from the model. The major contributor to the total risk in the sediment compartment was the grain size change. The cuttings from the untreated waste are assumed to increase the particle size in the sediment. The original particle size of the natural sediment was assumed to be 0.15 mm, thus approximately 40% of the untreated cuttings was bigger than the native particle size (according to figure 7.5).

The metals were added up to a 27% contribution to the total EIF. Not surprisingly, mercury was the main contributor among the metals. Mercury has the lowest MPa-value and the highest assessment factor (10 000, compared to 1000 for the others (Frost *et. al.*, 2006 (ERMS report no.4))), which indicates higher toxicity impact. Mercury was the only metal which did not decrease in concentration when treated.

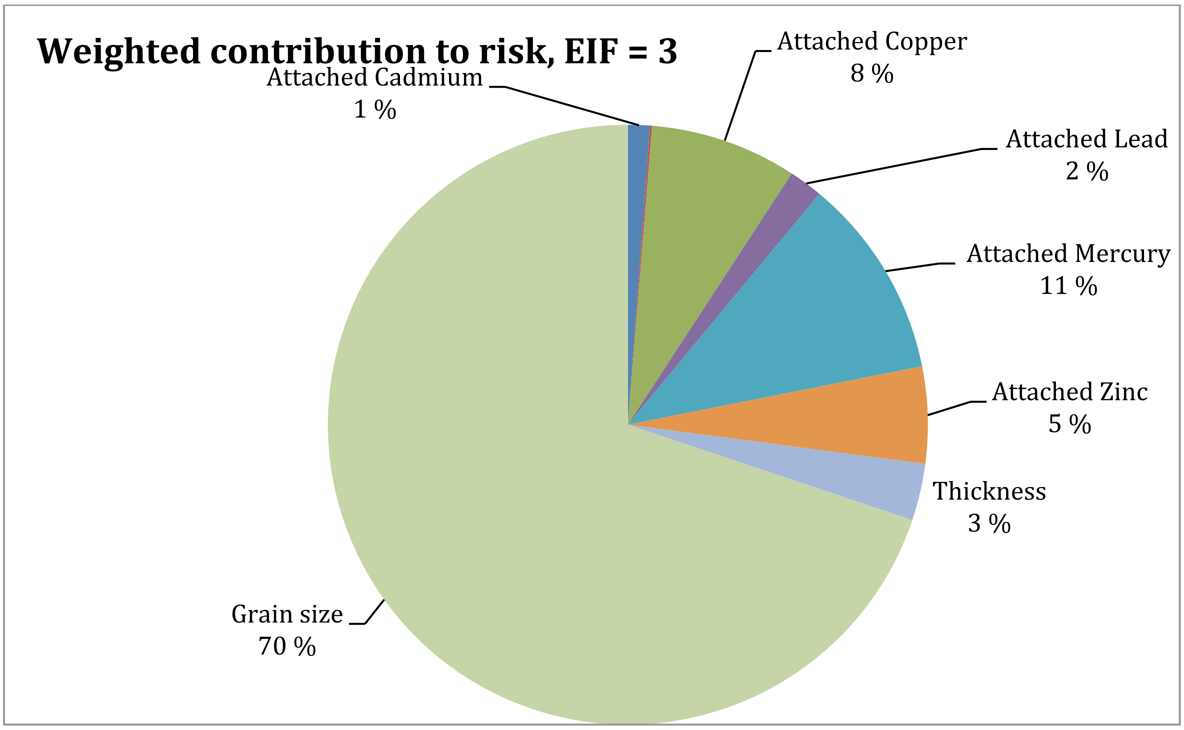


Figure 8.3: Overview of the different stressors weighted contribution to risk from untreated drilling waste in the sediment, represented by a pie chart. Attached metals were the only toxic stressor accounted for.

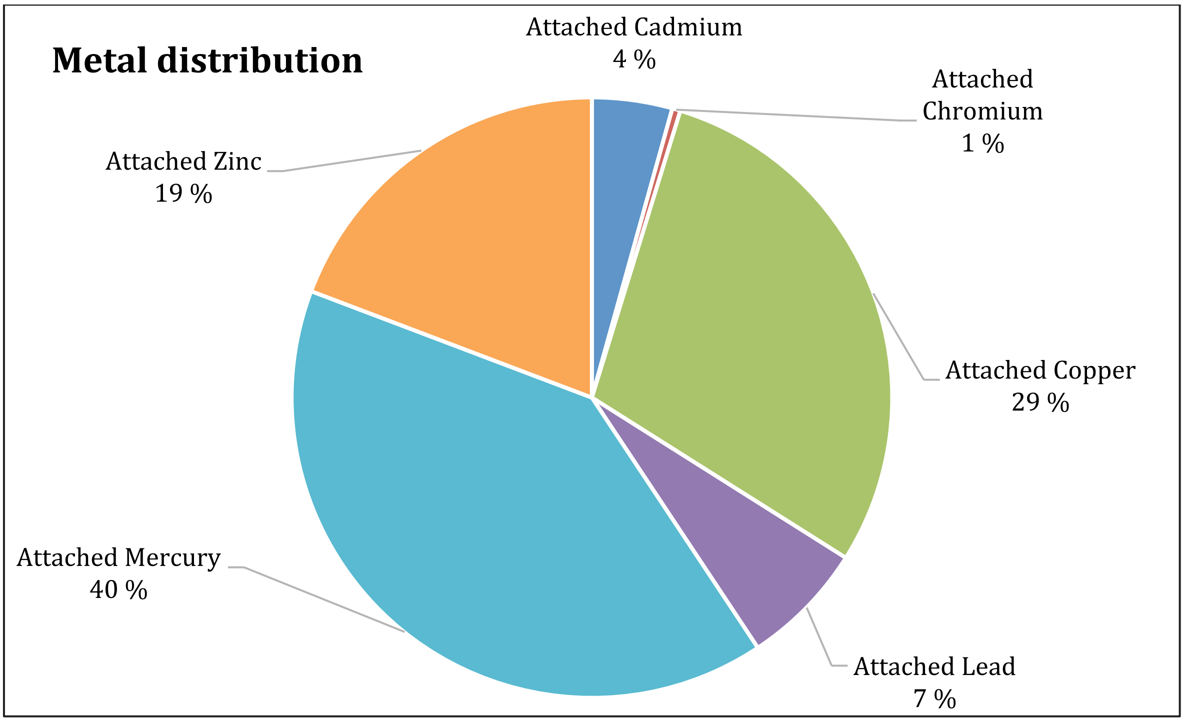


Figure 8.4: Pie chart showing the main metal contributors to the total environmental impact in the sediment from untreated drilling waste.

The numerical output given by the DREAM model is represented in table 8.1. The input concentration is given in ppm. The physical stressors were estimated from the 1000 tons of cuttings released and compared to the PNEC values given above.

Components	**Concentration ppm**	**PNEC ppb**	**Contribution to risk**	**Contribution EIF**	**EIF**
Attached Cadmium	0.22	0.21	1.17	0.03815838	**3.2614**
Attached Chromium	22	0.60	0.12	0.00391368	
Attached Copper	74	2.60	7.91	0.25797674	
Attached Lead	64	1.30	1.82	0.05935748	
Attached Mercury	0.37	0.047	10.86	0.35418804	
Attached Zinc	100	3.0	5.21	0.16991894	
Thickness			3.06	0.09979884	
Oxygen			0	0	
Grain size			69.85	2.2780879	

Table 8.1: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment. Attached metals were the only toxic stressor accounted for.

The time development chart given in figure 8.5 shows how the different contributing stressors vary with time. A uniform peak seems to be between 2 – 300 days, and thus phasing uniformly out. The sediments are not restored when the simulation time is done. This is represented with an EIF value around 2. The grain size seems to be the stressor with the slowest restitution time and highest contribution to EIF.

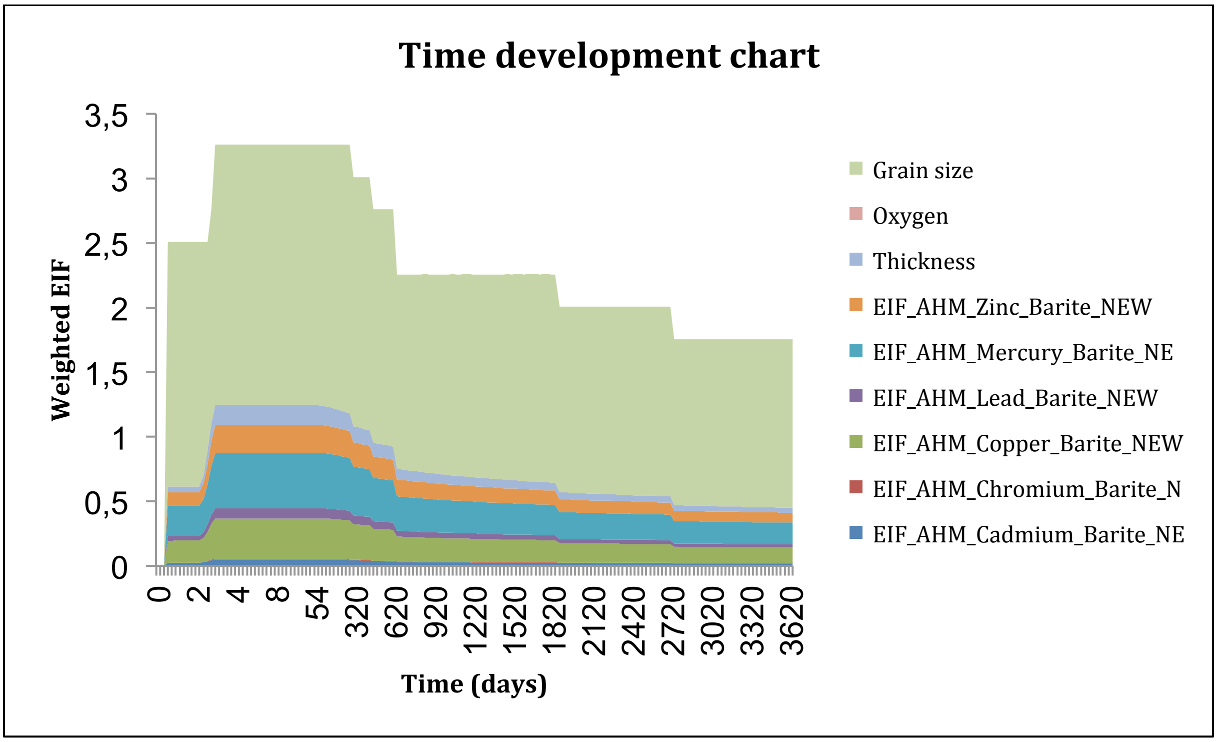


Figure 8.5: Time development showing the EIF variation in the sediment over time caused by untreated drilling waste. Low EIF values over a long period of time represents a chronic EIF.

8.1.2 Water Column

The same discharge effects were estimated for the water column. The total risk map given by the DREAM model is represented in figure 8.6. This figure shows an obvious wind and/or current direction against northwest. Due to the high sinking velocity of the particles it seems reasonable to assume that the spreading of the black area is because of the contributing metals in the water column.

During and shortly after discharge, exposure levels are present in the water column. As long as these expose levels are present in the water column risks on adverse effects could be present.

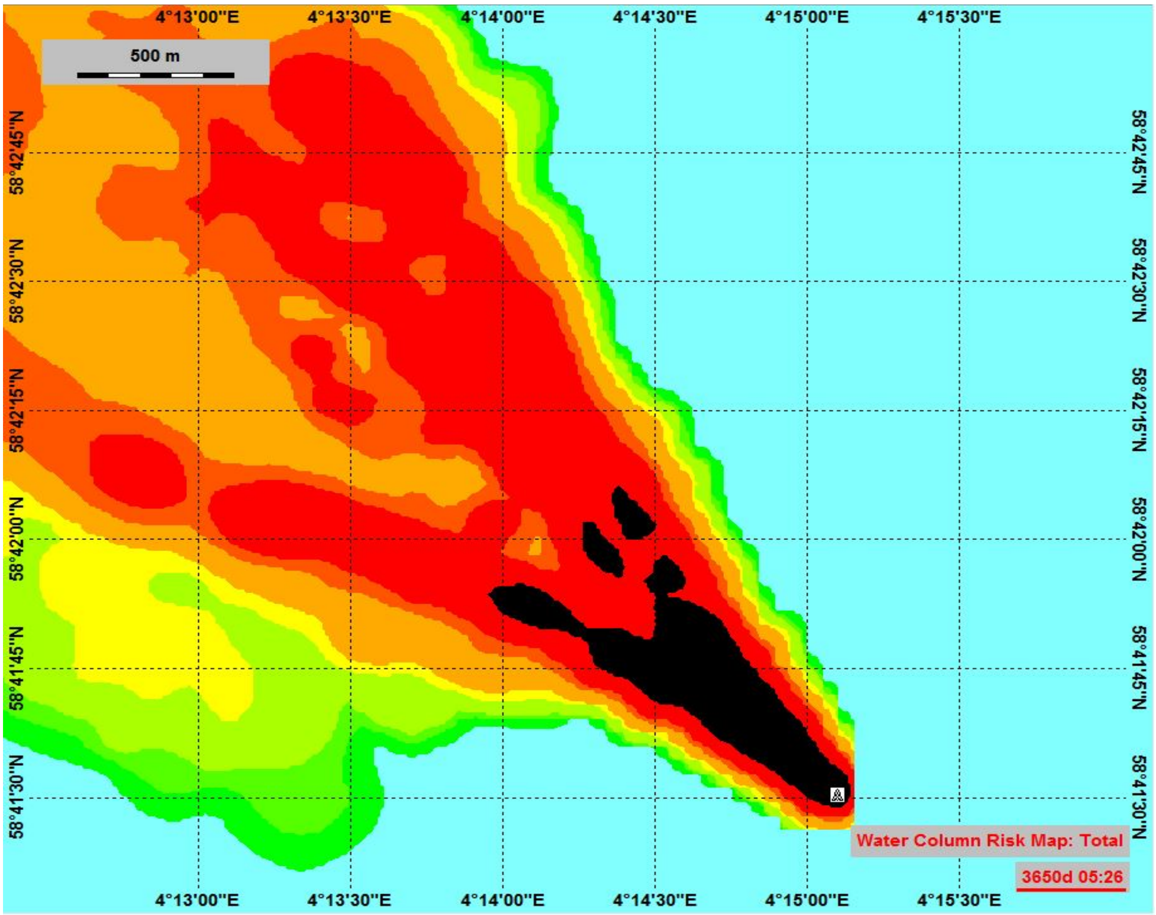


Figure 8.6: Water column risk map estimated by the model for the untreated drilling waste. Attached metals were the only toxic stressor.

The pie chart given in figures 8.7 and 8.8 shows the main contributing EIF factors and the distribution of metals. The contribution from cuttings is much lower in this case compared to the previous. The contribution from mercury also decreased considerably.

Dissolved mercury has a strong affinity for organic matter and suspended sediment and so can be expected to be bound to these particles in the water column and subsequently to accumulate in the sediments (UK Marine Special Areas of Conservation), which was indicated in the previous.

The metals did contribute to 77% of the total EIF value in the water column where chromium and lead was the major components. This indicates that these metals have a high solubility in water and thus are not ass easily adsorbed to particles. This assumption is also supported by the results found for the sediments.

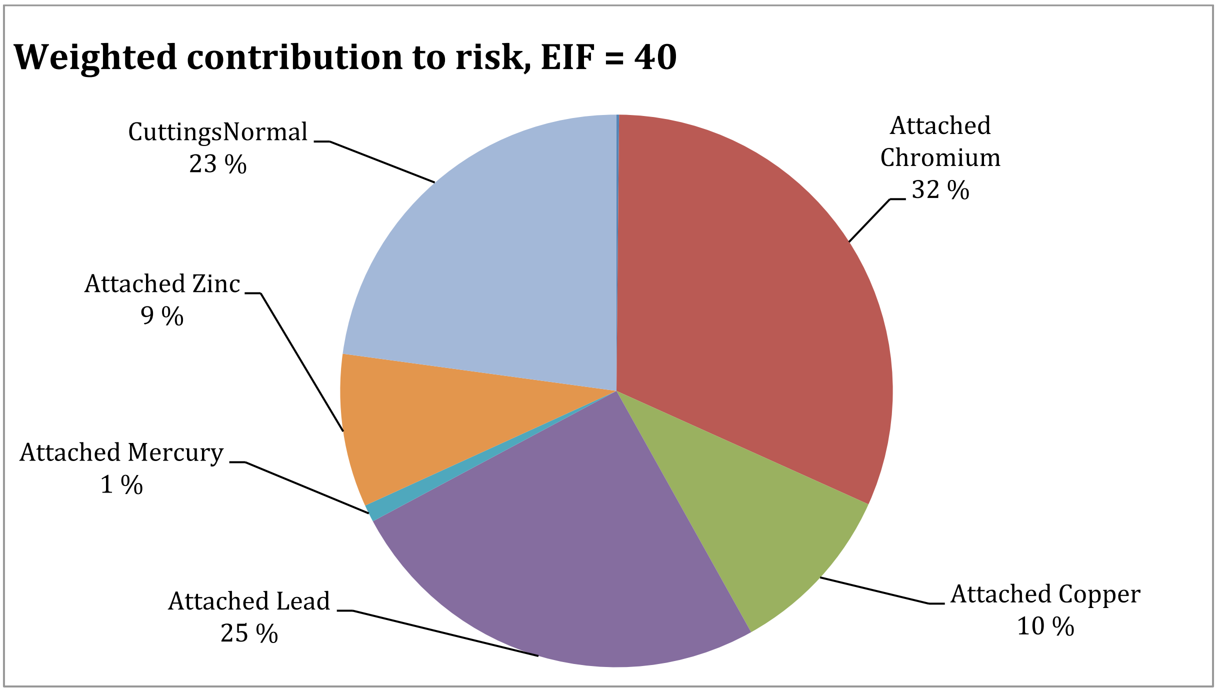


Figure 8.7: Overview of the different stressors in untreated drilling waste weighted contribution to risk in the water column, represented by a pie chart.

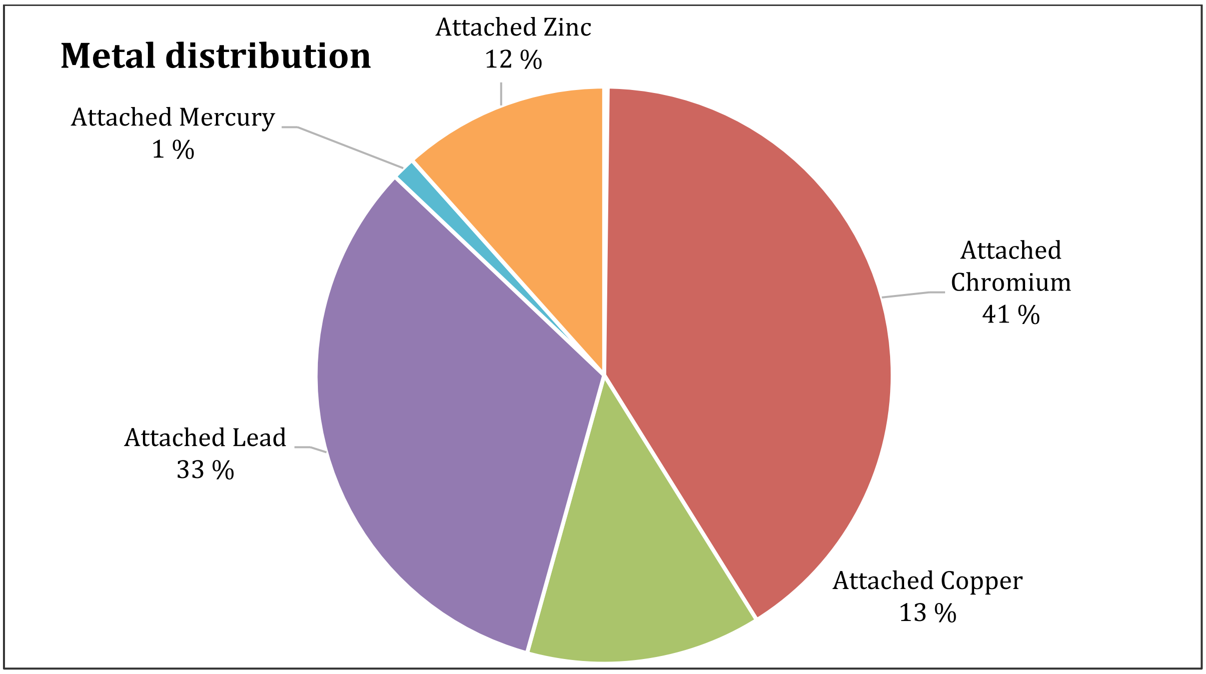


Figure 8.8: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge of untreated drilling waste.

Table 8.2 represents the numerical output given by the DREAM model. The input concentrations and PNECs are listed.

Components	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	EIF
Attached Cadmium	0.22	0.21	0.15	0.06096315	**40.6421**
Attached Chromium	22	0.60	31.58	12.83477518	
Attached Copper	74	2.60	10.17	4.13330157	
Attached Lead	64	1.30	25.28	10.27432288	
Attached Mercury	0.37	0.047	1.01	0.41048521	
Attached Zinc	100	3.0	8.96	3.64153216	
Cuttings		100000	22.85	9.28671985	

Table 8.2: Overview of the different stressors weighted contribution to risk and to the EIF value caused by untreated drilling waste in the water column.

The time development chart represented in figure 8.9 is showing the obviously differences between the sediment and the water column regarding the durability of the environmental impact. The two peaks are representing the two batches discharged. The impact lasts for a couple of hours.

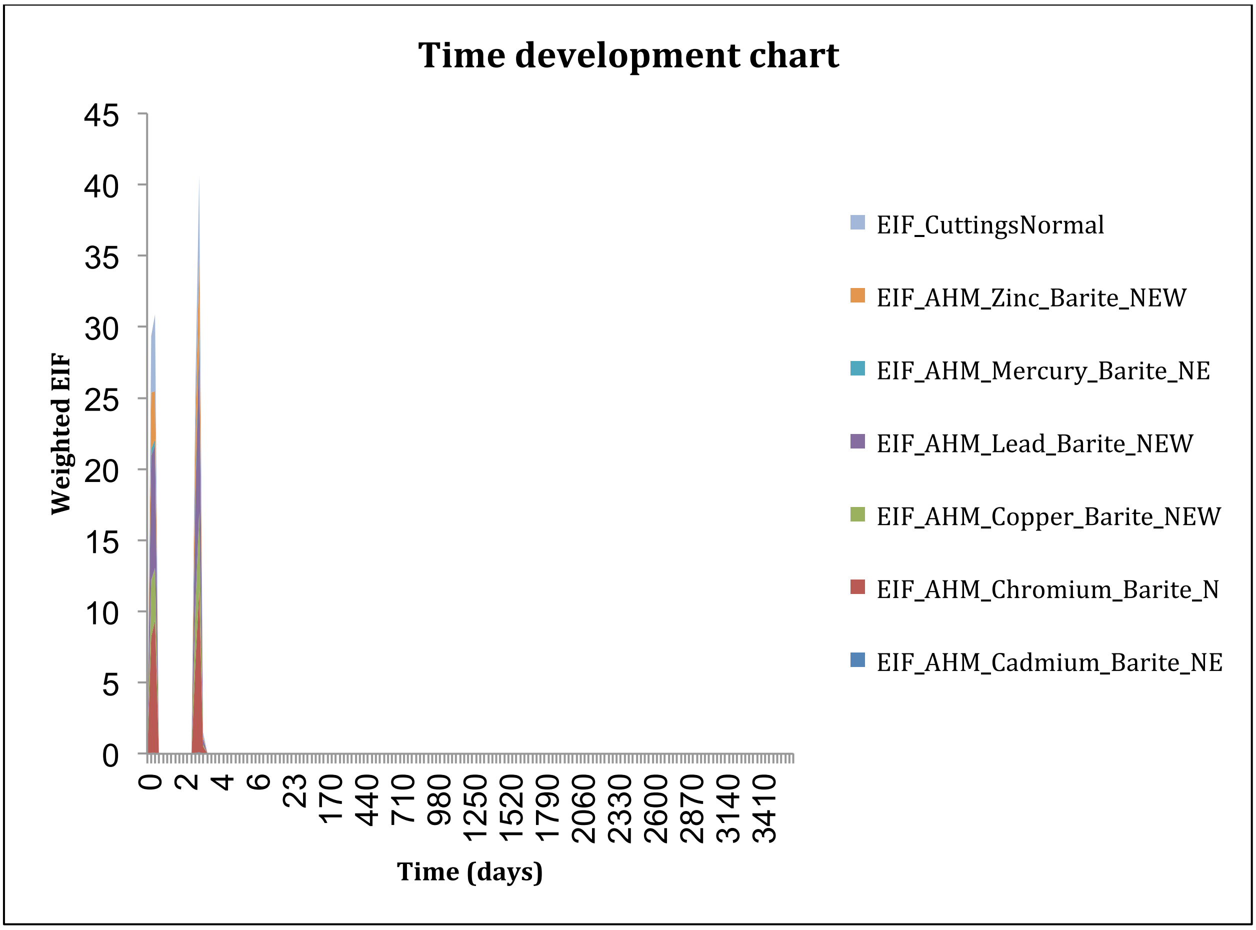


Figure 8.9: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by untreated drilling discharge.

8.2 Simulation 2; Treated drilling waste discharged in two batches. The PAH concentrations was excluded.

The second simulation was supposed to represent drilling discharge treated with TCC. The PAH concentrations was excluded, enabling isolation of the toxicity influence caused by metals only. The PAHs will be included in a later simulation.

The following figures (figure 8.10 – figure 8.17) and tables (8.3 and 8.4) are representing the results from the second simulation in both the sediment and in the water column.

8.2.1 Sediment

The risk map in figure 8.10 represents the total risk estimated by the DREAM model in the sediments. The highest risk present is in the red area with an EIF value between 1 and 5 %. The spreading seems to be more continuous compared to the sediment case in the first simulation, but the green contribution to the total risk can be considered negligible.

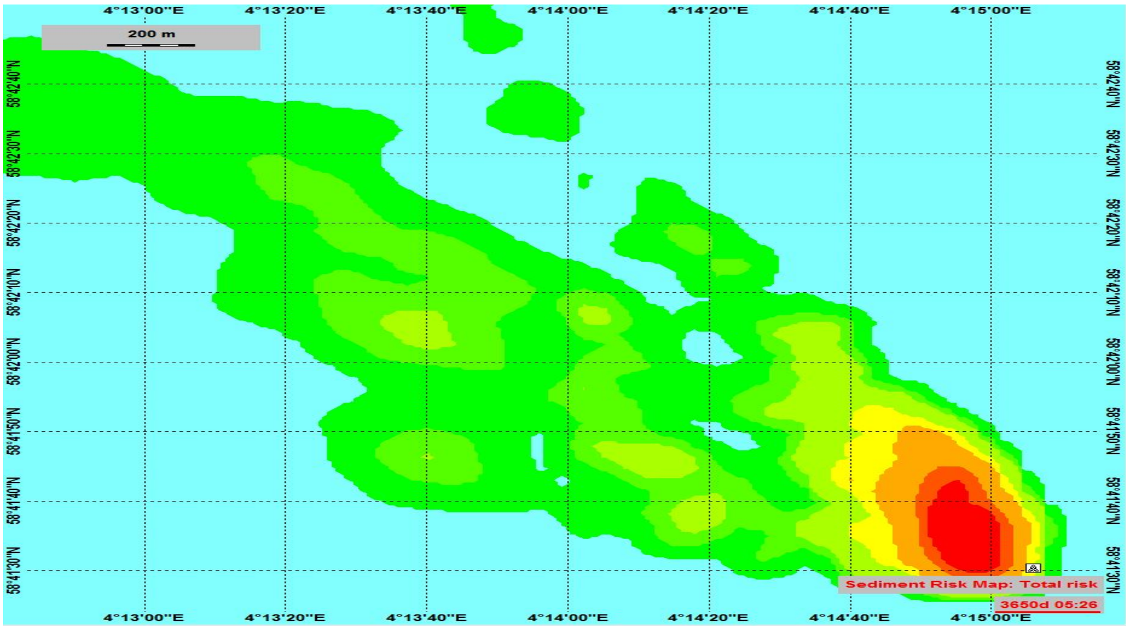


Figure 8.10: Sediment risk map estimated by the model for the treated drilling waste. Attached metals were the only toxic stressor.

The pie chart in the figure 8.11 shows the weighted contribution to the EIF value in the sediment caused by the discharge. The grain size contribution is considerably reduced compared with the first simulation, indicating that bigger cuttings particles have higher environmental impact. The contribution from mercury did more or less not exist at all, likelihood due to the TCC treatment where the concentration of mercury was reduced.

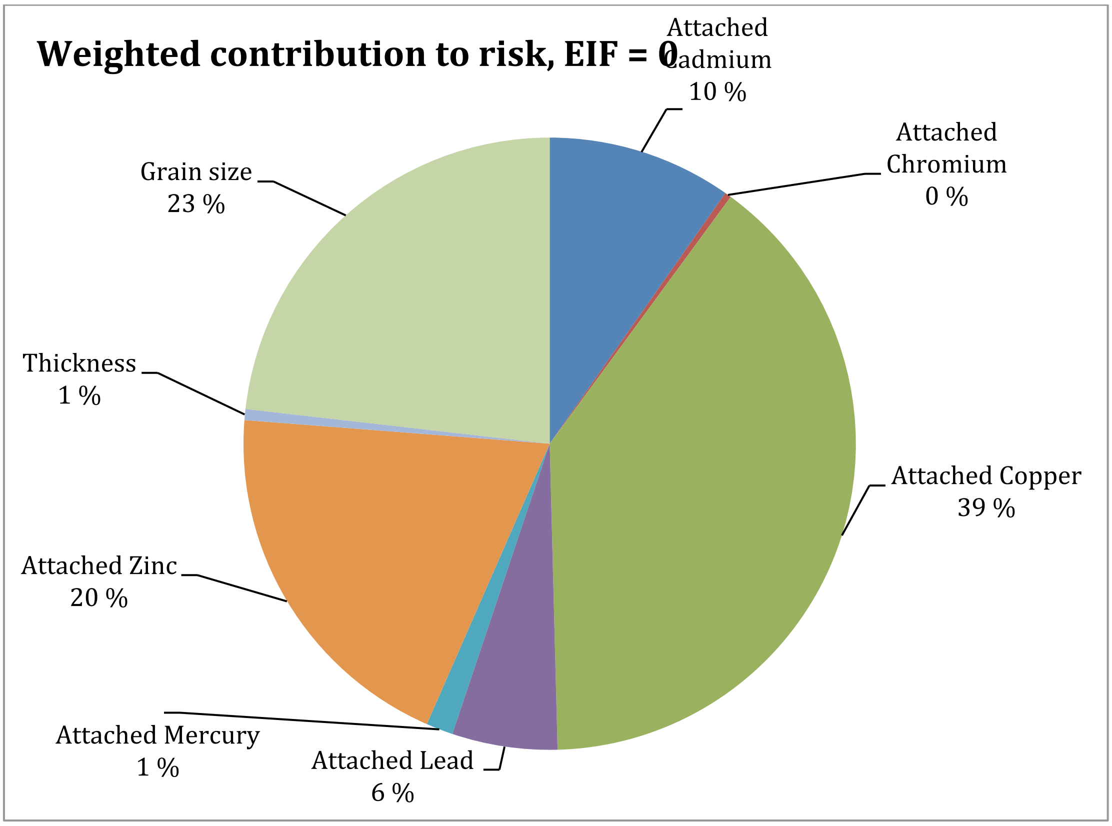


Figure 8.11: Overview of the different stressors weighted contribution to risk caused by treated drilling waste in the sediment, represented by a pie chart. Attached metals were the only toxic stressors accounted for.

The pie chart in figure 8.12 shows the metals distribution. 76 % of the total risk was due to metals. All the metal concentrations except from mercury did increase due to treatment, causing higher metal contributions to risk. The results represented in the pie chart above indicate high water solubility for chromium and lead, and a high affinity for suspended particles regarding copper and zinc.

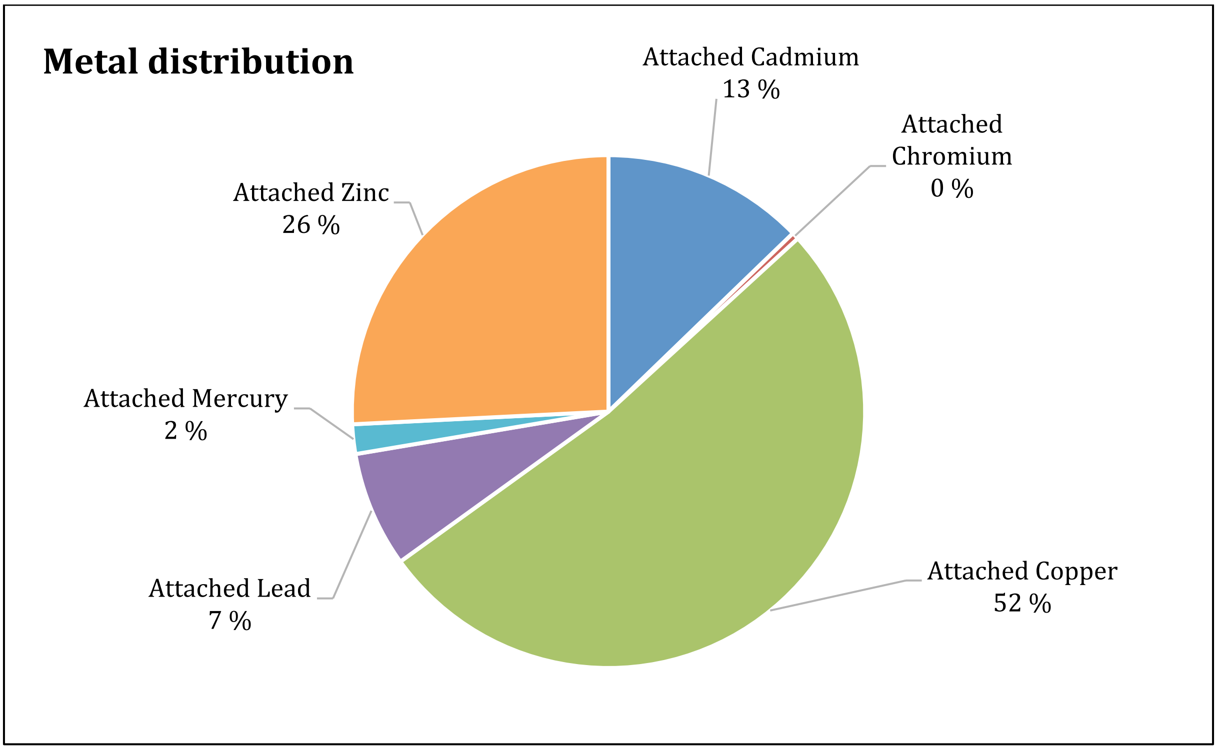


Figure 8.12: Pie chart showing the main metal contributors to the total environmental impact in the sediment from treated drilling waste.

The table represented in table 8.3 shows the concentrations of the different components in the treated drilling discharge. The non-toxic stressors are represented by the 1000 tons of cuttings. The PNEC for the metals are according to the numbers in table 6.7. Even though the increased concentration of heavy metals did contribute to an increased risk, the impact on the sediment environment was more or less zero.

Components	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	EIF
Attached Cadmium	0.35	0.21	9.73	0.04888352	**0.5024**
Attached Chromium	26	0.60	0.34	0.00170816	
Attached Copper	78	2.60	39.52	0.19854848	
Attached Lead	70	1.30	5.56	0.02793344	
Attached Mercury	0.049	0.047	1.42	0.00713408	
Attached Zinc	120	3.0	19.66	0.09877184	
Thickness			0.58	0.00291392	
Oxygen			0	0	
Grain size			23.19	0.11650656	

Table 8.3: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by treated drilling waste. Attached metals were the only toxic stressor accounted for.

The time development chart representing the second simulation is shown in figure 8.13. The impact on the environment seems to be zero after 470 days, thus the time duration is relatively short compared to the first sediment scenario. The different colours are showing the different components contributing to the overall risk, and seem to vary uniformly.

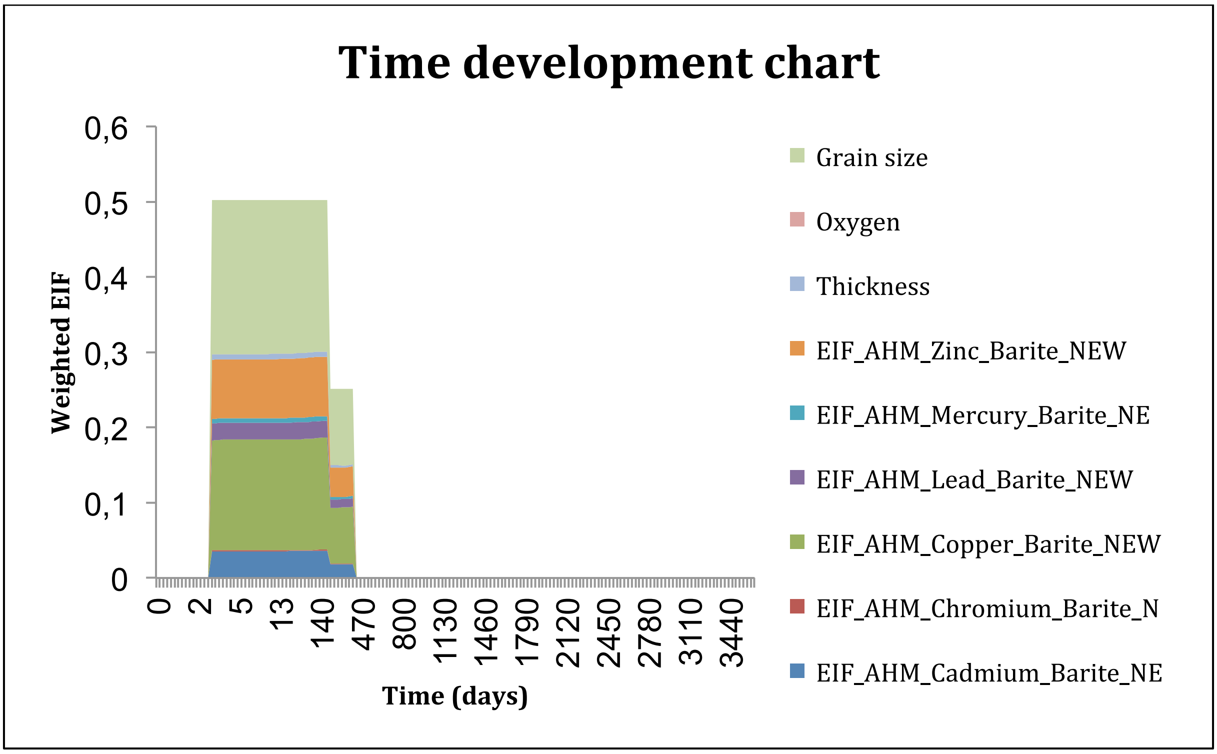


Figure 8.13: Time development showing the EIF variation in the sediment over time caused by treated drilling waste. Low EIF values over a long period of time represents a chronic EIF.

8.2.2 Water Column

The DREAM simulation gave the following figure (figure 8.14) as output. The risk map for the water column for the TCC treated discharge seems, at first sight, to give a smaller impact than in the first simulation. The two pictures are, on the other hand, given in different scales, thus the impacted volume of water occurs bigger in the second simulation.

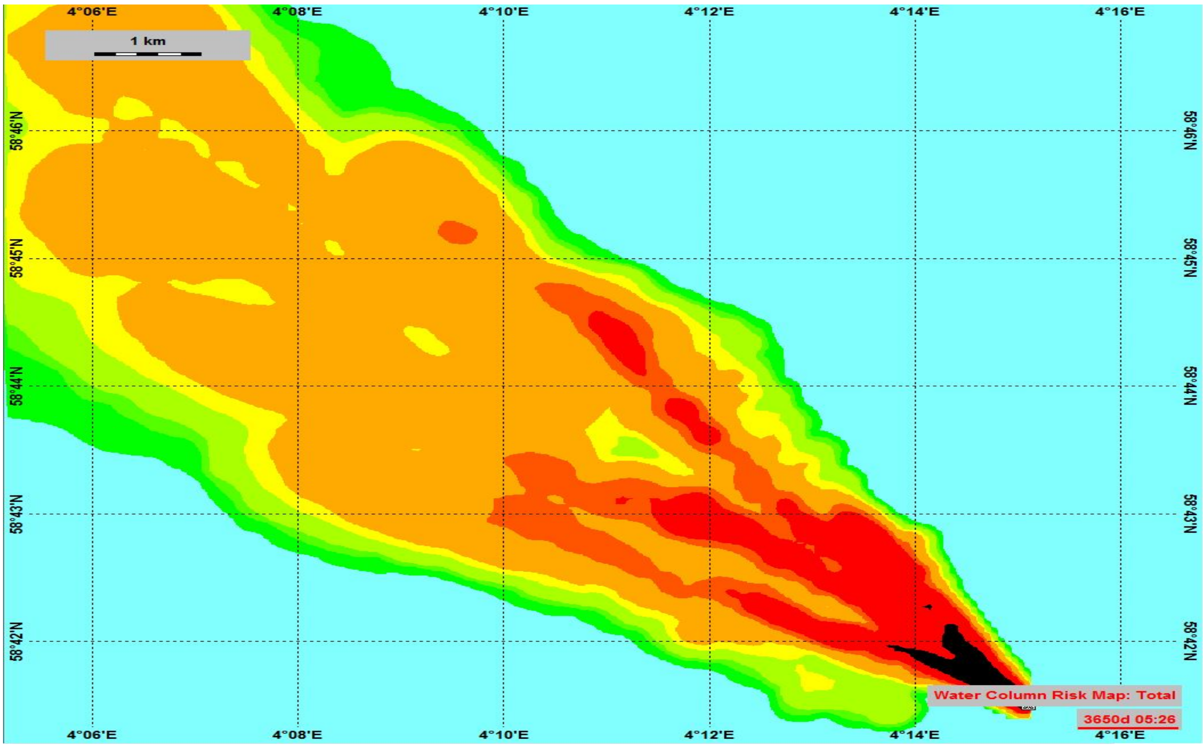


Figure 8.14: Water column risk map estimated by the model for the treated drilling waste. Attached metals were the only toxic stressor.

The increased copper concentration, lead concentration and the present cuttings represented the major risk contributors in the water column. This can be interpreted as, due to the increased surface area of particles in the water column, these metals becomes more bioavailable. The small sized particles can remain suspended in the water column for a time, thus leak and spread the pollutants to the water, either through the release of these compounds to the water column or through ingestion by organisms. The cuttings can also act as a hazard to filter feeding organisms in the water due to the different sizes and shapes. An EIF value of 68 was estimated to be representative for the impact on the water column environment. The pie charts in figures 8.15 and 8.16 make out the different risk contributors and their distribution percentage.

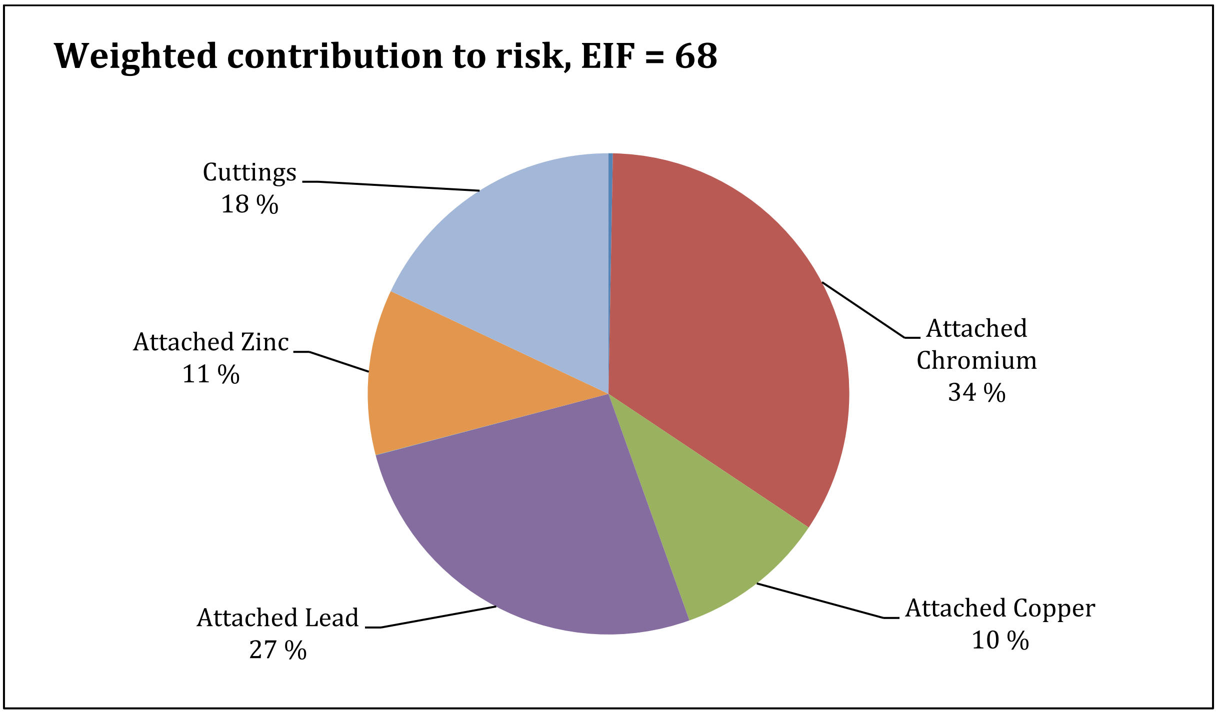


Figure 8.15: Overview of the different stressors in treated drilling waste weighted contribution to risk in the water column, represented by a pie chart.

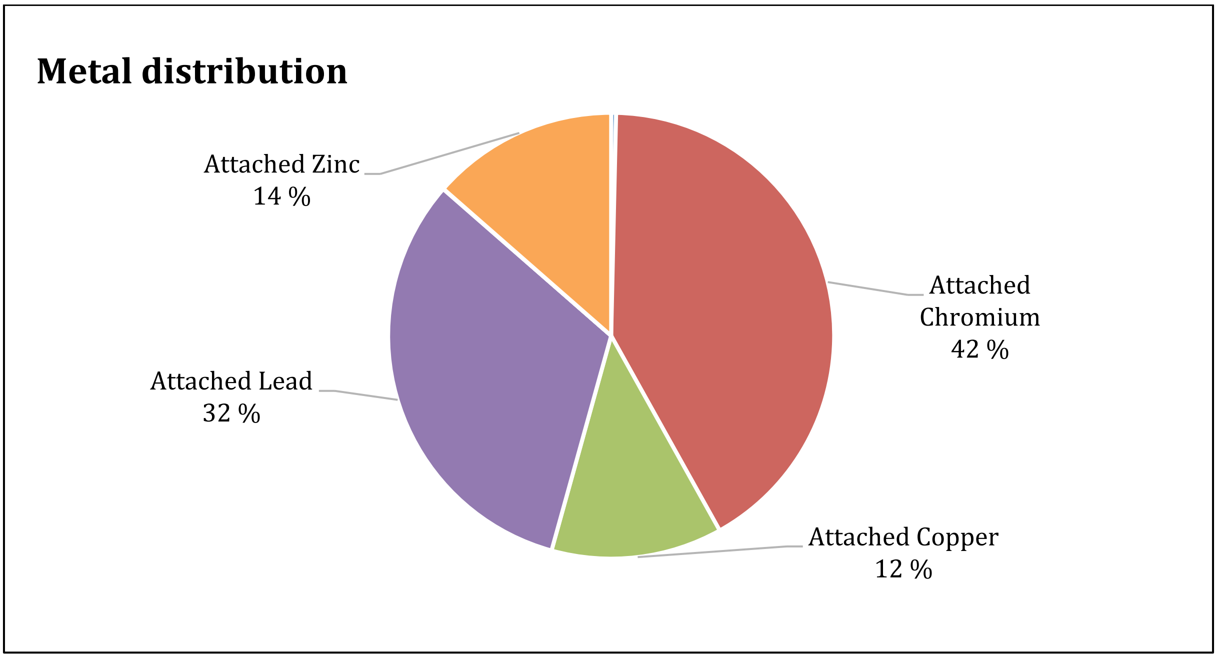


Figure 8.16: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge of treated drilling waste.

In table 8.4 the numerical output from the simulation is presented. The concentrations correspond with the model input. The concentration of cuttings is based on the 1000 tons discharged. The contribution to risk and to the EIF value from each of the compounds present is also listed. The EIF was estimated to be around 68, which are bigger than for the untreated discharge case.

Components	**Concentration ppm**	**PNEC ppb**	**Contribution to risk**	**Contribution EIF**	**EIF**
Attached Cadmium	0.35	0.21	0.29	0.1974204	**68.0692**
Attached Chromium	26	0.60	34.08	23.2003008	
Attached Copper	78	2.60	10.17	6.9233292	
Attached Lead	70	1.30	26.34	17.9312184	
Attached Mercury	0.049	0.047	0.02	0.0136152	
Attached Zinc	120	3.0	11.11	7.5632436	
Cuttings		100000	17.98	12.2400648	

Table 8.4: Overview of the different stressors weighted contribution to risk and to the EIF value, caused by treated drilling waste in the water column.

The time development chart given in figure 8.17 shows the characteristics for a discharge in the water column. The spreading rate is high due to the big volume of water. The EIF value has a big variation in a relatively short period of time, compared to the sediment compartment. The contribution to the total risk from each of the components is hard to observe at the figure due to the narrow "pillars", but the concept can be read of the table above.

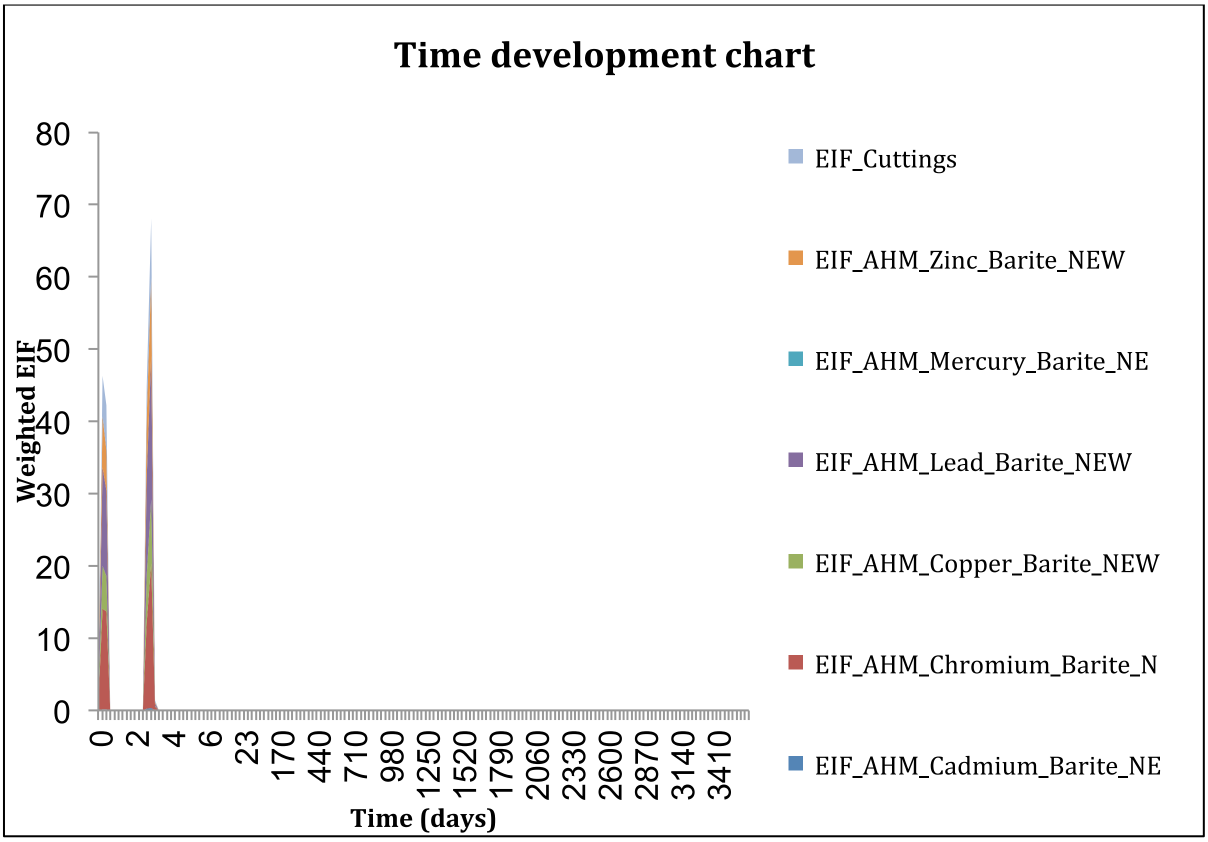


Figure 8.17: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by treated drilling discharge.

8.3 Simulation 3; Drilling waste discharged in two batches. Particle size as for treated discharge and metal concentrations as for untreated discharge. PAH concentrations excluded.

The purpose of the third simulation was to enable comparisons between the main contributors to the EIF value, regarding metal concentrations and particle sizes. In the first simulation the grain size change was found to be the biggest risk contributor in the sediment. This was assumed to be due to the big cuttings size. Of the metals, mercury was of biggest concern. In the water column on the other hand, metals did contribute to the total risk in a higher range compared to the cuttings, thus assuming that all of the cuttings did end up in the sediment.

In the second simulation TCC treated waste was discharged, given treated metal concentrations and particle sizes. This resulted in a lower EIF value in the sediment, indicating that the sustainability for smaller particles was higher than for the bigger ones. The EIF value for the water column did increase. This was assumed to happen because of lower sinking velocities of the cuttings and to the increased metal concentrations.

The following simulation was performed assuming treated particle size distribution and untreated metal concentrations.

The following figures (figure 8.18 – figure 8.25) and tables (8.5 – 8.7) are representing the results from the third simulation in both the sediment and in the water column.

8.3.1 Sediment

The total risk map given in figure 8.18 represents the sediment output from the third DREAM simulation, regarding treated particle size distribution and untreated metal concentrations. The red area represents the area of biggest concern, close to the discharge point. The wind and current directions are still obviously northwest.

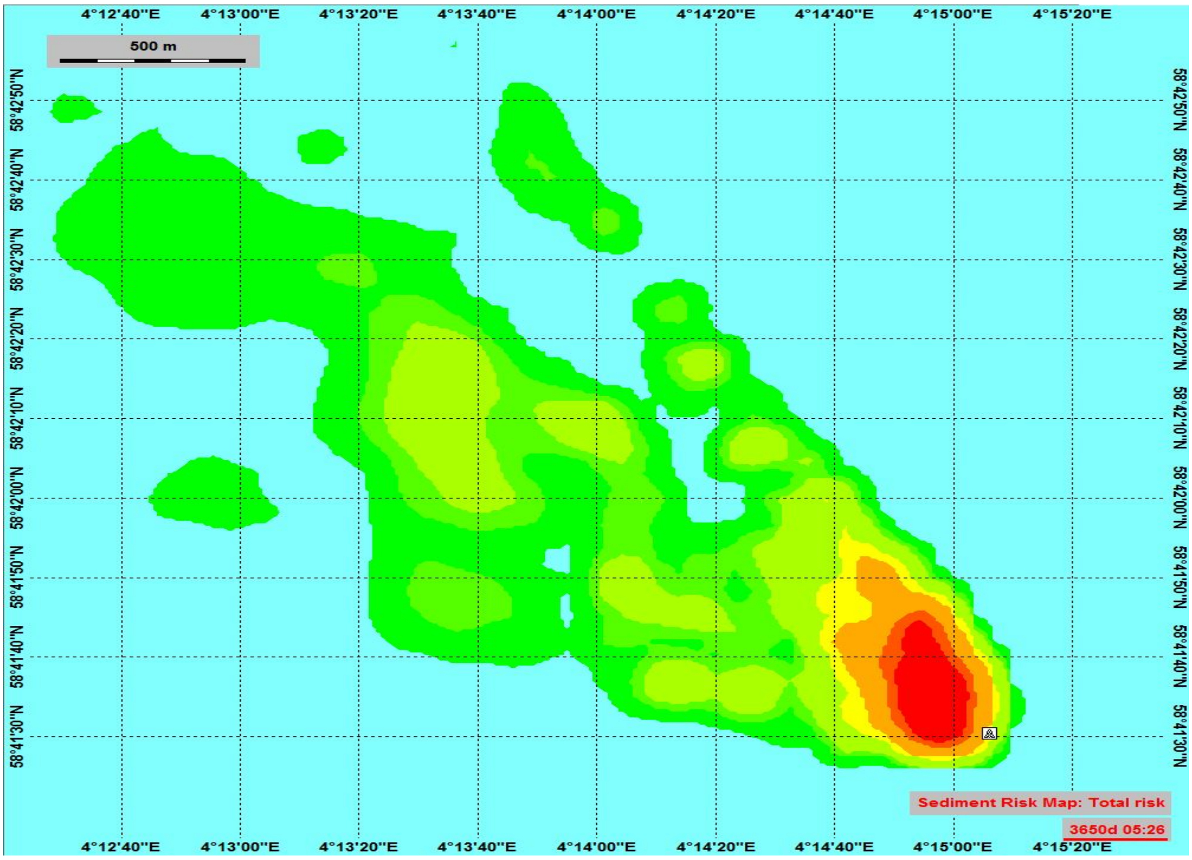


Figure 8.18: Sediment risk map estimated by the model for the discharge type in the third simulation. Attached metals were the only toxic stressor.

The pie charts given in figures 8.19 and 8.20 represent an overview of the EIF contributing factors. As in the first simulation (untreated discharge) the attached mercury was prominent. Also copper, as in both the above simulation, was one of the main contributors to risk in the sediment.

The grain size contribution decreased compared to the first simulation, obviously due to the big size difference. Compared to the second simulation (TCC treated discharge) it also decreased, thus in a much smaller extent. This seems to be because of the EIF contribution from the mercury, which was almost not present in the second simulation.

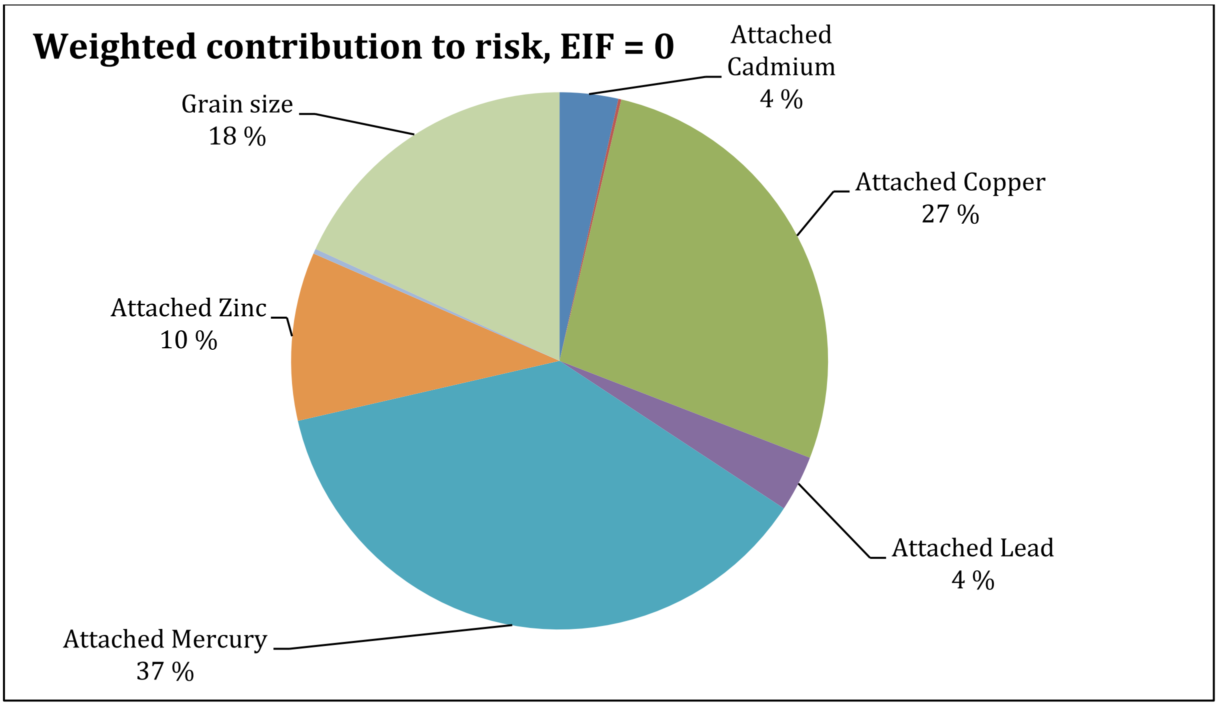


Figure 8.19: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. Attached metals were the only toxic stressors accounted for. Particles size distribution and metal concentrations as for treated and untreated discharge respectively.

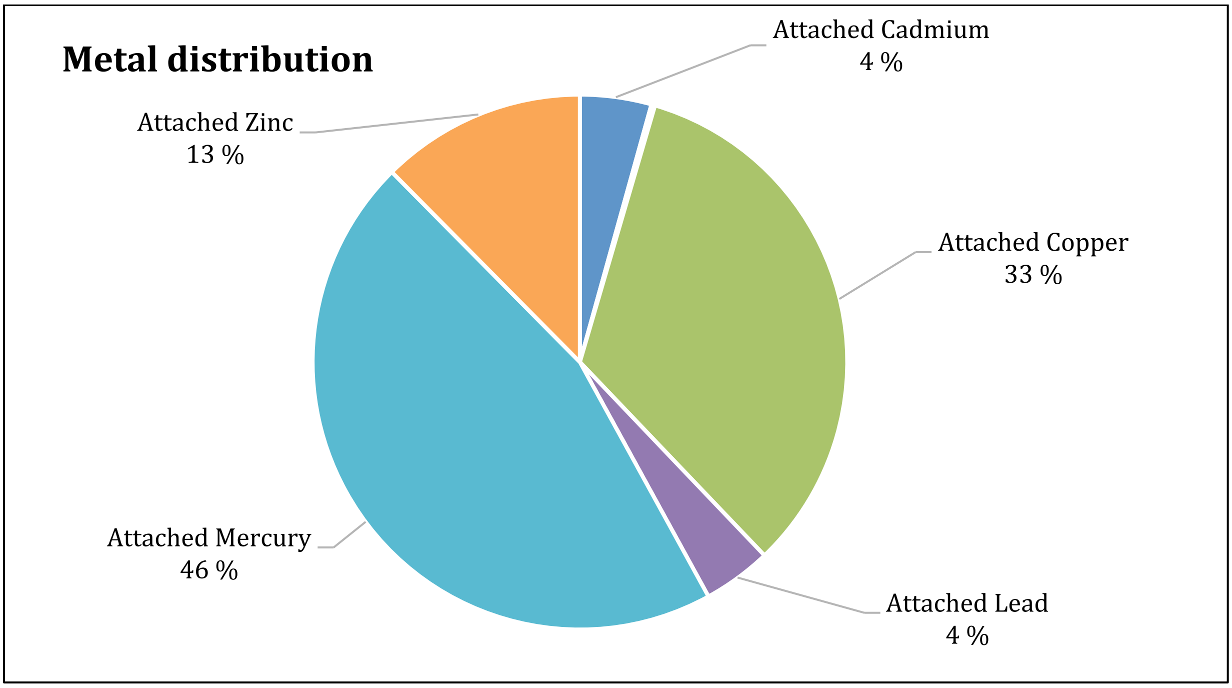


Figure 8.20: Pie chart showing the main metal contributors to the total environmental impact in the sediment from the type of discharge mentioned in figure 8.18.

The values given in table 8.5 represent the input metal concentrations and the belonging PNECs. The non-toxic stressors concentrations are not given in ppm and thus not represented in the table; these are based on the 1000 tons discharge. The non-toxic PNECs are given in section 7.2.

The contribution to risk and to EIF is listed and the EIF value is given.

Components	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	EIF
Attached Cadmium	0.22	0.21	3.52	0.00884576	**0.2513**
Attached Chromium	22	0.60	0.18	0.00045234	
Attached Copper	74	2.60	27.18	0.06830334	
Attached Lead	64	1.30	3.38	0.00849394	
Attached Mercury	0.37	0.047	37.16	0.09338308	
Attached Zinc	100	3.0	10.13	0.02545669	
Thickness			0.3	0.0007539	
Oxygen			0	0	
Grain size			18.16	0.04563608	

Table 8.5: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by the drilling waste. Attached metals were the only toxic stressor accounted for. Particle size as for treated discharge and metal concentrations as for the untreated discharge.

The time development chart representing the third simulation is presented in figure 8.21. The duration of impact is shorter than for both of the two cases given above. The time development seems to be uniform and parallel, regarding the different contributing compounds.

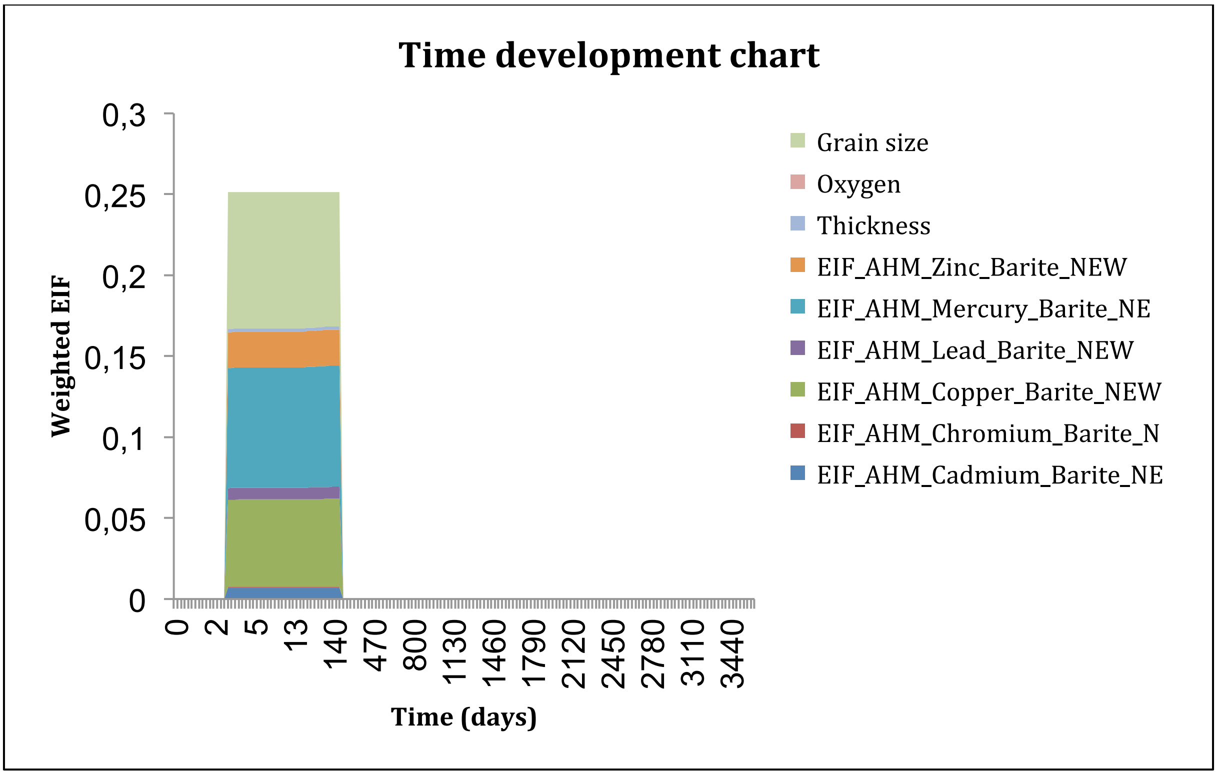


Figure 8.21: Time development showing the EIF variation in the sediment over time caused by the waste discharged. Low EIF values over a long period of time represents a chronic EIF.

8.3.2 Water Column

The total risk map given in figure 8.22 represents the water column output from the third DREAM simulation, regarding treated particle size distribution and untreated metal concentrations. The black area represents the water column of biggest concern. The spreading is increased compared to the untreated discharge case, due to smaller particle sizes. The scale is larger than in figure 8.6, enabling a better spreading impression.

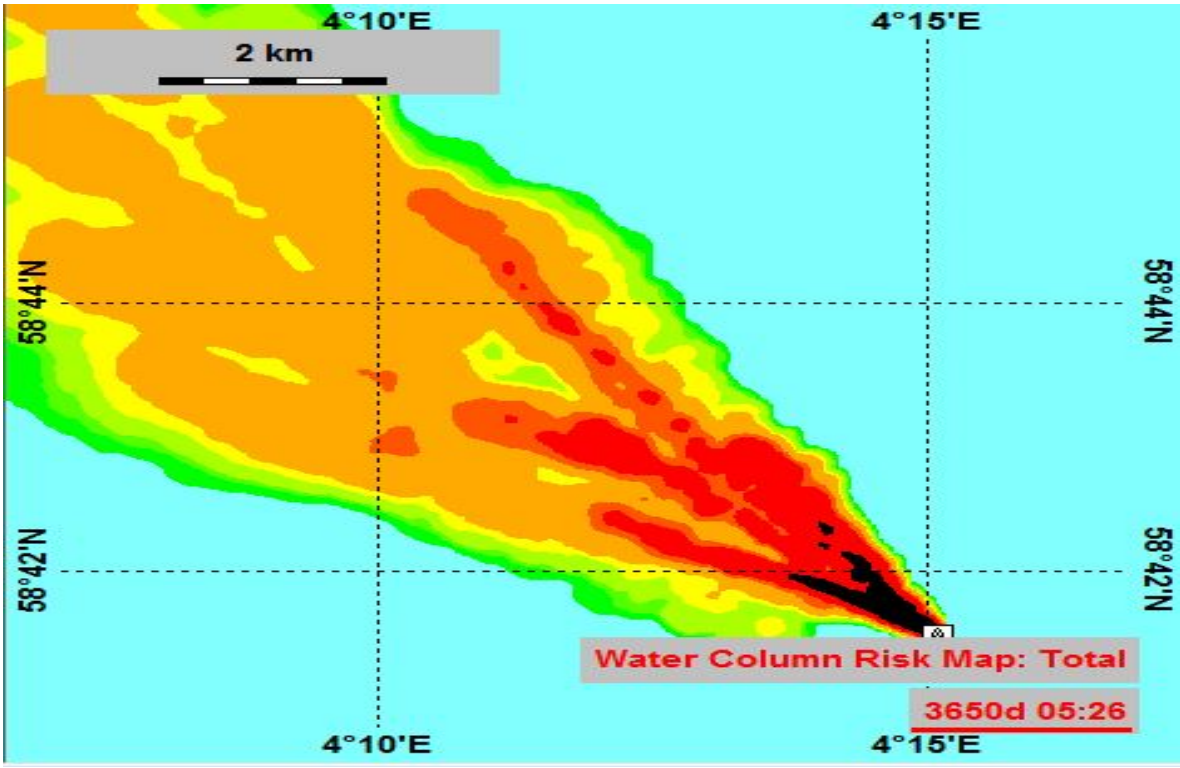


Figure 8.22: Water column risk map estimated by the DREAM model for the drilling waste from the third simulation.

The pie chart in figure 8.23 shows an EIF value of 57, which is higher than in the first scenario and lower than in the second scenario. It also shows the increase/decrease in contribution to risk from the different compounds compared to the above scenarios. Table 8.6 shows a summary of the different scenarios and the contributing factors.

	Scenario 1	**Scenario 2**	**Scenario 3**
Cuttings	23 %	18 %	20 %
Attached zinc	9 %	11 %	10 %
Attached cadmium	0 %	0 %	0 %
Attached chromium	32 %	34 %	31 %
Attached copper	10 %	10 %	11 %
Attached lead	25 %	27 %	27 %

Table 8.6: Overview of the different scenarios (1: untreated discharge, 2: TCC treated discharge, 3: TCC treated particle size, untreated metal concentration) and the different risk contributors given in per cent.

The result given in table 8.6 shows how the cuttings contribute to a higher risk when they stay untreated, but the metal contribution seems to increase due to a lower particle size. The margins are, however, minimal.

The pie chart given in figure 8.24 shows the metal distribution of the toxic EIF contribution.

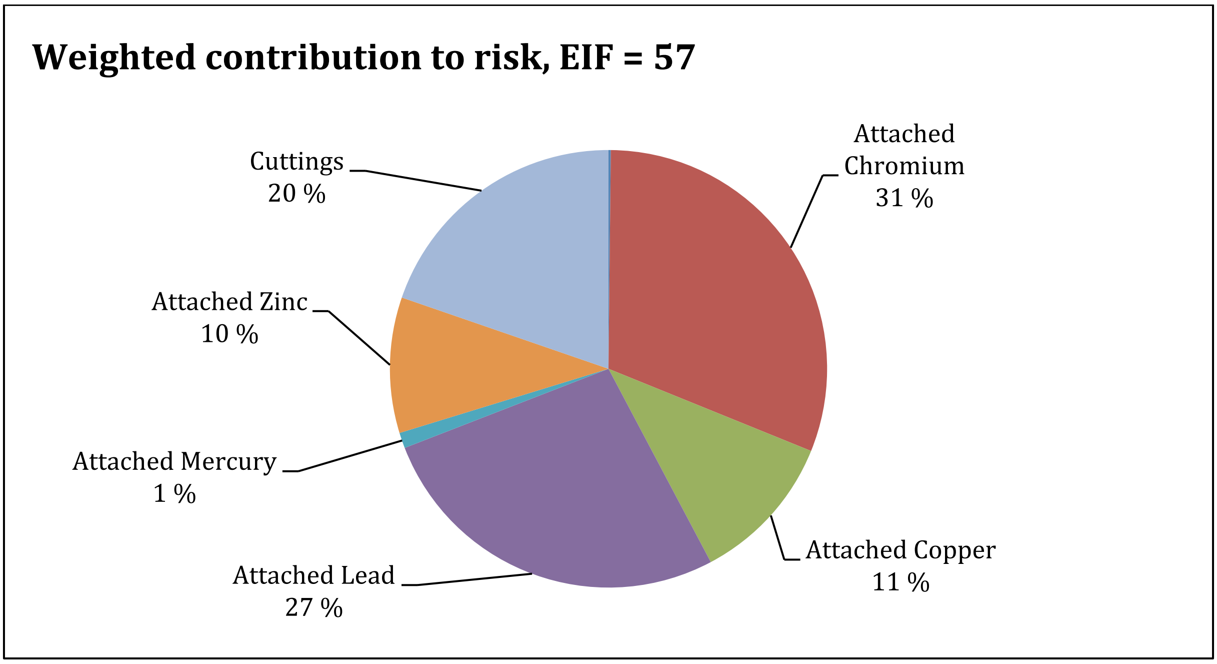


Figure 8.23: Overview of the different stressors weighted contribution to risk in the water column, represented by a pie chart. Metals were the only toxic stressor accounted for.

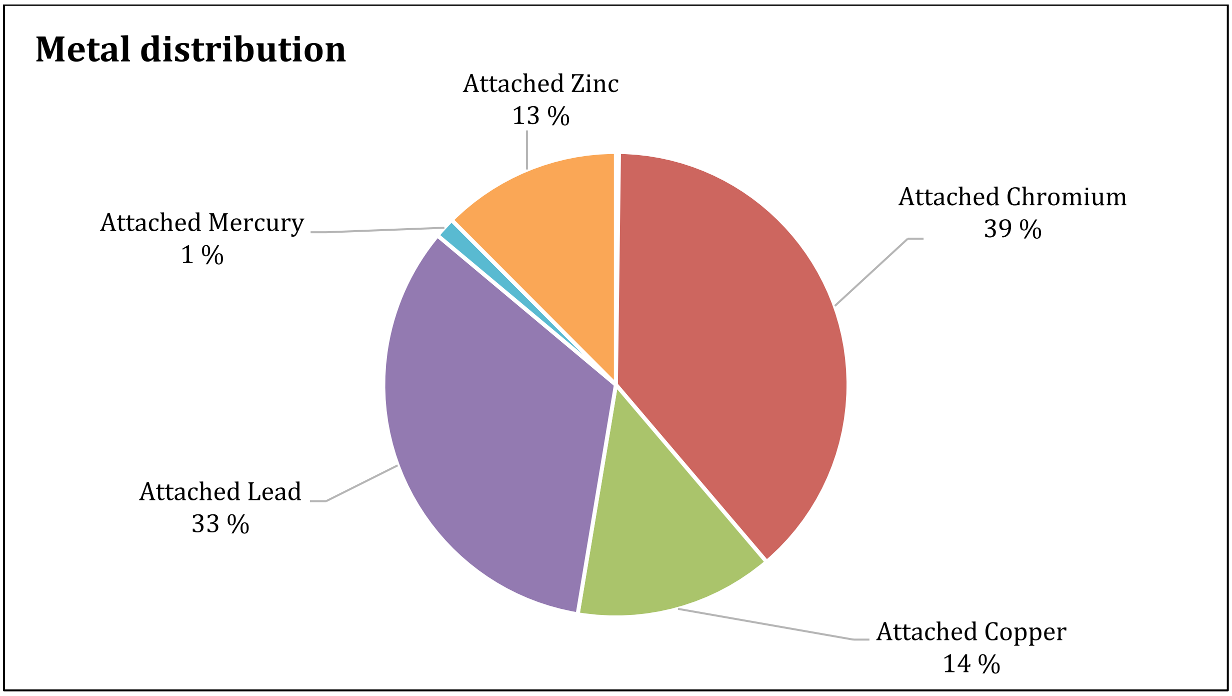


Figure 8.24: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by the discharge in the third simulation.

Table 8.7 shows the different stressors weighted contribution to risk and to the total EIF. The metal concentrations used as input are as for the untreated discharge. The cuttings concentration is based on the 1000 tons that was discharged.

Components	**Concentration ppm**	**PNEC ppb**	**Contribution to risk**	**Contribution EIF**	**EIF**
Attached Cadmium	0.22	0.21	0.17	0.09739436	**57.2908**
Attached Chromium	22	0.60	30.96	17.73723168	
Attached Copper	74	2.60	11.12	6.37073696	
Attached Lead	64	1.30	26.86	15.38830888	
Attached Mercury	0.37	0.047	1.15	0.6588442	
Attached Zinc	100	3.0	10.02	5.74053816	
Cuttings		100000	19.72	11.29774576	

Table 8.7: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by the discharge in the third simulation

The time development chart for this simulation is presented in figure 8.25. The different contributors are listed to the right in the figure. The time development trend is the same as for the two cases above; two peaks of short time durations, but higher EIF than for the sediment.

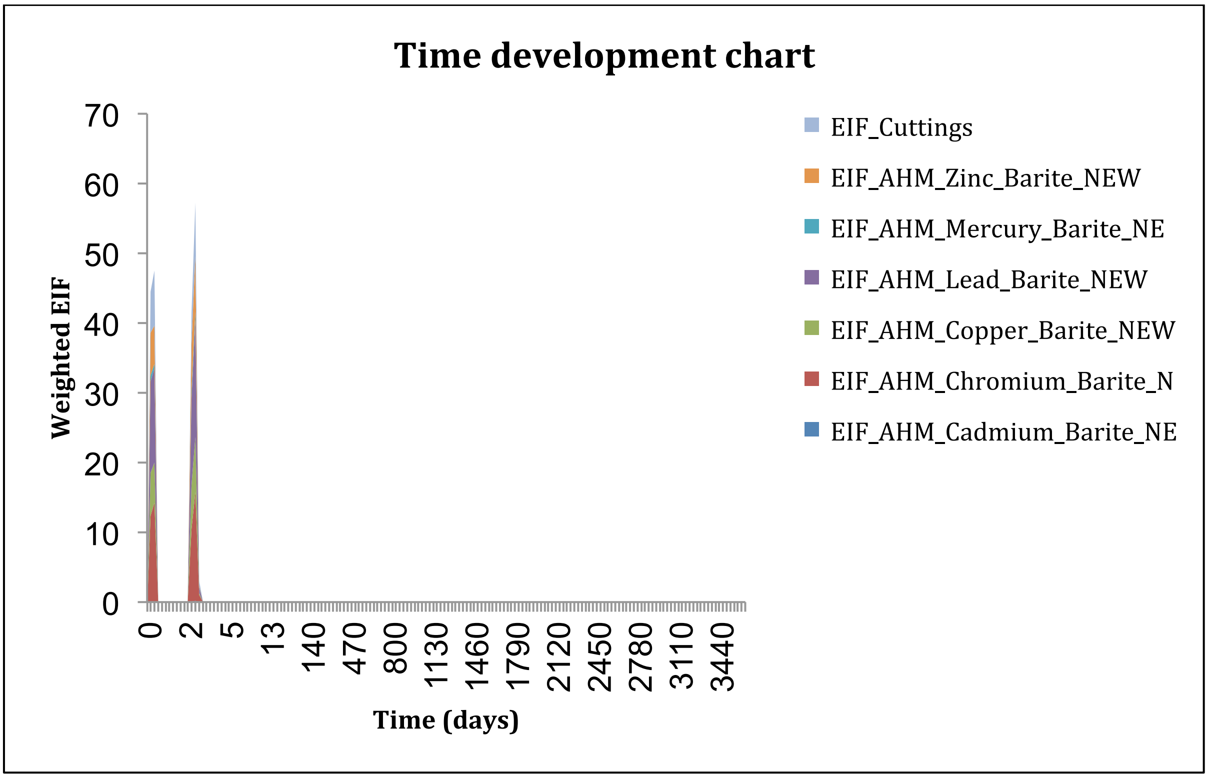


Figure 8.25: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by the drilling discharge in the third simulation.

8.4 Simulation 4; Treated drilling waste in two batches. PAH concentrations included.

The following simulation did calculate for a TCC treated drilling discharge where also the PAH concentrations were taken into consideration. The purpose of the previous scenarios was to look at the toxicity of the metals and the contribution from the particle size. In this scenario the PAHs are of specific interest, and thus the contribution from the metals when the PAHs are present.

The following figures (figure 8.26 – figure 8.33) and tables (8.9 and 8.10) are representing the results from the fourth simulation in both the sediment and in the water column. In this simulation also the effect from the PAH content was accounted for. To make the pie chart more readily the PAHs was divided into categories of 2-3 ring PAHs, 4 ring PAHs and 5-6 ring PAHs as shown in table 8.8:

2-3 ring PAHs	4 ring PAHs	5-6 ring PAHs
Napthalene	Fluoranthene	Benzo(b)fluoranthene
Acenaphthene	Pyrene	Benzo(k)fluoranthene
Acenaphtylene	Benzo(a)anthracene	Benzo(a)pyrene
Fluorene	Crysene	Indeno(1-2-3-cd)pyrene
Phenanthrene		Dibenzo(a-h)anthracene
Anthracene		Benzo(g-h-i)perylene

Table 8.8: Overview of the drifferent PAH groups.

8.4.1 Sediment

The sediment risk map presented in figure 8.26 gives a picture of the output estimated by the DREAM model. As for the previous sediment scenarios, the biggest impact occurs close to the point of discharge. Indicated by the red area.

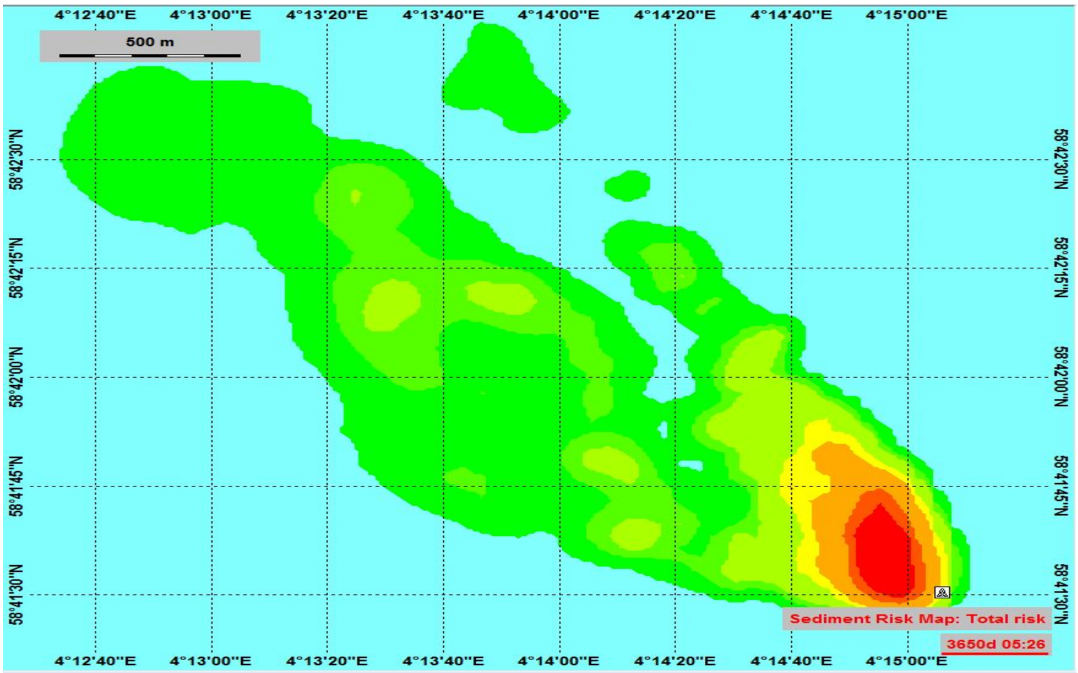


Figure 8.26: Sediment risk map estimated by the model for the treated discharge. Both PAH concentration and the metal concentrations are accounted for.

The pie chart in figure 8.27 shows the risk contributors and the EIF value for the sediment. The PAHs did not contribute to any risk which might indicate that the PAH never reaches the sediment. Figure 8.28 presents the metals distribution. The metals did contribute to 77% of the total risk, where copper and zinc was the major components. Copper and zinc tend to adsorb to suspended particles and settle at the sea floor.

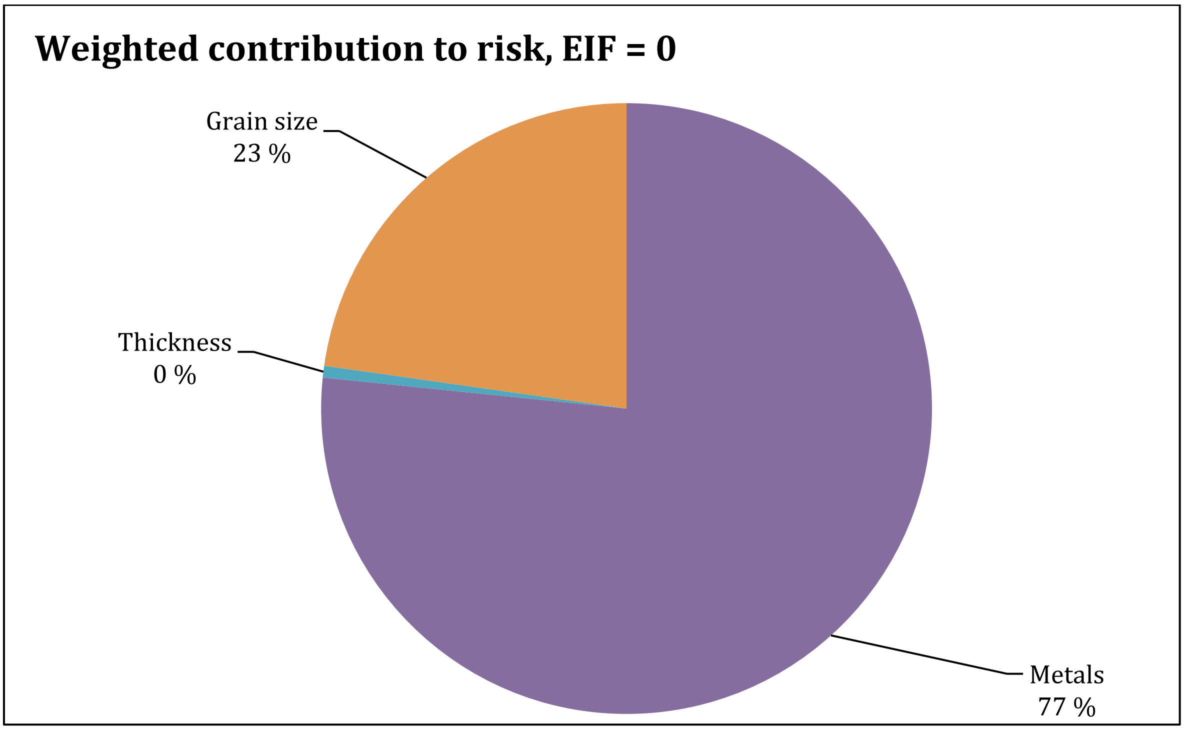


Figure 8.27: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. The PAH concentrations in the treated drilling waste was not significant enough to contribute to the total EIF (see table 8.8).

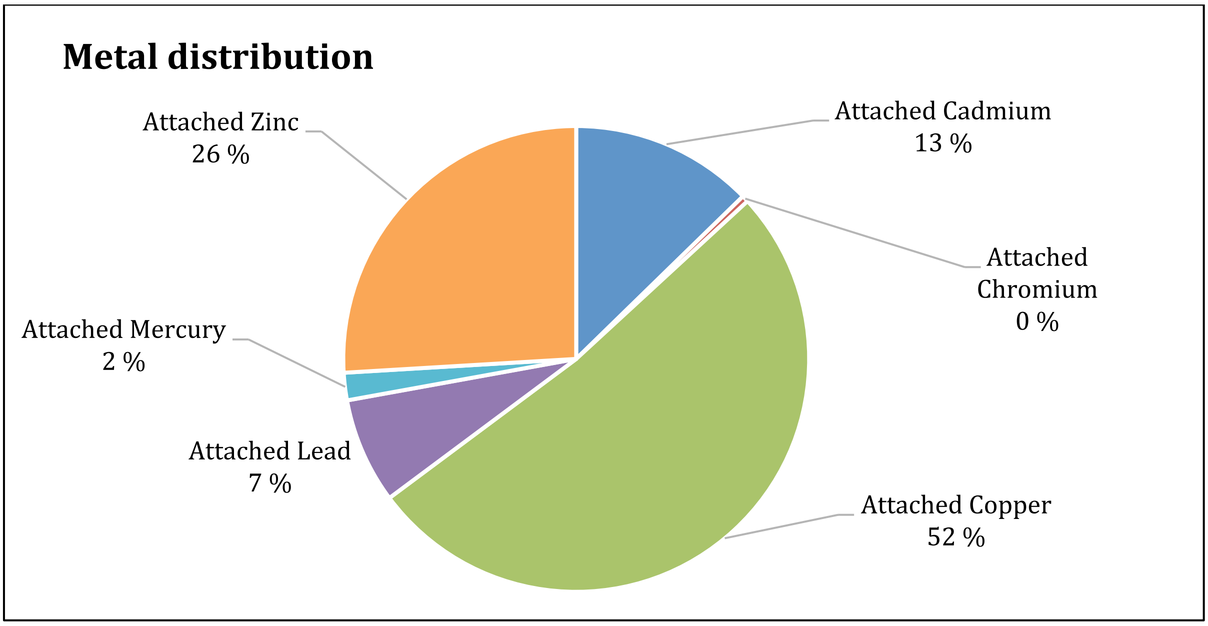


Figure 8.28: Pie chart showing the main metal contributors to the total environmental impact in the sediment from treated drilling waste.

The numerical overview presented in table 8.9 summarizes the input concentrations for the different components and their belonging PNEC values. The contribution to risk and to EIF columns shows zero contribution from the different PAHs.

All of the “contribution to risk”-values and “contribution to EIF”-values are approximately the same for the metals, grain size and thickness for this simulation compared to the simulation for TCC treated cuttings where PAHs was excluded. The EIF was also the same in the two simulations. Thus the treatment seems to be sufficient regarding PAH elimination and their toxic influence in the sediment.

Components	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	EIF
Attached Cadmium	0.35	0.21	9.73	0.04888352	**0.5024**
Attached Chromium	26	0.60	0.35	0.0017584	
Attached Copper	78	2.60	39.58	0.19884992	
Attached Lead	70	1.30	5.62	0.02823488	
Attached Mercury	0.049	0.047	1.46	0.00733504	
Attached Zinc	120	3.00	19.88	0.09987712	
Acenaphthene	<0.01	0.38	0	0	
Acenaphtylene	<0.05	0.13	0	0	
Fluorene	0.038	0.25	0	0	
Phenanthrene	0.13	1.30	0	0	
Napthalene	0.043	2.00	0	0	
Anthracene	0.014	0.10	0	0	
Fluoranthene	0.021	0.01	0	0	
Pyrene	0.063	0.023	0	0	
Benz(a)anthracene	0.028	0.0012	0	0	
Chrysene	0.046	0.007	0	0	
Benzo(b)fluoranthene	0.041	0.017	0	0	
Benzo(k)fluoranthene	<0.01	0.017	0	0	
Benzo(a)pyrene	0.031	0.022	0	0	
Indeno(1-2-3-cd)pyrene	0.022	0.00027	0	0	
Dibenzo(a-h)anthracene	0.015	0.00014	0	0	
Benzo(g-h-i)perylene	0.098	0.00082	0	0	
Thickness			0.62	0.00311488	
Oxygen			0	0	
Grain size			22.76	0.11434624	

Table 8.9: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by treated drilling waste.

The time development chart given in figure 8.29 is more or less similar as for the TCC treated discharge case where the PAHs were excluded. Also the EIF values are similar which again indicates that the PAHs in TCC treated discharge does not cause any harm to the sediment. This is, most likely, due to a combination of low PAH concentrations in treated discharge and dilution in the water column.

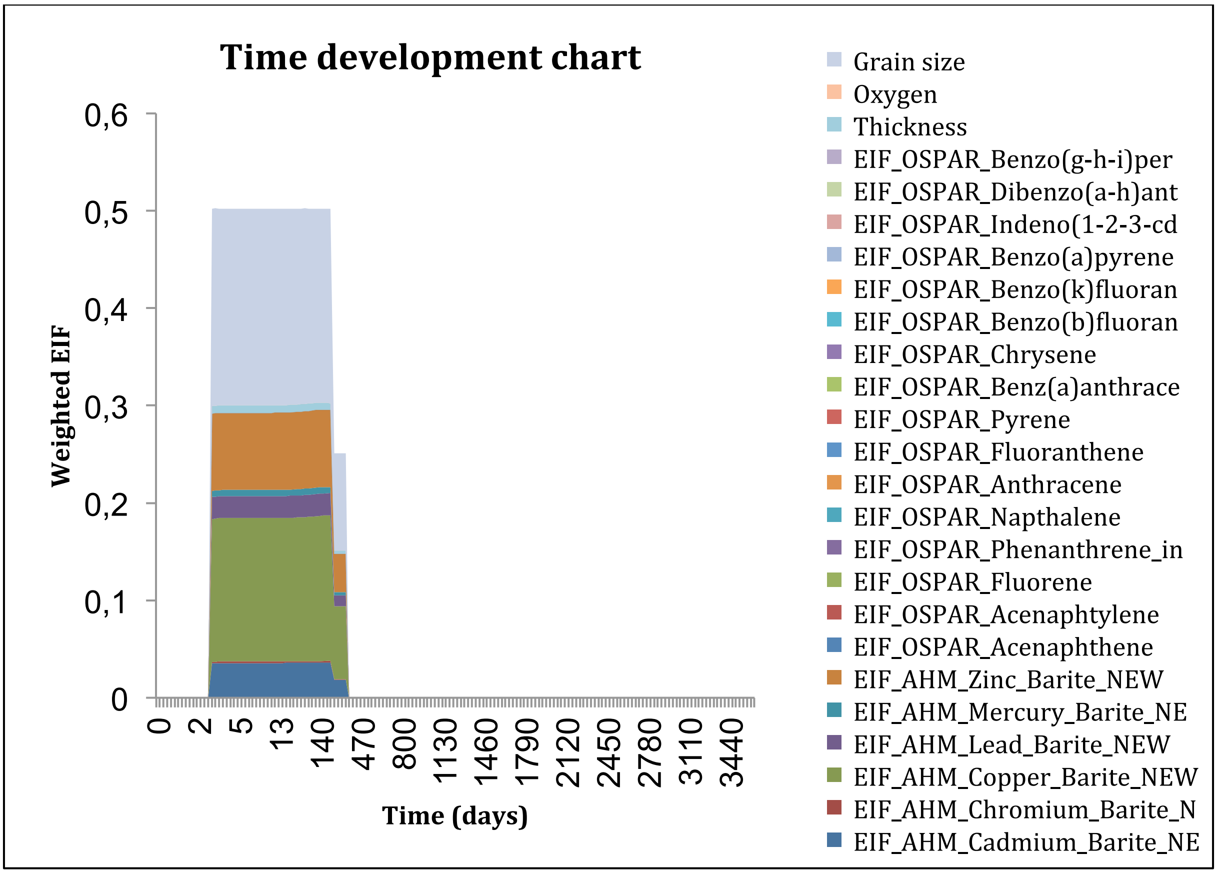


Figure 8.29: Time development showing the EIF variation in the sediment over time caused by the treated drilling waste discharged. Low EIF values over a long period of time represents a chronic EIF.

8.4.2 Water column

The DREAM estimated risk map for the water column is presented in figure 8.30. The spreading occurs due to the currents and wind speed. The contaminated volume, especially concerning the black and red area, are larger compared to the TCC treated discharge case where the PAHs were excluded. The environmental impact from PAHs is thus present.

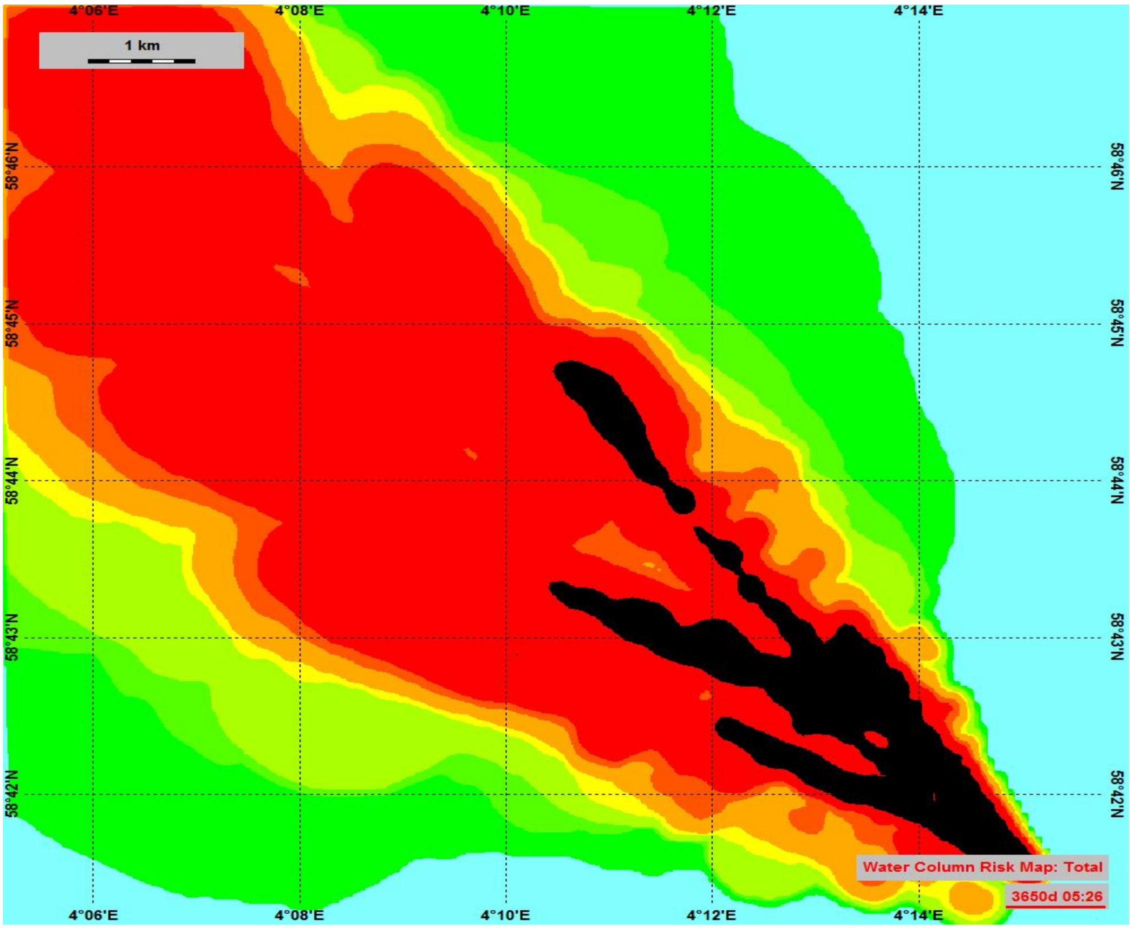


Figure 8.30: Water column risk map estimated by the DREAM model for the treated drilling waste.

In the following figures the distribution from the different contaminated compounds are represented. From the pie chart in figure 8.31 the present risk from the PAHs is given. The cuttings and the attached metals are only contributing by 15 % of the total EIF and thus can seem insignificant compared to the PAHs. Physical and chemical characteristics of PAHs vary with molecular weight. For instance, PAH increasing to oxidation and reduction increases with increasing molecular weight, whereas the aqueous solubility of theses compounds decreases. As a result, PAHs differ in their behaviour, distribution in the environment, and their effects on biological systems. The lower molecular weight (2-3 ring PAHs) has significant acute toxicity to aquatic organisms, whereas the high molecular weight PAHs do not. But due to the low PAHs concentrations, the large water volume and the small particle sizes (slow sinking velocity), it seems reasonable to assume that the PAHs will no reach the sea floor before degradation and all of them will contribute to the water column EIF.

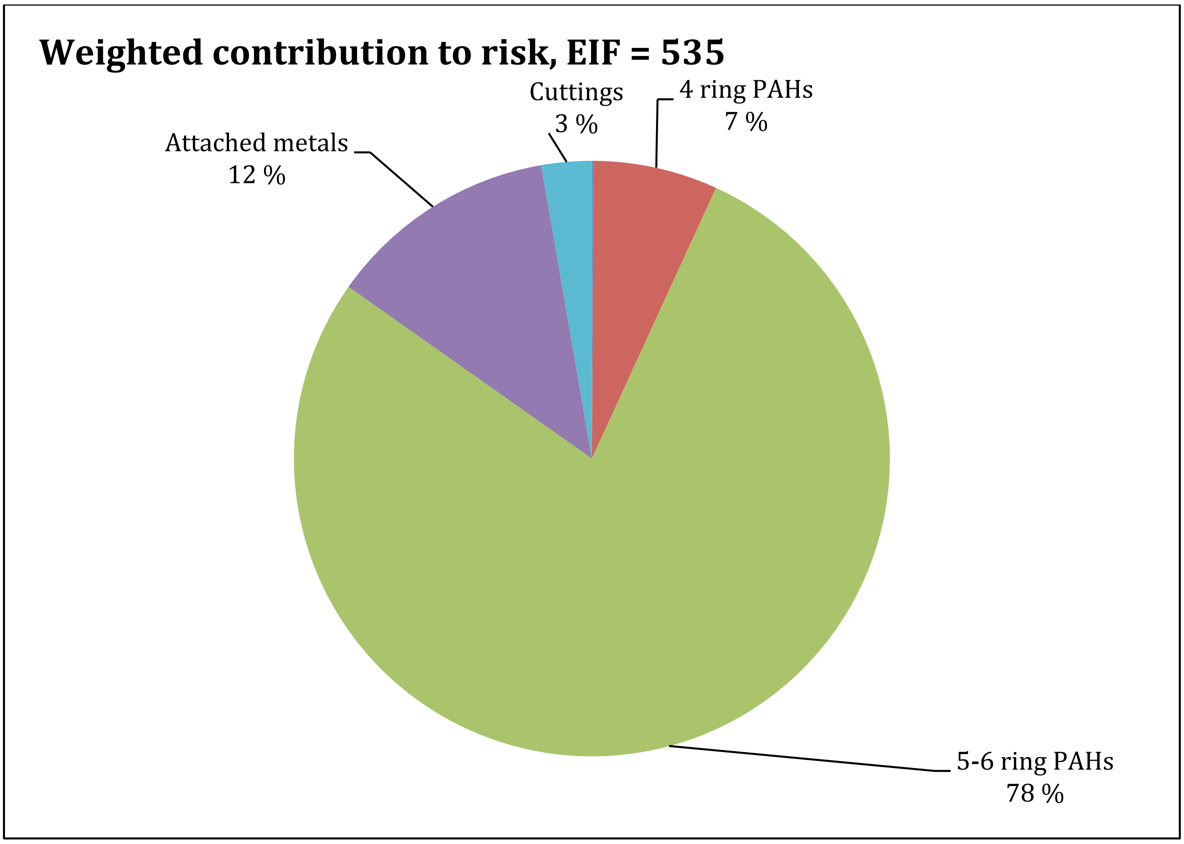


Table 8.31: Overview of the different stressors weighted contribution to risk from treated drilling waste in the water column, represented by a pie chart.

The pie chart in figure 8.32 gives an overview of the metal distribution. The main contributing metals, chromium and lead, are the same as in the previous simulations for the water column.

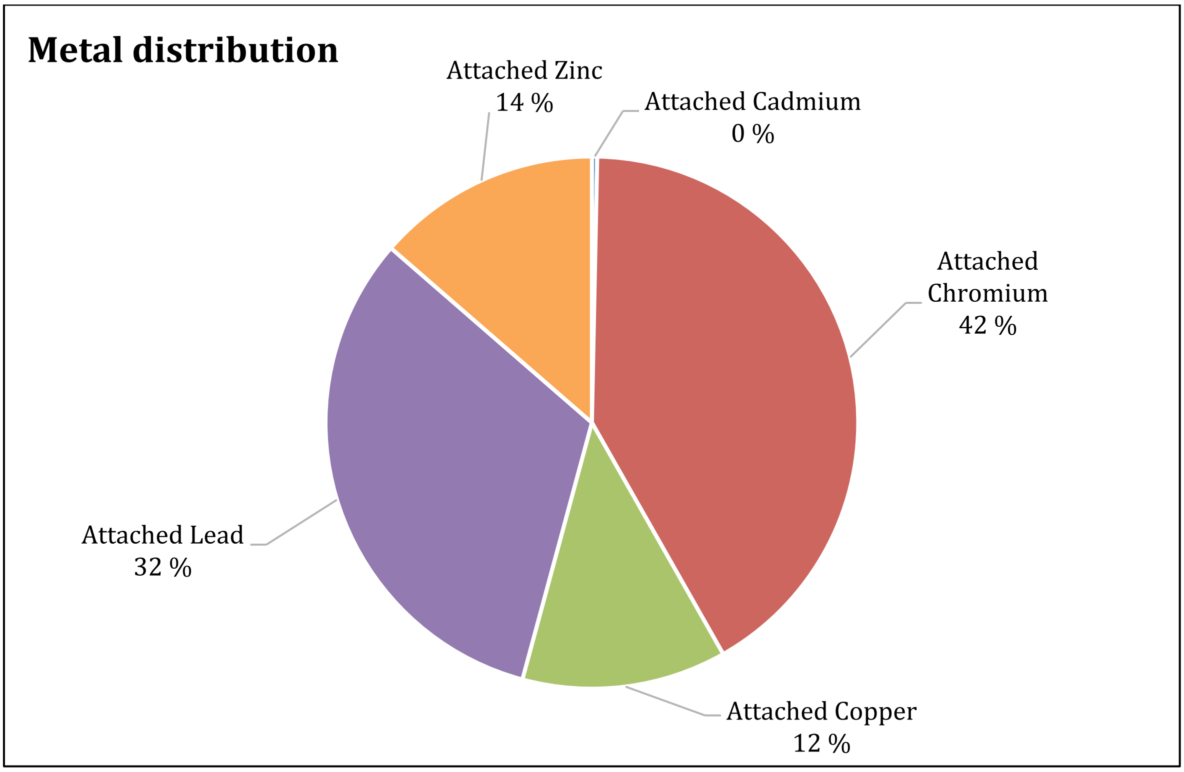


Figure 8.32: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by treated drilling waste discharge.

Table 8.10 on the next page shows the input concentrations for the different metals and PAHs. The corresponding PNEC values are listed as well. In the columns representing the contributions to risk and EIF, the numerical values from each of the contributing components can be observed. The total EIF for the water column when TCC treated cuttings were discharged, PAH concentrations included, was 535. This is almost 8 times the EIF for the TCC treated discharge in the second simulation, emphasizing the PAHs large influence on the impact on the environment in the water column.

Components	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	EIF
Attached Cadmium	0.35	0.21	0.04	0.2140308	**535.0235**
Attached Chromium	26	0.60	5.18	27.7169885	
Attached Copper	78	2.60	1.55	8.2936935	
Attached Lead	70	1.30	4.02	21.510094	
Attached Mercury	0.049	0.047	0	0	
Attached Zinc	120	3.00	1.7	9.096309	
Acenaphthene	<0.01	0.38	0	0	
Acenaphtylene	<0.05	0.13	0.05	0.2675385	
Fluorene	0.038	0.25	0.02	0.1070154	
Phenanthrene	0.13	1.30	0.01	0.0535077	
Napthalene	0.043	2.00	0	0	
Anthracene	0.014	0.10	0.01	0.0535077	
Fluoranthene	0.021	0.01	0.31	1.6587387	
Pyrene	0.063	0.023	0.42	2.2473234	
Benz(a)anthracene	0.028	0.0012	4.86	26.0047422	
Chrysene	0.046	0.007	1.16	6.2068932	
Benzo(b)fluoranthene	0.041	0.017	0.37	1.9797849	
Benzo(k)fluoranthene	<0.01	0.017	0.08	0.4280616	
Benzo(a)pyrene	0.031	0.022	0.2	1.070154	
Indeno(1-2-3-cd)pyrene	0.022	0.00027	19.85	106.2127845	
Dibenzo(a-h)anthracene	0.015	0.00014	26.97	144.3102669	
Benzo(g-h-i)perylene	0.098	0.00082	30.47	163.0379619	
Cuttings		100000	2.72	14.5540944	

Table 8.10: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by treated drilling waste.

The time development chart in figure 8.33 shows how the EIF varies between a few hours. The peak value is high, but the time duration is low. The importance of durability is regarding to the EIF value considering the restitution time for the water column impact to go back to "normal". The short impact duration in the water column compared to in the sediment makes the higher EIF values less crucial.

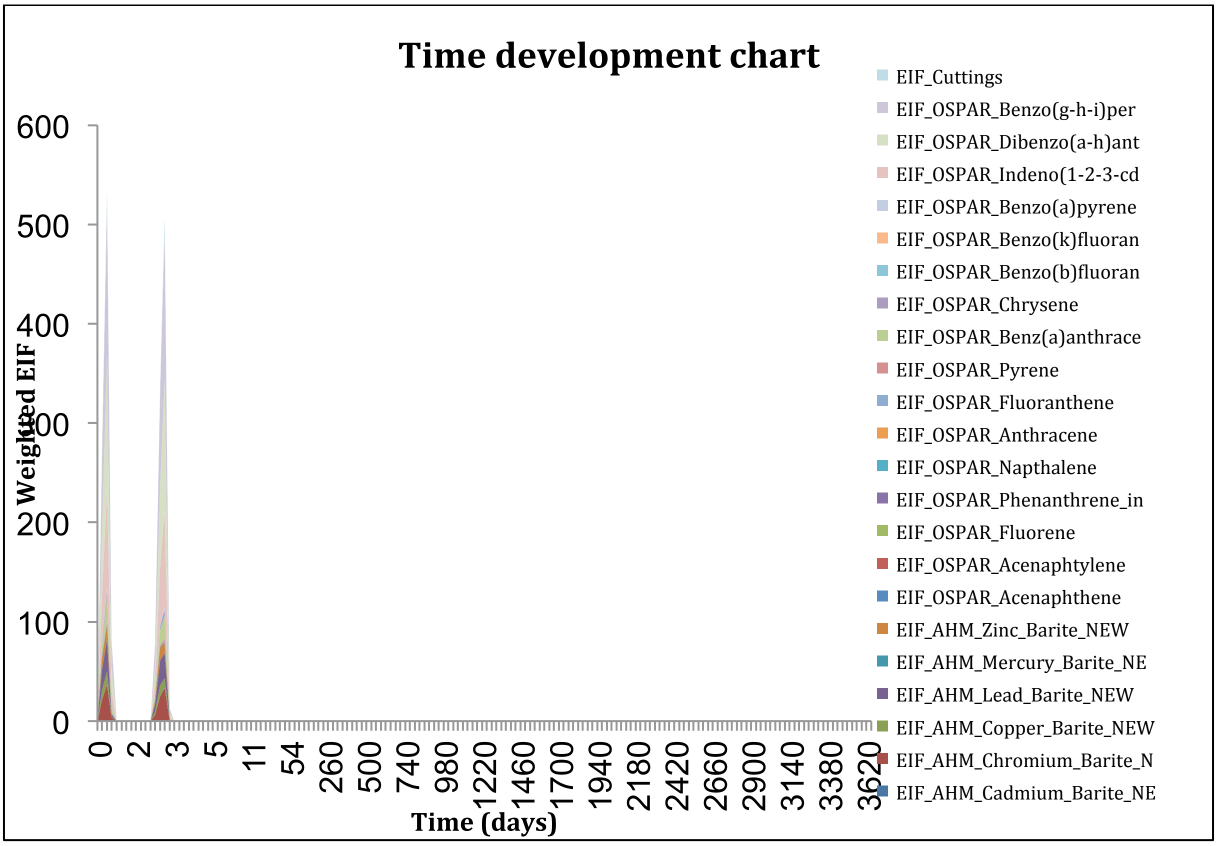


Figure 8.33: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by the treated drilling waste.

8.5 Simulation 5; Untreated drilling waste in two batches. PAH concentrations included.

The following scenario is represented as untreated discharge. This case is not realistic because an untreated waste would never be discharged on purpose, but from a comparable point of view this simulation was found necessary. The particle size impact from the untreated waste on EIF, compared to the TCC treated cuttings will be expected to deflect in the results. The PAHs will thus, most likely, contribute to the impact in the sediments due to the high sinking velocity and the PAHs "oily" particle attraction.

The following figures (figure 8.34 – figure 8.41) and tables (8.11 and 8.12) are representing the results from the fifth simulation in both the sediment and in the water column. In this simulation also the effect from the PAH content was accounted for. To make the pie chart more readily the PAHs was divided into categories of 2-3 ring PAHs, 4 ring PAHs and 5-6 ring PAHs (see table 8.8).

8.5.1 Sediment

The sediment risk map in figure 8.34 shows the total risk caused by the untreated drilling waste. As indicated in the previous, the risk was expected to increase compared to the TCC treated case, due to the bigger particle sizes and higher PAH concentrations. The black area, representing the highest risk, is concentrated around the discharge point because of low spreading and high sinking velocities.

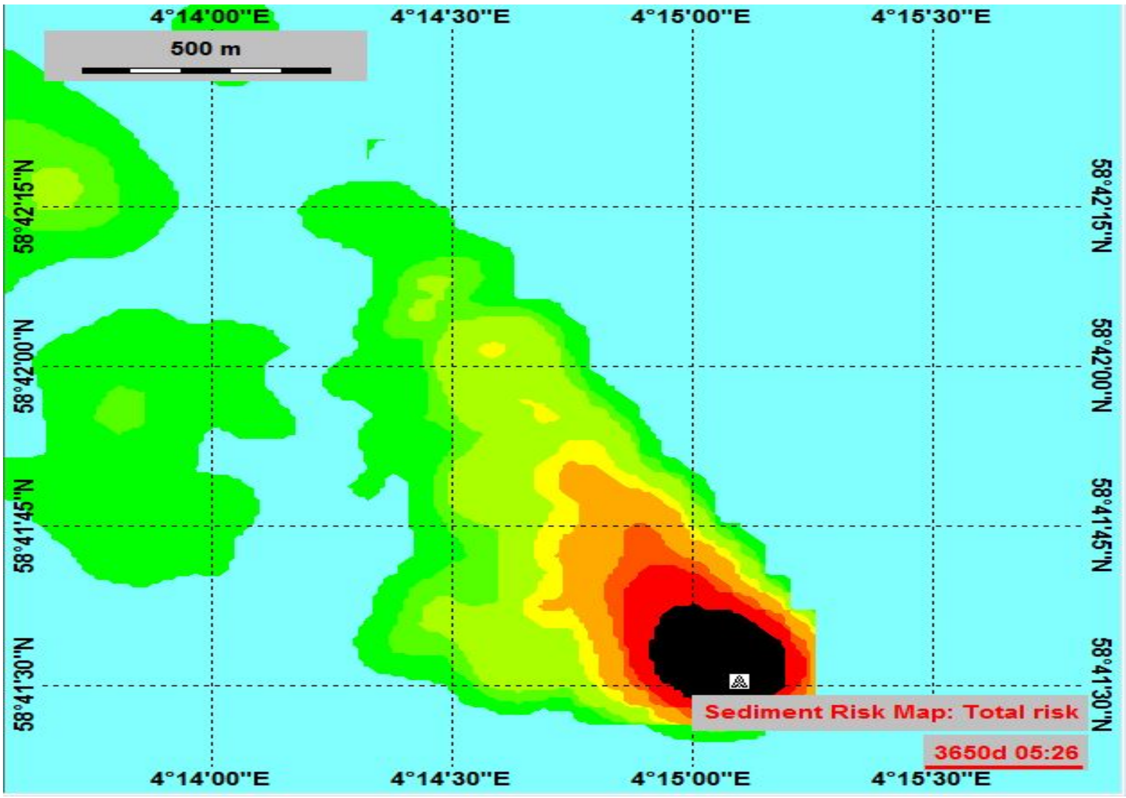


Figure 8.34: Sediment risk map estimated by the model for the untreated discharge. Both PAH concentration and the metal concentrations are accounted for.

In the following figures an overview of the weighted contribution to risk and the metal distribution is presented. In figure 8.35 it becomes obvious that the heaviest PAHs are the less soluble PAH compounds, and thus will adsorb to the cuttings particles and settle on the sea floor. The grain size is still a relatively big contributor, supporting the assumption that bigger particles cause a more negative change in grain size. The metals contribution to risk is reduced from 27% in the previous untreated case (where the PAHs were excluded) to zero. Thus it seems reasonable to assume that the high PAH concentrations become dominating compared to the metals.

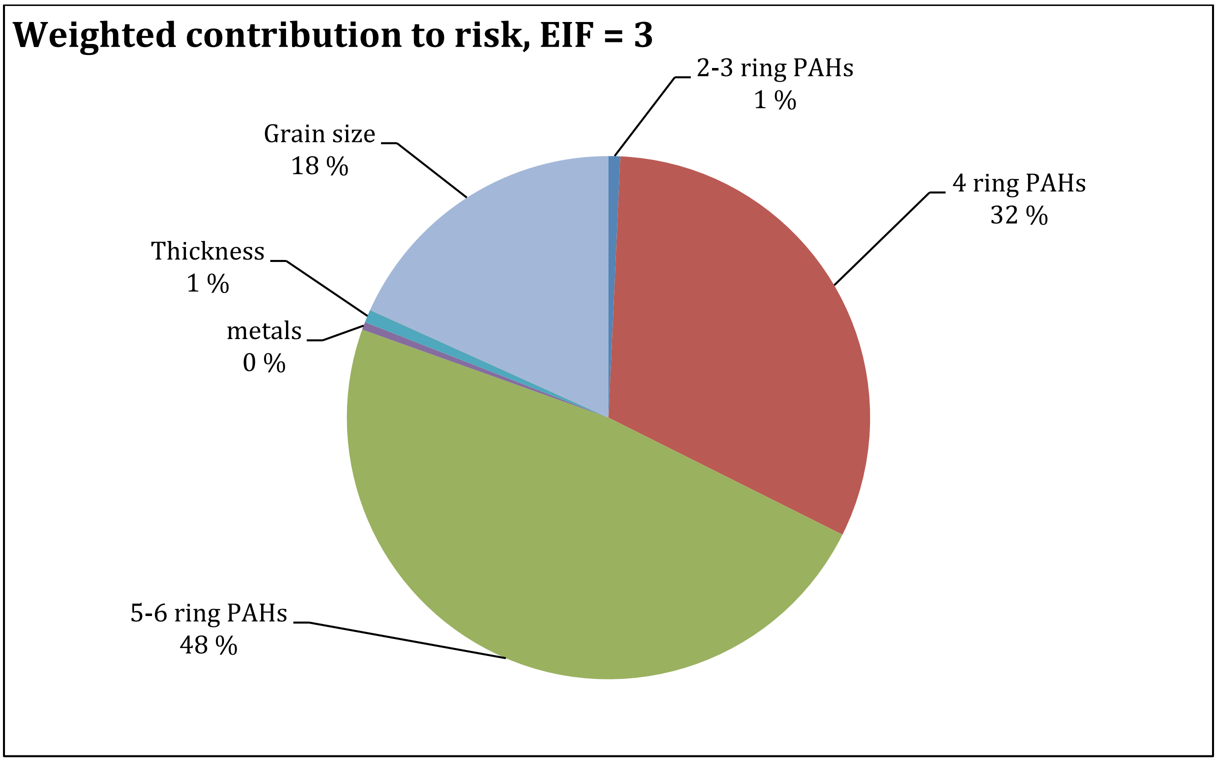


Figure 8.35: Overview of the different stressors weighted contribution to risk in the sediment, represented by a pie chart. The PAHs was the major risk contributors.

The metal distribution is represented in figure 8.36. Even though the metals didn't seemed to be of any harm to the sediment, the risk is still present. Not surprisingly, the major metal risk contributor was mercury. Mercury was the only metal where the concentration was decreased when the waste was treated.

The comparison made above between the untreated case where the PAHs were left out and this scenario, shows in both cases the same EIF. This seems to indicate that the grain size, as one single component, is the major contributor, while the PAHs are big in groups. And again, when the PAHs are included, the metals become less important.

In table 8.11 the numerical output to the EIF contribution is given. When comparing this table with the one given for untreated discharge where the PAHs were excluded (table 8.1) it becomes obvious that the grain size is the largest "single component contributor" in both cases. The metals contribution from the first scenario has been considerably reduced. The largest risk and EIF contribution is, as shown in the pie chart in figure 8.35, the heaviest group of PAHs.

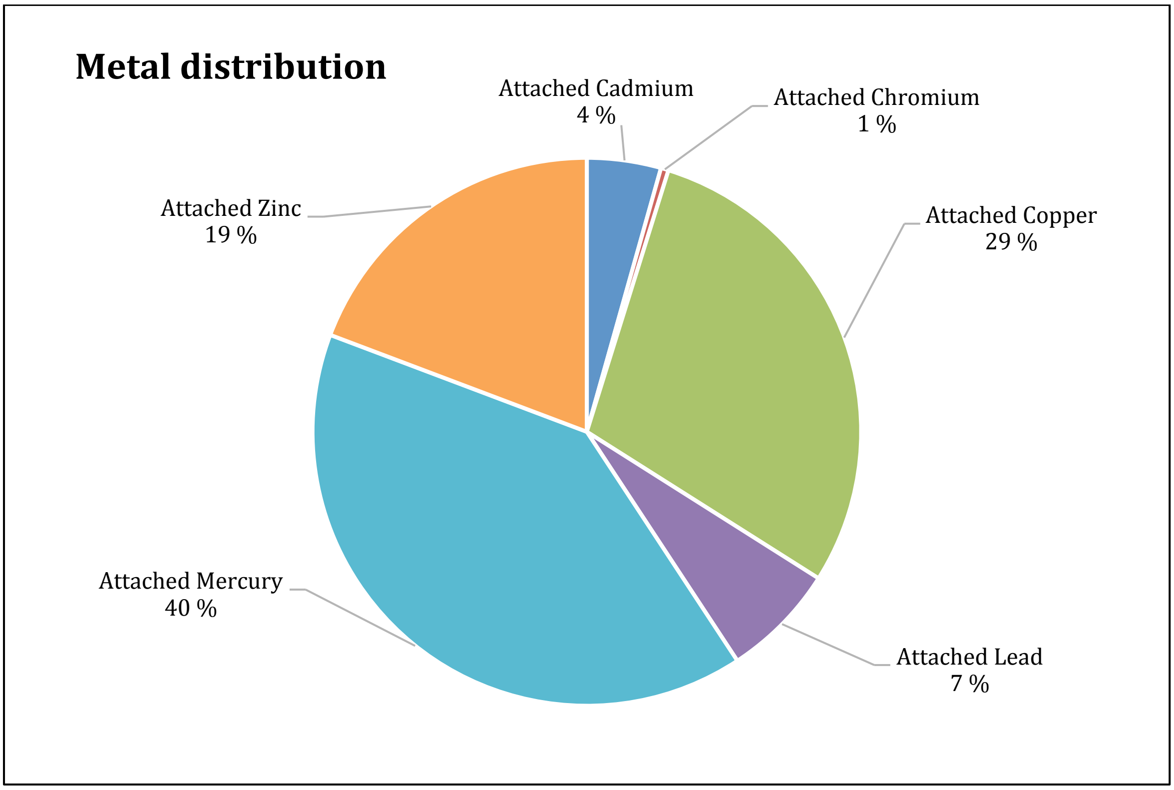


Figure 8.36: Pie chart showing the main metal contributors to the total environmental impact in the sediment from untreated drilling waste.

Components	**Concentration ppm**	**PNEC ppb**	**Contribution to risk**	**Contribution EIF**	**EIF**
Attached Cadmium	0.22	0.21	0.29	0.010186	**3.512**
Attached Chromium	22	0.60	0.03	0.001054	
Attached Copper	74	2.60	1.94	0.068139	
Attached Lead	70	1.30	0.45	0.015805	
Attached Mercury	0.37	0.047	2.66	0.093427	
Attached Zinc	100	3.00	1.28	0.044957	
Acenaphthene	3.3	0.38	0.16	0.00562	
Acenaphtylene	1.7	0.13	0.21	0.007376	
Fluorene	2.0	0.25	0.15	0.005268	
Phenanthrene	2.1	1.30	0.04	0.001405	
Napthalene	5.0	2.00	0.03	0.001054	
Anthracene	0.37	0.10	0.09	0.003161	
Fluoranthene	0.26	0.01	0.30	0.015038	
Pyrene	1.2	0.023	8.06	0.283091	
Benz(a)anthracene	0.26	0.0012	13.97	0.490668	
Chrysene	0.30	0.007	7.36	0.258505	
Benzo(b)fluoranthene	0.15	0.017	2.99	0.105018	
Benzo(k)fluoranthene	0.017	0.017	0.46	0.016157	
Benzo(a)pyrene	0.12	0.022	2.13	0.074812	
Indeno(1-2-3-cd)pyrene	0.037	0.0003	11.95	0.41972	
Dibenzo(a-h)anthracene	0.031	0.0001	14.07	0.494181	
Benzo(g-h-i)perylene	0.16	0.0008	13.5	0.474161	
Thickness			0.75	0.026342	
Oxygen			0	0	
Grain size			17.12	0.601306	

Table 8.11: Overview of the different stressors weighted contribution to risk and to the EIF value in the sediment caused by untreated drilling waste.

The time development chart given in figure 8.37 shows each single component contribution to EIF. The EIF value was still around 2 when the duration of the simulation was completed. The components contributions to EIF seems to be more varying in this case compared to scenario 1, but due to 16 more contributors in this case this seems reasonable. The grain size seems to be the stressor with the slowest restitution time.

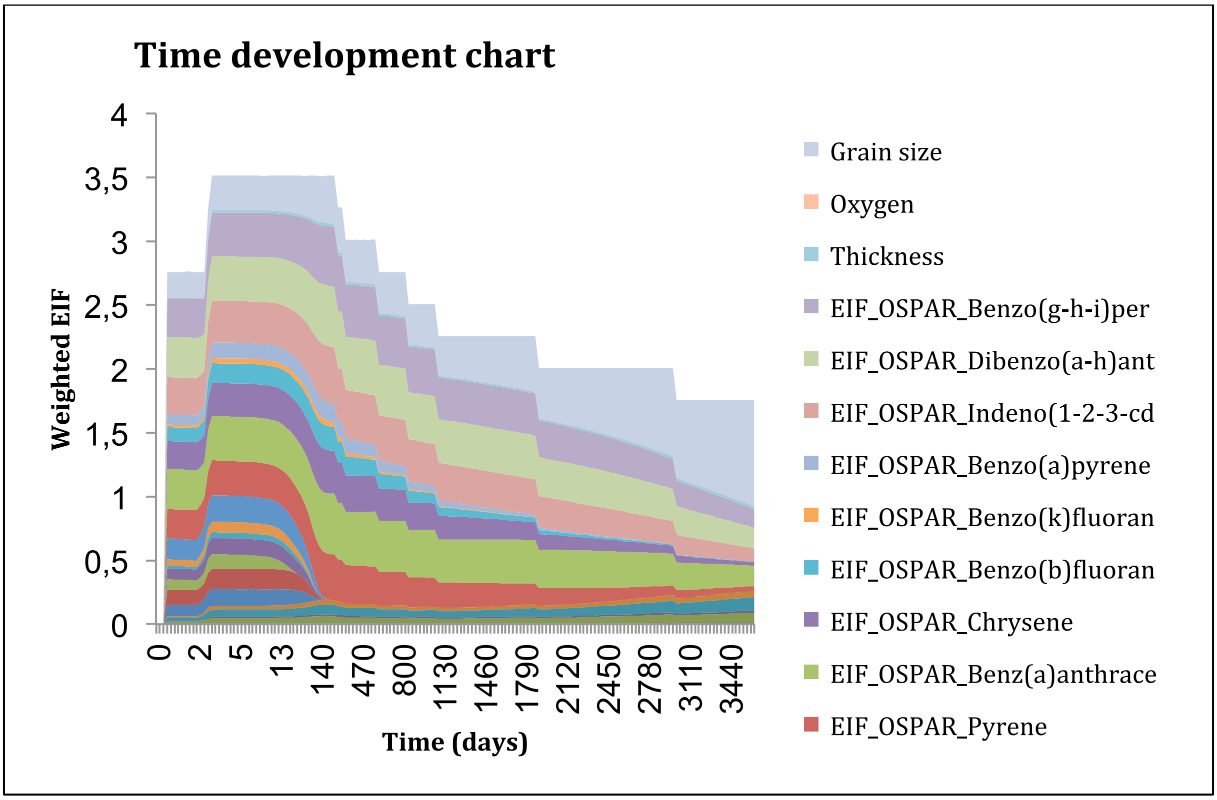


Figure 8.37: Time development showing the EIF variation in the sediment over time caused by the untreated drilling waste discharged. Relatively low EIF values over a long period of time represent a chronic EIF.

8.5.2 Water column

The risk map in figure 8.38 show the impact estimated for the water column. The whole grid was impacted (no blue area), but the crucial volume are represented by the black area in the figure, which tend to spread over a very large area, compared to e.g. figure 8.6. Note the scale difference in the two mentioned figures.

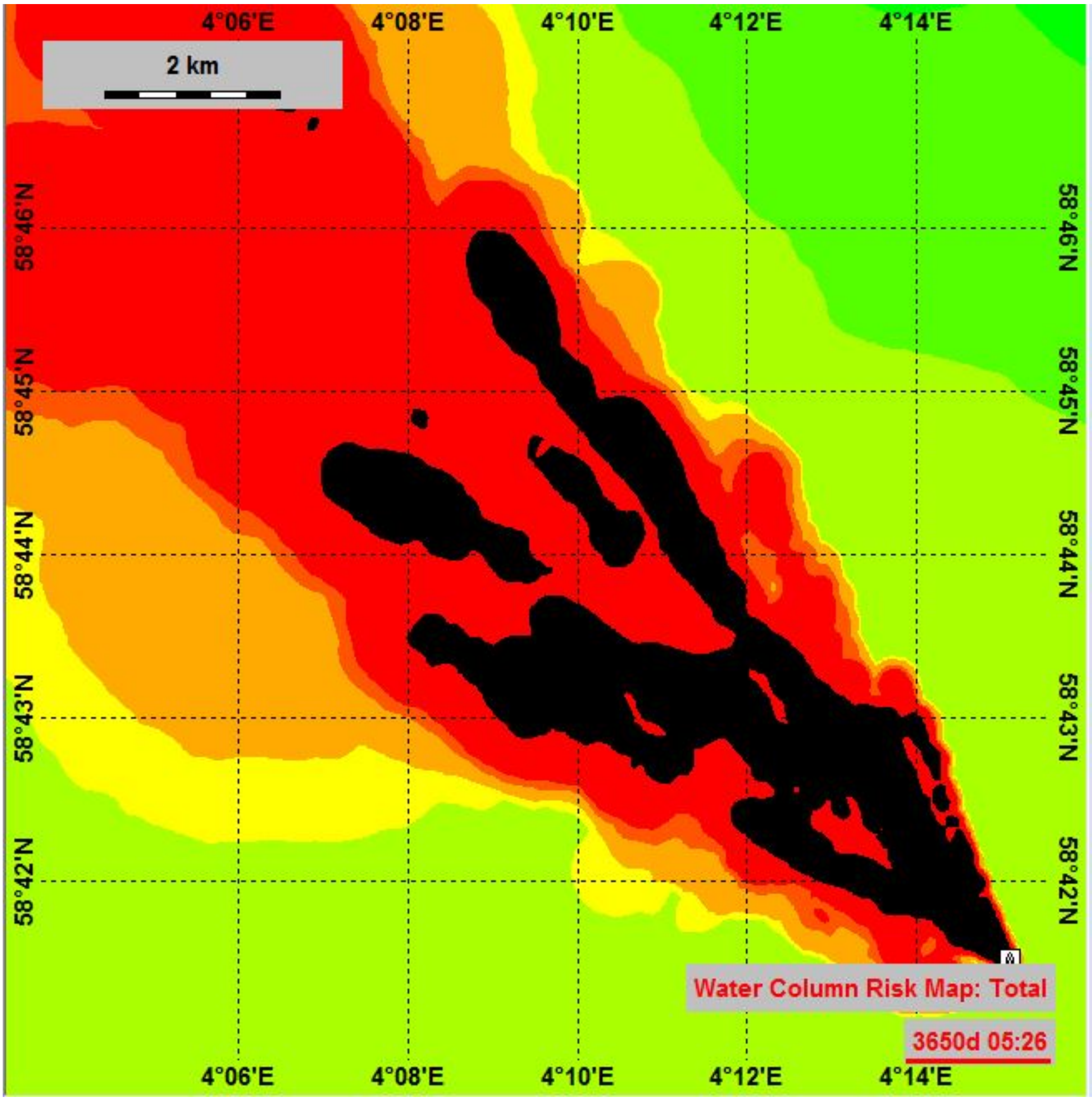


Figure 8.38: Water column risk map estimated by the DREAM model for the untreated drilling waste.

The pie chart given in figure 8.39 shows a high acute EIF value, where the PAHs are the major contributors. Compared to the pie chart in figure 8.7 (the untreated discharge where PAHs were left out) the relationship between the metals contribution and the cuttings seems to be reasonable. Thus the PAHs are in this case discharge in such high concentrations that the environmental impact becomes almost 30 times higher than for the previous untreated simulation. In the previous scenario for treated cuttings the small particles and low sinking velocities could explain the contribution from the heaviest PAHs in the water column. Thus the result from this simulation could seem to contradict with the theory explained earlier. But when comparing the discharged concentrations with the corresponding PNEC values, the high contribution from the heaviest PAHs can be understandable when it seems "to much to handle" for the water column environment.

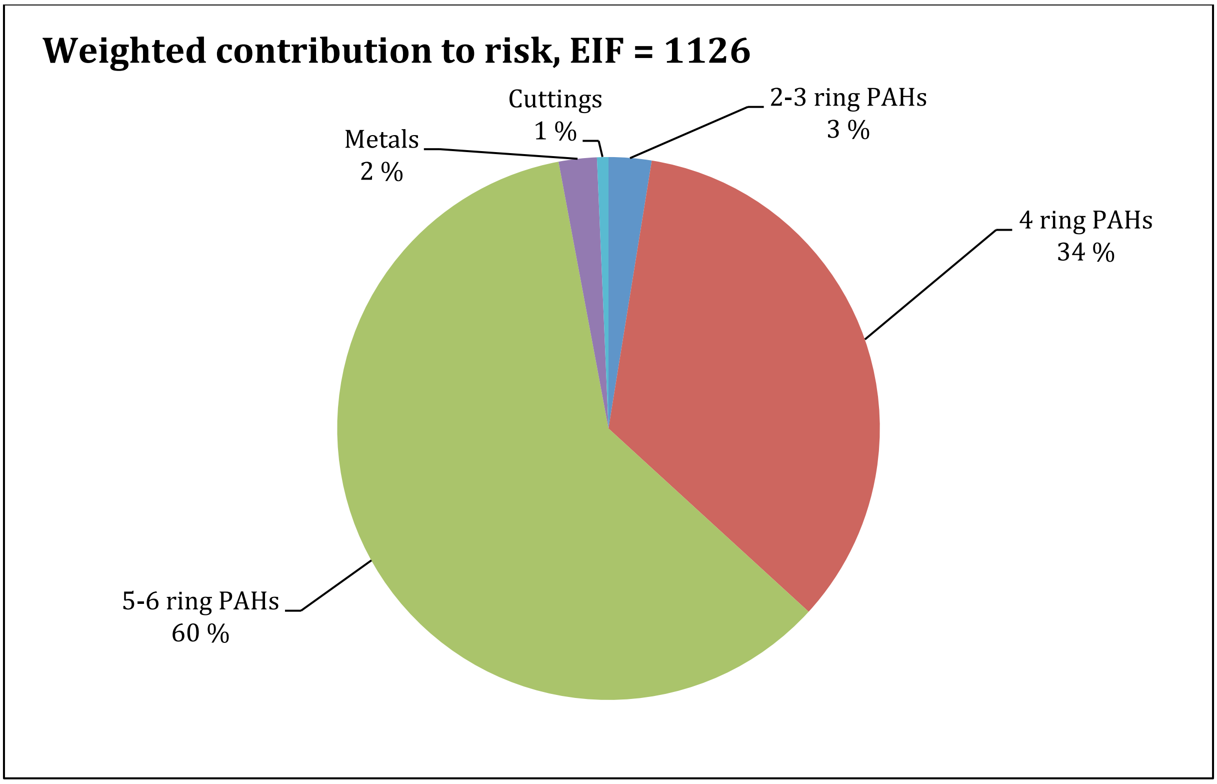


Figure 8.39: Overview of the different stressors weighted contribution to risk from untreated drilling waste in the water column, represented by a pie chart.

The metal distribution is represented in the pie chart in figure 3.40. As in the previous water column results, the main metal contributors are chromium and lead. Actually the allocation of metals is the same for this simulation and the previous untreated discharge, thus emphasizing the effect of the untreated PAH concentrations regarding the big increase in the EIF value.

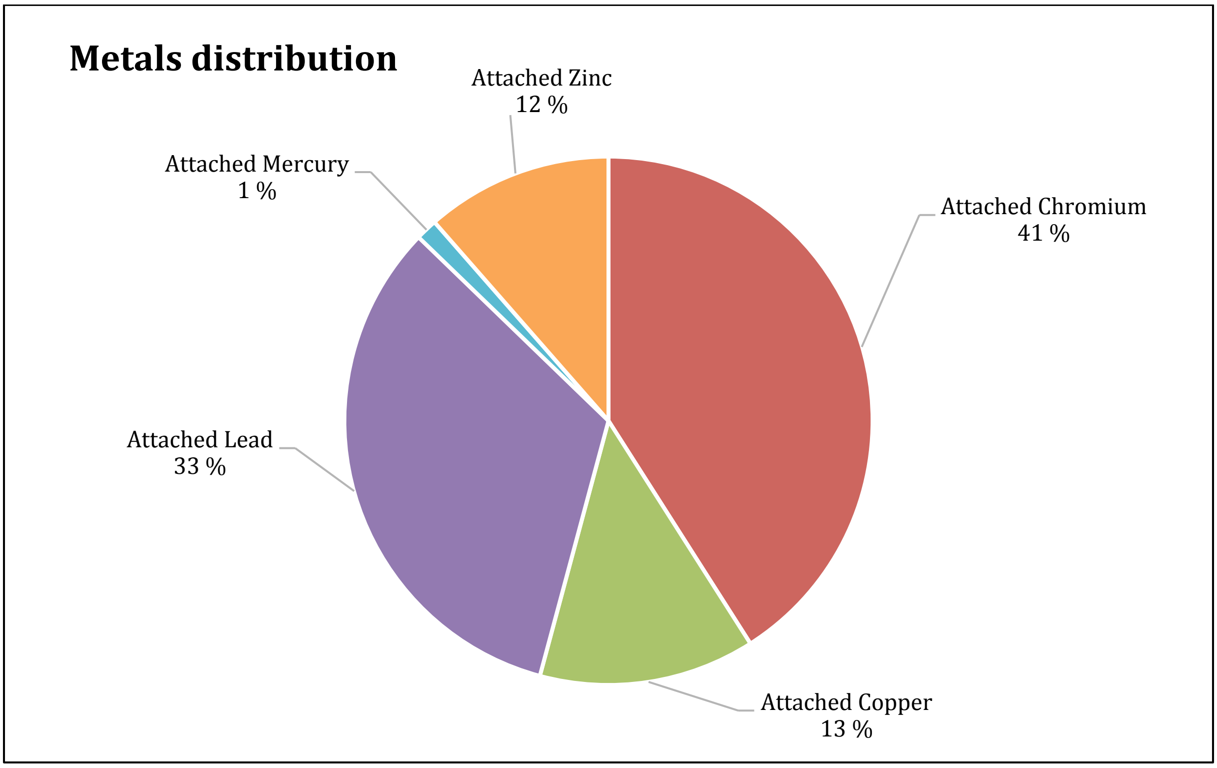


Figure 8.40: Pie chart showing the main metal contributors to the total environmental impact in the water column caused by untreated drilling waste discharge.

The table given below, table 8.12, shows the input concentrations of metals and PAHs for the untreated discharge. Through the PNECs, the DREAM model estimated the contribution to risk and EIF for each of the present components. The PNEC values for the heaviest PAHs compared to their concentrations shows the big difference, thus the big risk contribution seems reasonable.

Again, this discharge is not a realistic one due to the untreated PAH concentration, but to be able to compare and evaluate the effects of PAH and the model`s ability to estimate and express their impact, this simulation was carried out.

Components	**Concentration ppm**	**PNEC ppb**	**Contribution to risk**	**Contribution EIF**	**EIF**
Attached Cadmium	0.22	0.21	0	0	**1126.6**
Attached Chromium	22	0.60	0.93	10.47822	
Attached Copper	74	2.60	0.3	3.380072	
Attached Lead	70	1.30	0.75	8.45018	
Attached Mercury	0.37	0.047	0.03	0.338007	
Attached Zinc	100	3.00	0.26	2.929396	
Acenaphthene	3.3	0.38	0.61	6.872813	
Acenaphtylene	1.7	0.13	0.96	10.81623	
Fluorene	2.0	0.25	0.55	6.196798	
Phenanthrene	2.1	1.30	0.09	1.014022	
Napthalene	5.0	2.00	0.11	1.23936	
Anthracene	0.37	0.10	0.23	2.591388	
Fluoranthene	0.26	0.01	2.1	23.6605	
Pyrene	1.2	0.023	4.77	53.74314	
Benz(a)anthracene	0.26	0.0012	23.55	265.3356	
Chrysene	0.30	0.007	3.82	43.03958	
Benzo(b)fluoranthene	0.15	0.017	0.64	7.21082	
Benzo(k)fluoranthene	0.017	0.017	0.05	0.563345	
Benzo(a)pyrene	0.12	0.022	0.37	4.168755	
Indeno(1-2-3-cd)pyrene	0.037	0.00027	14.12	159.0887	
Dibenzo(a-h)anthracene	0.031	0.00014	24.12	271.7578	
Benzo(g-h-i)perylene	0.16	0.00082	20.95	236.0417	
Cuttings		100000	0.68	7.661496	

Table 8.12: Overview of the different stressors weighted contribution to risk and to the EIF value in the water column caused by untreated drilling waste.

The time development chart in figure 8.41 presents the same trend as the previous water column simulations; short time duration, higher EIF compared to the sediment. The acute risk is high, but does only last for a few hours. Thus meaning a short restitution time.

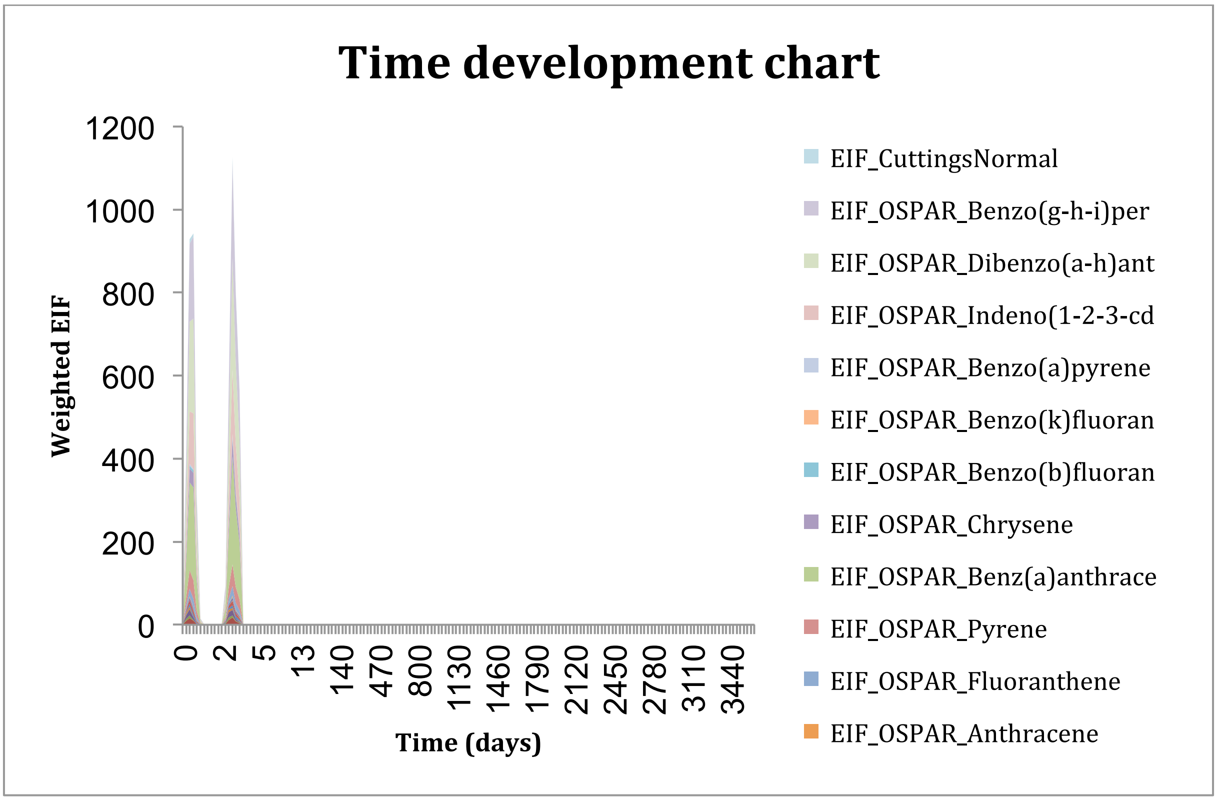


Figure 8.41: Time development showing the EIF variation in the water column over time. The EIF contribution from the first batch discharge is down to zero before the second batch is discharged. Representing an acute EIF caused by the untreated drilling waste.

9. Discussion and conclusion

The TCC treatment was not expected to produce significant changes in the concentrations of heavy metals. Nevertheless, results showed an increased concentration of all metals present, except from mercury. It is therefore reasonable to believe that the increase in surface area exposed to water in the TCC treated particles will make the heavy metals more bioavailable. The PAH concentrations in TCC treated cuttings and untreated cuttings are represented in table 7.5. The treatment process reduced the total PAH concentration by 96.53 per cent.

Due to the difference in size distribution between treated and untreated cuttings and the oil on cuttings ratio (OBM present in the untreated cuttings) the behaviour of the two waste products will deviate when discharged to the sea. The remaining chemicals will more easily adhere to the particles from the untreated cuttings due to the “stickiness” of the oil and thus expected to sediment on the sea floor. While in treated cuttings the chemicals will more easily detach from the particles and solubilize in the water column.

All simulations were carried out with different intentions in mind. The objectives were to evaluate the models ability to estimate the environmental impact from discharged drilling waste treated offshore by TCC, and how it seemed to react on the grain size and metal concentration change. The PAH concentrations was excluded from the simulations when the metal concentrations impact was the main chemical stressor to be evaluated. Table 9.1 summarize the main contributing stressors and the EIF values for both the water column and the sediment for the five different simulations.

Simulation	**Main contributors, water Column**	**EIF in water column**	**Main contributors, sediment**	**EIF in sediment**
Untreated drilling waste, PAH concentrations excluded	Chromium, 32% Lead, 25% Cuttings, 23%	40	Grain size, 70% Mercury, 11%	3
Treated drilling waste, PAH concentrations excluded	Chromium, 34% Lead, 27% Cuttings, 18%	68	Copper, 39% Grain size, 23% Zinc, 20%	0.5
Treated particle size, untreated metal conc. PAH concentrations excluded	Chromium, 31% Lead, 27% Cuttings, 20%	57	Mercury, 37% Copper, 27% Grain size, 18%	0.25
Treated drilling waste, PAH concentrations included	5-6 ring PAHs, 78% Metals, 12%	535	Metals, 77% Grain size, 23%	0.5
Untreated drilling waste, PAH concentrations included	5-6 ring PAHs, 60% 4 ring PAHs, 34%	1126	5-6 ring PAHs, 48% 4 ring PAHs, 32% Grain size 18%	3

Table 9.1: The EIF values variation and the main contributing stressors for the water column and for the sediment.

The EIF values in the sediment will always be lower than the EIFs in the water column, but that does not necessarily mean that the environmental impact always will be worse in the water column. Due to the different time frames the two EIFs are hard to compare. A low EIF over a long period of time could be more environmental harmful than a higher value over a short time range. The different time development charts show the peak in the EIFs and the time the different values will influence.

Mercury was the only metal that didn't increase in concentration after the drilling waste was treated. When mercury settles in the sediment it may be transformed to methylmercury through microbial activity. Methylmercury shows strong evidence of bioaccumulation and biomagnification in the marine food web, potentially posing risks to consumer species (United States Environmental Protection Agency, 1997). The treatment reduced the mercury concentration by almost 90 per cent (87%).

Mercury was the main contributing metal to the total EIF in the sediment from the untreated drilling waste. The metals contributions seemed on the other hand not so important compared to the change in grain size. This implies that the cuttings did settle relatively fast through the water column. The time development chart shows how the EIF value varies over time. For the untreated drilling waste case, the restitution in the sediment was not completed after 3410 days (as far as the time estimation goes), and the EIF value was around 2.

In the water column, the metals did constitute almost 80 per cent of the total EIF, but the cuttings influenced more than expected. The size of the particles would call for immediate settling, but it seems like the cuttings do cause a physical disturbance in the water column on its way down to the sea floor. The metals are attached to the cuttings, but tend to solubilize when in contact with water and thus the bioavailability will increase. The EIF value reaches its maximum after 2 days, when the second batch is discharged. The value is relatively low (40) and is reduced to zero after a few hours.

When the drilling waste is treated by TCC the particle sizes decrease while the metal concentrations tend to increase. The interesting part of this study, and the main aspect of the objective, is how this change in metal and particle size composition will affect the sediments and the water column, and what the model will consider as the main contributor to EIF.

The metals did contribute to a larger extent to the risk in both the sediment and in the water column for the TCC treated discharge. The time development chart for the sediment shows a relatively short restitution time, compared to the first simulation, which can indicate that the sediments are more vulnerable regarding bigger particles. In the water column, the EIF value increased. This supports the assumption that the metals and the fine-grained particles becomes more bioavailable for the filter feeding organisms and thus contributes to a higher EIF value. To be able to decide if these changes in EIF values from the first to the second simulation were because of the increased metal concentrations or due to the decreased particle size, the third simulation was performed.

In the third simulation the discharge was a combination of treated and untreated drilling waste. The particle size was kept as for TCC treated cuttings, and the metal concentration was as for untreated discharge. As anticipated, the main risk contributor to the risk in the sediment was mercury. The copper and grain size contribution was reduced a little; this seems to be due to the mercury increase. The time development chart did again showed a low restitution time, which support the assumption that bigger particles influence the sediment more negatively than the TCC treated cuttings sizes. The EIF in the water column was higher than in the first simulation, implying that the difference in particle size was the decisive contributor. That the EIF value for the water column in the third simulation was lower than the second simulation was not surprising, due to the lower metal concentrations.

The different EIF values in the sediment for the different simulations are difficult to compare. The uncertainties attached to the model will cause variations to the impact factor by 5-10 %, thus the restitution time for each simulation is maybe more appropriate to compare with each other.

The presence of a risk does not necessarily imply occurrence of effects in the environment. Reducing the risk, however, does reduce the probability of the occurrence of effects. From a water column point of view it seems like an untreated discharge, where the PAHs are removed, will impact the environment less than for discharge treated with TCC. In the sediments on the other hand, the small particle sizes seem to be more environmental friendly than the bigger ones.

The two EIF values, $EIF_{sediment}$ and $EIF_{water-column}$ should be compared quantitatively, which is beyond the objectives of this thesis. The discussion should deal with the different time scales, chronic/acute, and the difference in expression, area/volume. The EIF values in it selves does not seem comparable.

In the fourth and fifth simulation the PAH concentrations was taken into consideration. Even though it is the heaviest PAHs (5-6 ring PAHs) that will settle the fastest and degrade the slowest, the PAH didn't affect the sediment compartment at all in the TCC treated discharge simulation, which might indicate that the PAHs didn't reach the sediment. In the water column on the other hand, the 5-6 ring PAHs was the main contributor to the total EIF, this seems to be due to the slow sinking velocity of the particles, and thus the PAHs attached to the particles will stay in the water column over a longer period of time. Due to the stratification in the water the particle plume may not reach the sediment. When the waste is discharged to the seawater the PAH will be diluted. Fish have a great ability to break down and excrete substances such as PAH, but products of the biodegradation may form DNA damage, oxidative stress or cardiac function defects (Bakke & Klungsøyr & Sanni, 2013).

Even though the PAH concentrations was low, it did affect the water column. This resulted in an EIF value almost eight times bigger than in the case where the PAHs were excluded. If the EIF value is evaluated too high, despite the low time duration, the PAH concentration in the discharge should be reconsidered discharged. Thus again, the weighting of the EIF values has to be taken into account when deciding what to prioritize. Constant monitoring and measuring of concentrations of the PAH content will be necessary.

In the last simulation performed an untreated discharge was assumed, PAH concentrations included. This resulted in an effect in the sediment due to the PAHs most likely due to the attraction to the particles and their high sinking velocity. Thus the contribution from the metals to the total EIF was decreased, but the distribution of metals stayed constant compared to the untreated discharge simulation where PAHs were excluded. However, the EIF in the two cases where the same. The time development chart for this scenario showed time duration longer than the time simulated for (10 years), thus the restitution time is longer than 10 years. The EIF value in the end of the simulation was around 2; this was the case for the first scenario as well. Both scenarios also showed that the toxic stressors contributions are the ones easiest removed in the sediments, while the grain size change was the major EIF contributor towards the end of the simulation.

In the water column the PAHs was the major contributor to the high EIF value. Infact, the presence of PAHs increased the EIF almost 30 times. This could be explained by the big difference between the concentrations of PAHs and their corresponding PNEC values, especially considering the heaviest PAHs.

Conclusion:

The objective of this thesis was primarily to evaluate the model`s ability to estimate the EIF values from a TCC treated discharge according to the decreased particle size and the metal concentrations, and how the particle size did affect the EIF value. Based on the previous discussion and results the model seems to handle the different scenarios realistically. When the different parameters input changed in the different scenarios, the EIF value did vary in accordance with what was more or less expected. Thus the model seems to be able to anticipate environmental risks and the major contributors. This makes it possible to anticipate in advance the biggest risk contributors in the discharge and thus reduce the final EIF.

Refrences:

- Aarrestad, S.J., 2013 "Utvikling av borevæsker i et helhetlig HMS perspektiv i M-I SWACO Ptil/Klif seminar 27.02.13
- About the industry: Drill cuttings 2009, viewed 9 March 2015, http://www.oilandgasuk.co.uk/knowledgecentre/cuttings.cfm
- Akvaplan-Niva AS 2010, "Effekter av petroleumsvirksomhet på bunnfauna i Nordsjøen", TA2658/2010, viewed 9 March 2015, http://www.miljodirektoratet.no/old/klif/publikasjoner/2658/ta2658.pdf
- Altin, D. & Frost, T.K. & Nilssen, I. 2007, "Approaches for Derivation of Environmental Quality Criteria for Substances Applied in Risk Assessment of Discharges from Offshore Drilling Operations", Integrated Environmental Assessment and Management vol 4, nr. 2, pp. 204-214, viewed 12 March 2015, via http://www.sintef.no/Projectweb/ERMS/Reports/
- Amani, M., Al-Jubouri, M. & Shadravan, A., 2012. "Comparative study of using Oil-Based mud versus Water-Based mud in HPHT fields" Advances in Petroleum Exploration and Development, Vol. 4, No. 2, pp. 18-27
- Andino, P. & Moyano J., 2013. "Thermal Desorption Technologies, Thermo mechanical Cutting Cleaner (TCC)". Tarija, Bolivia, November 2013. Viewed 11 May 2015 via < http://figas.org/v4/wp-content/uploads/2013/11/09Pablo_Andino_FIGAS2013_r.pdf>
- Bakke, T. & Klungsøyr, J. & Sanni, S. 2013, "Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry", Marine Environmental Research vol.92, pp. 154-169, viewed 12 March 2015, via ScienceDirect database
- Blytt, L.D., Henninge, L.B., Kjønnø, O., Stang, P., Vik, E.A. 2014. "Characterising Thermal Treated OBM Drill Cuttings. Sampling, characterization, environmental analysis and risk assessment of offshore discharges", Aquateam COWI, Report No: 14-028, Version; 1
- Buzzelli C.P., Luettich Jr. R.A., Powers S. P., Peterson C. H., McNinch J. E., Pinckney J. L., Paerl H. W, 2002. "Estimating the spatial extent of bottom-

water hypoxia and habitat degradation in a shallow estuary". Marine Ecology Progress Series 230:103-112, viewed 5 May 2015 via < http://www.int-res.com/articles/meps2002/230/m230p103.pdf>

- DREAM – Dose-related Risk and Effect Assessment Model, viewed 7 February 2015, < http://www.sintef.no/home/SINTEF-Materials-and-Chemistry/About-us/Departments/Environmental-Monitoring-and-Modelling/DREAM--Dose-related-Risk-and-Effects-Assessment-Model/
- European Communities, 2003 (EC 2003), "Technical Guidance Document on risk assessment in support of Commission Directive 93/67/EEC on risk assessment for new notified substances and Commission Regulation (EC) No 1488/94 on risk assessment for existing substances and Directive 98/8/EC of the European parliament and of the council concerning the placing of biocidal products on the market". Part II.
- Halliburton 2015, "Thermomechanical Cuttings Cleaner (TCC)", viewed 10 March 2015, <http://www.halliburton.com/en-US/ps/baroid/fluid-services/waste-management-solutions/waste-treatment-and-disposal/thermal-processing-systems/thermomechanical-cuttings-cleaner-tcc.page#>
- IPT Global – Innovative Solutions For The 21ST Century, image, viewed 8 June 2015, < http://3ipt.com/solutions/sureplan/>
- Johnsen, S & Frost T.K 2011, "Application of a Quantitative Risk Assessment in Produced Water Management – The Environmental Impact Factor (EIF)", Lee, K & Neff, J viewed 9 April 2015, via SpringerLink database.
- Neff, J.M., 2008. "Estimation of Bioavailability of Metals from Drillin Mud". Integrated Environmental Assessment and Management – Volume 4, Number 2 – pp. 184 – 193- 2008 SETAC. Viewed 20 May 2015 via http://onlinelibrary.wiley.com.ezproxy.uis.no/doi/10.1897/IEAM_2007-037.1/full
- Newman, M.C, Ownby, D.R, Mezin, L.C.A, Powell, D.C, Christensen, T.R.L, Lerberg, S.B and Anderson, B-A 2000, "Applying species-sensitivity distribution in ecological risk assessment: assumptions of distribution type and sufficient numbers of species" Environmental Toxicology and

Chemistry, Vol. 19, No. 2, pp. 508–515, viewed 29. October 2014, http://www.vims.edu/people/newman_mc/pubs/Newmanetal2000.pdf

- Norwegian Petroelum Directorate (4.juli 2011). ”Facts; The Norwegian Petroleum Sector”, Norwegian Petroelum Directorate. Viewed 3 November 2014, http://www.npd.no/en/Publications/Facts/Facts-2011/
- Reed, M., Høverstad, B., Rye, H., Durgut, I., Johansen, Ø., Brönner, U., Hetland, B., Ditlevsen, M. K., ArslanoĞlu, Y., Rønningen, P. & Daae, R. L. 2011. MEMW Users Manual version 6.1. In: SINTEF (ed.).
- Reed, M. & Rye, H. 2011, “The DREAM Model and the Environmental Impact Factor: Decision Support for Environmental Risk Management”, in Lee, K. & Neff, J. (eds), “Produced Water – Environmental Risks and Advances in Mitigation Technologies” via SpringerLink database, pp. 189-203
- Rye, H., 2005. “The influence of flocculation processes on the depostition of drill cuttings and mud on the sea floor”. Paper presented at the 8th International Marine Environmental Modeling Seminar, Helsinki, 23-25 August 2005.
- Rye, H., 2012. “”Getting Started” guidance for Drilling Discharge calculated with the DREAM 6.2 version”. Report no. – Confidential. SINTEF Materials and Chemistry, Project no. 801562.09/801923.05
- Rye, H. & Ditlevsen, M.K., 2013. “WP1 – DREAM Charter project. Revision of parameters used for calculating sediment impact”. Final Report, SINTEF Materials and Chemistry, Environmental Modelling, Report no. F24365
- Rye, H., Reed, M., Durgut, I., Ditlevsen, M.K., 2006. “The use of the diagenetic equations to predict impact on sediment due to discharges of drill cuttings and mud”, International Marine Environmental Modeling Seminar, Rio, 9-11 October 2006, SINTEF.
- Rye, H., Reed, M., Frost, T.K., Smit, M.GD., Durgut, I., Johansen, Ø., Ditlevsen, M.K., 2007, “Development of a Numerical Model for Calculating Exposure to Toxic and Nontoxic Stressors in the Water Column and Sediment from Drilling Discharges”, Integrated Environmental Assessment and Management vol. 4, nr. 2, pp. 194 – 203
- Schaanning, M. T., Trannum, H. C., Pinturier, L., Rye, H., 2011. “Metal Partitioning in Ilmenite- and Barite-Based Drill Cuttings on Seabed Sections in a Mesocosm Laboratory”. Society of Petroleum Engineers, Document ID: SPE

– 126478-PA pp. 268 – 277. Volume 26, issue 02. Viewed 20 May 2015 via https://www-onepetro-org.ezproxy.uis.no/download/journal-paper/SPE-126478-PA?id=journal-paper%2FSPE-126478-PA

- Singsaas, I., Rye, H., Frost, T.K., Smit, M.GD., Garpestad, E., Skare, I., Bakke, K., Veiga, L.F., Buffagni, M., Follum, O., Johnsen, S., Molutn, U., Reed, M. 2007. "Development of a Risk-Based Envrionmental Management Tool for Drilling Discharges. Summary of a Four-Year Project", Integrated Environmental Assessment and Management vol. 4, nr. 2, pp. 171-176
- Sintef 2007, "ERMS – Poject objectives" viewed 16 April 2015 via. http://www.sintef.no/projectweb/erms/project-objectives/
- Sintef – project info, "EIF – Environmental Impact Factor", viewed 18 March 2015, http://www.sintef.no/globalassets/project/erms/pdf/erms-brosjyre-07.pdf
- Taraldsen, L 2014, "Total blir først i Norge til å bruke TCC-teknologi offshore", *Teknisk Ukeblad*, vol. 19, viewed 11 March 2015 http://www.tu.no/petroleum/2014/08/28/martin-linge-blir-forst-pa-sokkelen-med-ny-renseteknologi
- Thermtech AS, "Efficient treatment of oily drilling waste", viewed 16 March 2015 http://www.thermtech.no/
- Thermtech AS, "Footprint and mobility", viewed 11 March 2015 <http://www.thermtech.no/TCC-R-Advantages/Footprint-and-Mobility>
- Thermtech AS, "Our technology", viewed 11 March 2015 http://www.thermtech.no/Our-Technology
- UK Marine Special Areas of Conservation, "Mercury", UK Marine – SACs Project, viewed 21 June 2015 via < http://www.ukmarinesac.org.uk/activities/water-quality/wq8_3.htm>
- United States Environmental Protection Agency, 1997. "Mercury Study Report to Congress. Volume III: fate and Transport of Mercury in the Environment". Office of Air Quality Planning and Standards and Office of Research and Development, viewed 12 June 2015 via < http://www.epa.gov/ttn/oarpg/t3/reports/volume3.pdf>
- User's manual – Multisizer™ 4, Particle Analyzer, 2010. PN A51387AB, Beckman Coulter, Inc.

- Van STRAALEN, N. M. 2002. “Threshold models for species sensitivity distribution applied to aquatic risk assessment for zinc”. Environmental Toxicology and Pharmacology. Vol. 11, Issues 3-4, pp. 167-172. Viewed 7 May 2015 via http://www.sciencedirect.com.ezproxy.uis.no/science/article/pii/S1382668901001144

ERMS reports:

- **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. & Westerlund S., 2004. “Input from RF-AM to literature study task 1 toxicity: Metals”. Akvamiljø report no. AM-2004/023 – open
- **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-411.30881 - restricted
- **ERMS Report no. 9B:** Kjeilen-Eilertsen, G., Trannum, H., Jak, R., Smit, M., Neff, J., Durell, G., 2004. “Literature report on burial: derivation of PNEC as component in the MEMW model tool”. RF report no. 695401 – 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. 12:** Trannum, H. C., Brakstad, F. & Neff, J., 2006. “Sediment characterisation and parameter estimation. ERMS task 3.” Akvaplan-NIVA Report no. APN-411.3119 – open
- **ERMS Report no. 15:** Bjørgsæter, A., 2006. “Field Based Predicted No Effect Concentrations (F-PNECs) for macro benthos on the Norwegian Continental Shelf”. UoO Report – open.
- **ERMS Report no. 18:** Rye, H., Reed, M., Durgut, I., Ditlevsen, M. K., 2006. “Documentation report for the revised DREAM model”. SINTEF Report no. STF80MK F06224 – open
- **ERMS Report no. 24:** Singsaas, I., Smit, M. G. D., Garpestad, E., Skare. I,.

Bakke, K., Falcao Veiga, L., Buffagni, M., Follum, O. A., Johnsen, S., Moltu, U. E., 2007. "Environmental Risk Management System (ERMS). A summary report". SINTEF Report no. STF80MK A06368 – open

Appendix A

Fraction 1: Smaller than 1.00mm

Multisizer 4	11.05.15 13:33
Control mode:	Time, 10 seconds
Acquired:	11.05.15 13:30
Size bins:	116
From	40
To	600

				Number				
		and up)		1	2	3	4	5
				40	45	50	55	60
Sample 1	**Run 1**	Number		2791	1748	1473	1319	1100
		Volume	um^3	1,13E+08	9,73E+07	1,10E+08	1,28E+08	1,36E+08
		Area	um^2	1,58E+07	1,23E+07	1,26E+07	1,34E+07	1,32E+07
	Run 2	Number		2622	1969	1530	1300	1164
		Volume	um^3	1,06E+08	1,10E+08	1,14E+08	1,26E+08	1,44E+08
		Area	um^2	1,49E+07	1,38E+07	1,31E+07	1,32E+07	1,40E+07
	Run 3	Number		1946	1505	1291	1156	1092
		Volume	um^3	7,85E+07	8,37E+07	9,60E+07	1,12E+08	1,35E+08
		Area	um^2	1,10E+07	1,06E+07	1,10E+07	1,18E+07	1,31E+07
Sample 2	**Run 1**	Number		1607	1467	1173	1040	882
		Volume	um^3	6,53E+07	8,30E+07	8,95E+07	1,04E+08	1,13E+08
		Area	um^2	9,15E+06	1,04E+07	1,02E+07	1,08E+07	1,08E+07
	Run 2	Number		1587	1343	1127	941	796
		Volume	um^3	6,45E+07	7,60E+07	8,60E+07	9,42E+07	1,02E+08
		Area	um^2	9,04E+06	9,55E+06	9,78E+06	9,79E+06	9,78E+06
	Run 3	Number		1529	1289	1083	947	772
		Volume	um^3	6,21E+07	7,29E+07	8,26E+07	9,48E+07	9,92E+07
		Area	um^2	8,71E+06	9,16E+06	9,40E+06	9,85E+06	9,49E+06
Sample 3	**Run 1**	Number		1534	1315	1205	1050	918
		Volume	um^3	6,23E+07	7,44E+07	9,19E+07	1,05E+08	1,18E+08
		Area	um^2	8,73E+06	9,35E+06	1,05E+07	1,09E+07	1,13E+07
	Run 2	Number		1273	1170	1095	1062	928
		Volume	um^3	5,17E+07	6,62E+07	8,35E+07	1,06E+08	1,19E+08
		Area	um^2	7,25E+06	8,32E+06	9,50E+06	1,11E+07	1,14E+07
	Run 3	Number		1241	1200	1076	1022	935
		Volume	um^3	5,04E+07	6,79E+07	8,21E+07	1,02E+08	1,20E+08
		Area	um^2	7,07E+06	8,53E+06	9,34E+06	1,06E+07	1,15E+07

1,18E+07	1,14E+07	1,18E+07	1,19E+07	1,03E+07	8,96E+06	8,67E+06	9,08E+06	7,56E+06	7,76E+06	6,38E+06	5,09E+06
1,33E+08	1,39E+08	1,52E+08	1,63E+08	1,51E+08	1,38E+08	1,41E+08	1,55E+08	1,36E+08	1,46E+08	1,25E+08	1,04E+08
820	692	622	554	429	333	290	275	208	195	147	108
1,13E+07	1,20E+07	1,12E+07	1,07E+07	1,00E+07	8,72E+06	8,46E+06	8,32E+06	7,26E+06	6,92E+06	6,47E+06	6,74E+06
1,28E+08	1,45E+08	1,45E+08	1,47E+08	1,46E+08	1,35E+08	1,38E+08	1,42E+08	1,30E+08	1,30E+08	1,27E+08	1,38E+08
790	725	592	499	416	324	283	252	200	174	149	143
1,16E+07	1,16E+07	1,05E+07	9,22E+06	9,44E+06	8,77E+06	8,25E+06	7,17E+06	6,83E+06	5,49E+06	5,64E+06	5,52E+06
1,31E+08	1,41E+08	1,36E+08	1,27E+08	1,38E+08	1,35E+08	1,34E+08	1,23E+08	1,23E+08	1,03E+08	1,11E+08	1,13E+08
812	704	558	431	392	326	276	217	188	138	130	117
9,47E+06	9,56E+06	8,46E+06	7,70E+06	8,74E+06	8,15E+06	6,72E+06	7,07E+06	6,54E+06	5,17E+06	5,68E+06	6,04E+06
1,07E+08	1,16E+08	1,10E+08	1,06E+08	1,28E+08	1,26E+08	1,09E+08	1,21E+08	1,17E+08	9,71E+07	1,11E+08	1,23E+08
661	578	448	360	363	303	225	214	180	130	131	128
1,04E+07	1,02E+07	9,37E+06	8,73E+06	8,38E+06	7,32E+06	6,90E+06	7,43E+06	6,83E+06	6,88E+06	6,25E+06	5,61E+06
1,17E+08	1,24E+08	1,21E+08	1,20E+08	1,22E+08	1,13E+08	1,12E+08	1,27E+08	1,23E+08	1,29E+08	1,23E+08	1,15E+08
722	619	496	408	348	272	231	225	188	173	144	119
1,12E+07	1,17E+07	9,86E+06	9,82E+06	8,11E+06	7,80E+06	7,02E+06	5,88E+06	6,28E+06	5,45E+06	4,90E+06	5,33E+06
1,26E+08	1,42E+08	1,28E+08	1,35E+08	1,19E+08	1,20E+08	1,14E+08	1,01E+08	1,13E+08	1,02E+08	9,61E+07	1,09E+08
781	708	522	459	337	290	235	178	173	137	113	113
1,42E+07	1,40E+07	1,56E+07	1,47E+07	1,46E+07	1,33E+07	1,47E+07	1,38E+07	1,35E+07	1,19E+07	1,21E+07	1,03E+07
1,58E+08	1,67E+08	1,99E+08	1,99E+08	2,09E+08	2,02E+08	2,35E+08	2,32E+08	2,37E+08	2,19E+08	2,32E+08	2,05E+08
1018	875	856	712	630	516	514	437	389	314	292	228
1,31E+07	1,40E+07	1,28E+07	1,20E+07	1,18E+07	1,03E+07	8,80E+06	9,62E+06	7,34E+06	8,82E+06	8,33E+06	6,66E+06
1,45E+08	1,67E+08	1,63E+08	1,63E+08	1,68E+08	1,57E+08	1,40E+08	1,61E+08	1,29E+08	1,62E+08	1,60E+08	1,33E+08
938	872	702	583	507	400	307	304	211	232	201	148
1,34E+07	1,34E+07	1,25E+07	1,14E+07	1,15E+07	9,39E+06	9,26E+06	9,18E+06	8,48E+06	8,52E+06	7,54E+06	8,05E+06
1,49E+08	1,60E+08	1,59E+08	1,54E+08	1,65E+08	1,42E+08	1,48E+08	1,54E+08	1,49E+08	1,56E+08	1,45E+08	1,61E+08
964	838	683	551	495	363	323	290	244	224	182	179
65	70	75	80	85	90	95	100	105	110	115	120
6	7	8	9	10	11	12	13	14	15	16	17

5,21E+06	4,74E+06	4,52E+06	3,83E+06	3,90E+06	3,87E+06	2,65E+06	3,98E+06	3,17E+06	2,24E+06	2,57E+06	1,99E+06
1,11E+08	1,05E+08	1,04E+08	9,10E+07	9,59E+07	9,85E+07	6,96E+07	1,08E+08	8,86E+07	6,45E+07	7,62E+07	6,05E+07
102	86	76	60	57	53	34	48	36	24	26	19
5,21E+06	5,41E+06	4,99E+06	4,15E+06	4,44E+06	3,51E+06	3,66E+06	3,82E+06	3,79E+06	2,81E+06	2,18E+06	3,03E+06
1,11E+08	1,20E+08	1,15E+08	9,86E+07	1,09E+08	8,92E+07	9,62E+07	1,03E+08	1,06E+08	8,07E+07	6,45E+07	9,24E+07
102	98	84	65	65	48	47	46	43	30	22	29
5,26E+06	3,92E+06	3,56E+06	3,45E+06	3,49E+06	3,07E+06	4,21E+06	3,24E+06	3,79E+06	3,09E+06	2,57E+06	2,20E+06
1,12E+08	8,66E+07	8,18E+07	8,19E+07	8,58E+07	7,81E+07	1,11E+08	8,77E+07	1,06E+08	8,88E+07	7,62E+07	6,69E+07
103	71	60	54	51	42	54	39	43	33	26	21
5,88E+06	4,69E+06	3,56E+06	3,51E+06	3,69E+06	3,87E+06	3,51E+06	2,99E+06	2,03E+06	2,62E+06	1,88E+06	1,47E+06
1,25E+08	1,04E+08	8,18E+07	8,34E+07	9,08E+07	9,85E+07	9,21E+07	8,09E+07	5,66E+07	7,53E+07	5,57E+07	4,46E+07
115	85	60	55	54	53	45	36	23	28	19	14
4,65E+06	3,86E+06	4,69E+06	3,70E+06	4,10E+06	2,85E+06	3,12E+06	2,90E+06	2,38E+06	2,24E+06	2,47E+06	2,72E+06
9,89E+07	8,54E+07	1,08E+08	8,80E+07	1,01E+08	7,25E+07	8,19E+07	7,87E+07	6,65E+07	6,45E+07	7,33E+07	8,28E+07
91	70	79	58	60	39	40	35	27	24	25	26
4,60E+06	3,20E+06	4,34E+06	4,79E+06	3,56E+06	3,07E+06	3,27E+06	2,82E+06	2,12E+06	2,24E+06	2,67E+06	1,99E+06
9,78E+07	7,07E+07	9,95E+07	1,14E+08	8,75E+07	7,81E+07	8,60E+07	7,64E+07	5,91E+07	6,45E+07	7,91E+07	6,05E+07
90	58	73	75	52	42	42	34	24	24	27	19
9,59E+06	8,67E+06	8,09E+06	7,10E+06	7,41E+06	5,90E+06	5,55E+06	5,04E+06	4,10E+06	4,25E+06	4,13E+06	4,46E+06
1,99E+08	1,87E+08	1,81E+08	1,65E+08	1,78E+08	1,46E+08	1,42E+08	1,33E+08	1,11E+08	1,19E+08	1,19E+08	1,32E+08
197	165	143	117	114	85	75	64	49	48	44	45
6,67E+06	5,73E+06	4,86E+06	4,92E+06	5,91E+06	5,69E+06	4,51E+06	3,94E+06	4,76E+06	3,46E+06	3,09E+06	3,77E+06
1,39E+08	1,24E+08	1,09E+08	1,14E+08	1,42E+08	1,41E+08	1,16E+08	1,04E+08	1,30E+08	9,68E+07	8,91E+07	1,12E+08
137	109	86	81	91	82	61	50	57	39	33	38
7,35E+06	7,04E+06	6,50E+06	5,28E+06	5,26E+06	4,51E+06	5,11E+06	4,09E+06	5,35E+06	4,43E+06	3,56E+06	1,98E+06
1,53E+08	1,52E+08	1,46E+08	1,22E+08	1,26E+08	1,12E+08	1,31E+08	1,08E+08	1,46E+08	1,24E+08	1,03E+08	5,87E+07
151	134	115	87	81	65	69	52	64	50	38	20
125	130	135	140	145	150	155	160	165	170	175	180
18	19	20	21	22	23	24	25	26	27	28	29

2,32E+06	3,26E+06	1,35E+06	1,55E+06	2,16E+06	1,56E+06	1,93E+06	1,09E+06	2,11E+06	1,53E+06	1,60E+06	5,54E+05
7,25E+07	1,05E+08	4,44E+07	5,22E+07	7,49E+07	5,53E+07	7,01E+07	4,04E+07	8,02E+07	5,93E+07	6,32E+07	2,24E+07
21	28	11	12	16	11	13	7	13	9	9	3
2,21E+06	2,91E+06	2,08E+06	2,32E+06	1,62E+06	1,70E+06	2,08E+06	1,09E+06	6,50E+05	2,21E+06	1,24E+06	1,66E+06
6,91E+07	9,34E+07	6,86E+07	7,83E+07	5,62E+07	6,03E+07	7,55E+07	4,04E+07	2,47E+07	8,56E+07	4,91E+07	6,72E+07
20	25	17	18	12	12	14	7	4	13	7	9
2,10E+06	1,86E+06	2,57E+06	3,09E+06	1,89E+06	1,99E+06	1,64E+06	1,71E+06	2,76E+06	1,87E+06	1,42E+06	9,24E+05
6,56E+07	5,98E+07	8,48E+07	1,04E+08	6,55E+07	7,04E+07	5,93E+07	6,35E+07	1,05E+08	7,24E+07	5,61E+07	3,74E+07
19	16	21	24	14	14	11	11	17	11	8	5
1,88E+06	2,21E+06	2,33E+06	1,29E+06	1,76E+06	1,42E+06	1,04E+06	1,09E+06	6,50E+05	1,53E+06	1,06E+06	1,11E+06
5,87E+07	7,10E+07	7,67E+07	4,35E+07	6,08E+07	5,03E+07	3,77E+07	4,04E+07	2,47E+07	5,93E+07	4,21E+07	4,48E+07
17	19	19	10	13	10	7	7	4	9	6	6
2,21E+06	2,21E+06	1,59E+06	1,42E+06	6,76E+05	2,13E+06	1,34E+06	9,33E+05	1,14E+06	1,36E+06	1,24E+06	7,39E+05
6,91E+07	7,10E+07	5,25E+07	4,79E+07	2,34E+07	7,54E+07	4,85E+07	3,46E+07	4,32E+07	5,27E+07	4,91E+07	2,99E+07
20	19	13	11	5	15	9	6	7	8	7	4
2,21E+06	3,03E+06	2,33E+06	1,93E+06	1,49E+06	1,70E+06	1,19E+06	1,24E+06	1,63E+06	1,36E+06	1,06E+06	9,24E+05
6,91E+07	9,72E+07	7,67E+07	6,53E+07	5,15E+07	6,03E+07	4,31E+07	4,62E+07	6,17E+07	5,27E+07	4,21E+07	3,74E+07
20	26	19	15	11	12	8	8	10	8	6	5
3,24E+06	2,09E+06	3,13E+06	3,29E+06	1,92E+06	2,28E+06	2,81E+06	1,32E+06	3,07E+06	8,01E+05	2,01E+06	1,57E+06
9,86E+07	6,53E+07	1,00E+08	1,08E+08	6,45E+07	7,85E+07	9,89E+07	4,76E+07	1,13E+08	3,02E+07	7,72E+07	6,16E+07
31	19	27	27	15	17	20	9	20	5	12	9
2,61E+06	3,53E+06	2,90E+06	2,80E+06	3,07E+06	2,68E+06	2,25E+06	2,06E+06	2,61E+06	2,89E+06	3,51E+06	6,97E+05
7,95E+07	1,10E+08	9,28E+07	9,20E+07	1,03E+08	9,23E+07	7,92E+07	7,41E+07	9,62E+07	1,09E+08	1,35E+08	2,74E+07
25	32	25	23	24	20	16	14	17	18	21	4
3,35E+06	3,64E+06	3,25E+06	3,78E+06	2,30E+06	2,41E+06	2,81E+06	2,35E+06	1,84E+06	1,76E+06	1,67E+06	1,57E+06
1,02E+08	1,14E+08	1,04E+08	1,24E+08	7,74E+07	8,31E+07	9,89E+07	8,47E+07	6,79E+07	6,64E+07	6,43E+07	6,16E+07
32	33	28	31	18	18	20	16	12	11	10	9
185	190	195	200	205	210	215	220	225	230	235	240
30	31	32	33	34	35	36	37	38	39	40	41

1,15E+06	1,80E+06	1,25E+06	2,38E+06	8,99E+05	4,67E+05	7,26E+05	1,25E+06	7,79E+05	2,69E+05	1,11E+06	1,44E+06
4,76E+07	7,59E+07	5,37E+07	1,04E+08	4,01E+07	2,12E+07	3,36E+07	5,90E+07	3,73E+07	1,31E+07	5,52E+07	7,25E+07
6	9	6	11	4	2	3	5	3	1	4	5
1,54E+06	2,00E+06	6,25E+05	1,73E+06	2,25E+05	1,87E+06	1,94E+06	2,01E+06	1,82E+06	5,38E+05	1,11E+06	5,75E+05
6,35E+07	8,43E+07	2,68E+07	7,58E+07	1,00E+07	8,48E+07	8,95E+07	9,45E+07	8,71E+07	2,62E+07	5,52E+07	2,90E+07
8	10	3	8	1	8	8	8	7	2	4	2
1,35E+06	1,00E+06	1,25E+06	2,16E+05	1,12E+06	4,67E+05	9,68E+05	7,52E+05	7,79E+05	1,08E+06	1,11E+06	1,44E+06
5,56E+07	4,22E+07	5,37E+07	9,47E+06	5,01E+07	2,12E+07	4,48E+07	3,54E+07	3,73E+07	5,24E+07	5,52E+07	7,25E+07
7	5	6	1	5	2	4	3	3	4	4	5
7,70E+05	6,01E+05	2,08E+05	1,08E+06	4,50E+05	1,17E+06	9,68E+05	0,00E+00	7,79E+05	5,38E+05	5,56E+05	5,75E+05
3,18E+07	2,53E+07	8,94E+06	4,74E+07	2,01E+07	5,30E+07	4,48E+07	0,00E+00	3,73E+07	2,62E+07	2,76E+07	2,90E+07
4	3	1	5	2	5	4	0	3	2	2	2
1,15E+06	8,01E+05	1,04E+06	2,16E+05	6,74E+05	1,17E+06	9,68E+05	5,01E+05	0,00E+00	5,38E+05	1,11E+06	5,75E+05
4,76E+07	3,37E+07	4,47E+07	9,47E+06	3,01E+07	5,30E+07	4,48E+07	2,36E+07	0,00E+00	2,62E+07	5,52E+07	2,90E+07
6	4	5	1	3	5	4	2	0	2	4	2
7,70E+05	4,01E+05	8,33E+05	1,08E+06	1,35E+06	9,33E+05	9,68E+05	7,52E+05	1,82E+06	1,88E+06	5,56E+05	2,87E+05
3,18E+07	1,69E+07	3,58E+07	4,74E+07	6,02E+07	4,24E+07	4,48E+07	3,54E+07	8,71E+07	9,17E+07	2,76E+07	1,45E+07
4	2	4	5	6	4	4	3	7	7	2	1
2,00E+06	1,51E+06	1,18E+06	1,02E+06	1,69E+06	1,98E+06	1,37E+06	4,72E+05	7,34E+05	5,06E+05	2,62E+05	1,62E+06
8,00E+07	6,18E+07	4,91E+07	4,33E+07	7,34E+07	8,72E+07	6,14E+07	2,16E+07	3,41E+07	2,39E+07	1,26E+07	7,94E+07
11	8	6	5	8	9	6	2	3	2	1	6
1,81E+06	1,70E+06	1,18E+06	1,43E+06	1,27E+06	2,42E+06	3,42E+06	2,13E+06	2,45E+06	1,27E+06	1,05E+06	5,41E+05
7,27E+07	6,95E+07	4,91E+07	6,07E+07	5,50E+07	1,07E+08	1,53E+08	9,71E+07	1,14E+08	5,99E+07	5,04E+07	2,65E+07
10	9	6	7	6	11	15	9	10	5	4	2
2,36E+06	1,51E+06	1,77E+06	8,16E+05	2,75E+06	1,54E+06	1,37E+06	2,13E+06	1,47E+06	1,27E+06	7,85E+05	1,62E+06
9,45E+07	6,18E+07	7,37E+07	3,47E+07	1,19E+08	6,78E+07	6,14E+07	9,71E+07	6,82E+07	5,99E+07	3,78E+07	7,94E+07
13	8	9	4	13	7	6	9	6	5	3	6
245	250	255	260	265	270	275	280	285	290	295	300
42	43	44	45	46	47	48	49	50	51	52	53

1,19E+06	3,07E+05	9,50E+05	9,80E+05	3,37E+05	3,47E+05	7,16E+05	0,00E+00	0,00E+00	1,17E+06	4,02E+05	4,13E+05
6,09E+07	1,60E+07	5,03E+07	5,27E+07	1,84E+07	1,93E+07	4,03E+07	0,00E+00	0,00E+00	6,88E+07	2,39E+07	2,50E+07
4	1	3	3	1	1	2	0	0	3	1	1
8,91E+05	9,20E+05	9,50E+05	1,31E+06	6,74E+05	3,47E+05	3,58E+05	1,11E+06	3,79E+05	3,90E+05	4,02E+05	4,13E+05
4,57E+07	4,80E+07	5,03E+07	7,03E+07	3,68E+07	1,93E+07	2,01E+07	6,31E+07	2,20E+07	2,29E+07	2,39E+07	2,50E+07
3	3	3	4	2	1	1	3	1	1	1	1
1,49E+06	1,23E+06	9,50E+05	9,80E+05	1,01E+06	1,04E+06	7,16E+05	3,69E+05	3,79E+05	7,81E+05	0,00E+00	0,00E+00
7,61E+07	6,39E+07	5,03E+07	5,27E+07	5,52E+07	5,78E+07	4,03E+07	2,10E+07	2,20E+07	4,59E+07	0,00E+00	0,00E+00
5	4	3	3	3	3	2	1	1	2	0	0
2,97E+05	3,07E+05	0,00E+00	3,27E+05	0,00E+00	6,95E+05	0,00E+00	0,00E+00	3,79E+05	3,90E+05	4,02E+05	4,13E+05
1,52E+07	1,60E+07	0,00E+00	1,76E+07	0,00E+00	3,85E+07	0,00E+00	0,00E+00	2,20E+07	2,29E+07	2,39E+07	2,50E+07
1	1	0	1	0	2	0	0	1	1	1	1
1,19E+06	0,00E+00	0,00E+00	3,27E+05	3,37E+05	6,95E+05	7,16E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,13E+05
6,09E+07	0,00E+00	0,00E+00	1,76E+07	1,84E+07	3,85E+07	4,03E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,50E+07
4	0	0	1	1	2	2	0	0	0	0	1
8,91E+05	6,14E+05	3,17E+05	1,31E+06	0,00E+00	0,00E+00	3,58E+05	7,37E+05	3,79E+05	0,00E+00	4,02E+05	8,26E+05
4,57E+07	3,20E+07	1,68E+07	7,03E+07	0,00E+00	0,00E+00	2,01E+07	4,21E+07	2,20E+07	0,00E+00	2,39E+07	4,99E+07
3	2	1	4	0	0	1	2	1	0	1	2
8,39E+05	5,77E+05	8,94E+05	9,22E+05	9,51E+05	3,27E+05	6,73E+05	0,00E+00	3,57E+05	0,00E+00	3,77E+05	7,76E+05
4,17E+07	2,92E+07	4,59E+07	4,81E+07	5,03E+07	1,76E+07	3,67E+07	0,00E+00	2,00E+07	0,00E+00	2,18E+07	4,54E+07
3	2	3	3	3	1	2	0	1	0	1	2
8,39E+05	8,66E+05	1,19E+06	6,15E+05	3,17E+05	6,53E+05	6,73E+05	1,04E+06	3,57E+05	7,34E+05	1,13E+06	3,88E+05
4,17E+07	4,38E+07	6,12E+07	3,20E+07	1,68E+07	3,51E+07	3,67E+07	5,75E+07	2,00E+07	4,18E+07	6,54E+07	2,27E+07
3	3	4	2	1	2	2	3	1	2	3	1
1,68E+06	1,15E+06	1,49E+06	9,22E+05	6,34E+05	9,80E+05	1,35E+06	6,93E+05	1,43E+06	3,67E+05	3,77E+05	2,33E+06
8,34E+07	5,83E+07	7,65E+07	4,81E+07	3,36E+07	5,27E+07	7,34E+07	3,84E+07	8,01E+07	2,09E+07	2,18E+07	1,36E+08
6	4	5	3	2	3	4	2	4	1	1	6
305	310	315	320	325	330	335	340	345	350	355	360
54	55	56	57	58	59	60	61	62	63	64	65

8,49E+05	4,36E+05	0,00E+00	4,60E+05	4,72E+05	4,84E+05	0,00E+00	1,53E+06	1,04E+06	0,00E+00	1,10E+06	5,61E+05
5,20E+07	2,71E+07	0,00E+00	2,93E+07	3,05E+07	3,17E+07	0,00E+00	1,02E+08	7,09E+07	0,00E+00	7,62E+07	3,95E+07
2	1	0	1	1	1	0	3	2	0	2	1
4,24E+05	4,36E+05	0,00E+00	1,38E+06	0,00E+00	0,00E+00	4,96E+05	0,00E+00	5,22E+05	5,35E+05	5,48E+05	0,00E+00
2,60E+07	2,71E+07	0,00E+00	8,79E+07	0,00E+00	0,00E+00	3,29E+07	0,00E+00	3,54E+07	3,68E+07	3,81E+07	0,00E+00
1	1	0	3	0	0	1	0	1	1	1	0
4,24E+05	8,72E+05	8,95E+05	4,60E+05	0,00E+00	0,00E+00	4,96E+05	5,09E+05	0,00E+00	0,00E+00	5,48E+05	0,00E+00
2,60E+07	5,41E+07	5,63E+07	2,93E+07	0,00E+00	0,00E+00	3,29E+07	3,42E+07	0,00E+00	0,00E+00	3,81E+07	0,00E+00
1	2	2	1	0	0	1	1	0	0	1	0
4,24E+05	0,00E+00	4,48E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2,60E+07	0,00E+00	2,82E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	1	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	4,60E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	2,93E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	1	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	4,48E+05	4,60E+05	0,00E+00	4,84E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,48E+05	5,61E+05
0,00E+00	0,00E+00	2,82E+07	2,93E+07	0,00E+00	3,17E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,81E+07	3,95E+07
0	0	1	1	0	1	0	0	0	0	1	1
1,20E+06	8,19E+05	4,21E+05	0,00E+00	4,43E+05	9,09E+05	4,66E+05	0,00E+00	4,90E+05	5,02E+05	5,14E+05	5,26E+05
7,10E+07	4,93E+07	2,57E+07	0,00E+00	2,77E+07	5,76E+07	2,99E+07	0,00E+00	3,22E+07	3,34E+07	3,47E+07	3,59E+07
3	2	1	0	1	2	1	0	1	1	1	1
1,20E+06	2,46E+06	1,26E+06	1,30E+06	8,86E+05	9,09E+05	4,66E+05	4,78E+05	1,96E+06	2,01E+06	5,14E+05	1,05E+06
7,10E+07	1,48E+08	7,69E+07	8,00E+07	5,55E+07	5,76E+07	2,99E+07	3,11E+07	1,29E+08	1,34E+08	3,47E+07	7,18E+07
3	6	3	3	2	2	1	1	4	4	1	2
3,99E+05	2,05E+06	0,00E+00	4,32E+05	8,86E+05	4,54E+05	0,00E+00	4,78E+05	9,80E+05	5,02E+05	5,14E+05	0,00E+00
2,37E+07	1,23E+08	0	2,67E+07	5,55E+07	2,88E+07	0	3,11E+07	6,45E+07	3,34E+07	3,47E+07	0
1	5	0	1	2	1	0	1	2	1	1	0
365	370	375	380	385	390	395	400	405	410	415	420
66	67	68	69	70	71	72	73	74	75	76	77

0,00E+00	5,88E+05	0,00E+00	6,15E+05	6,29E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	4,24E+07	0,00E+00	4,54E+07	4,69E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	1	1	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	6,15E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,01E+05	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	4,54E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,52E+07	0,00E+00	0,00E+00
0	0	0	1	0	0	0	0	0	1	0	0
0,00E+00	5,88E+05	0,00E+00	1,23E+06	1,26E+06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	4,24E+07	0,00E+00	9,07E+07	9,39E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	2	2	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	5,88E+05	0,00E+00	0,00E+00	0,00E+00	6,43E+05	6,58E+05	0,00E+00	0,00E+00	7,01E+05	0,00E+00	7,31E+05
0,00E+00	4,24E+07	0,00E+00	0,00E+00	0,00E+00	4,85E+07	5,01E+07	0,00E+00	0,00E+00	5,52E+07	0,00E+00	5,88E+07
0	1	0	0	0	1	1	0	0	1	0	1
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,21E+06	0,00E+00	0,00E+00	6,44E+05	0,00E+00	6,72E+05	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,82E+07	0,00E+00	0,00E+00	4,86E+07	0,00E+00	5,18E+07	0,00E+00
0	0	0	0	0	2	0	0	1	0	1	0
0,00E+00	1,10E+06	0,00E+00	5,77E+05	5,90E+05	0,00E+00	1,85E+06	6,30E+05	0,00E+00	0,00E+00	1,34E+06	0,00E+00
0,00E+00	7,70E+07	0,00E+00	4,12E+07	4,26E+07	0,00E+00	1,37E+08	4,71E+07	0,00E+00	0,00E+00	1,04E+08	0,00E+00
0	2	0	1	1	0	3	1	0	0	2	0
5,39E+05	5,51E+05	5,64E+05	5,77E+05	0,00E+00	0,00E+00	0,00E+00	6,30E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
3,72E+07	3,85E+07	3,99E+07	4,12E+07	0	0	0	4,71E+07	0	0	0	0
1	1	1	1	0	0	0	1	0	0	0	0
425	430	435	440	445	450	455	460	465	470	475	480
78	79	80	81	82	83	84	85	86	87	88	89

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	7,62E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	6,26E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
7,47E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
6,07E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	0	0	0	0	0	0	0	0	0
7,00E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	7,15E+05	0,00E+00	0,00E+00	0,00E+00	7,74E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	5,68E+07	0,00E+00	0,00E+00	0,00E+00	6,40E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	0	0	1	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
485	490	495	500	505	510	515	520	525	530	535	540
90	91	92	93	94	95	96	97	98	99	100	101

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,08E+06	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,06E+08	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	1	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,12E+06	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,12E+08	
0	0	0	0	0	0	0	0	0	0	1	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,05E+06	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,01E+08	0,00E+00
0	0	0	0	0	0	0	0	0	0	1	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,03E+06	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,87E+07	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	1	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
545	550	555	560	565	570	575	580	585	590	595	600
102	103	104	105	106	107	108	109	110	111	112	113

0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00
0	0	0
0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00
0	0	0
0,00E+00	0,00E+00	1,12E+06
0	0	1,12E+08
0	0	1
605	610	615
114	115	116

Appendix B

Fraction 2: Smaller than 500 µm

Multisizer 4	11.05.15 13:33
Control mode:	Time, 10 seconds
Acquired:	11.05.15 13:30
Size bins:	116
From	40
To	600

	Number			1	2	3	4	5
		and up)		40	45	50	55	60
Sample 1	Run 1	Number		3130	2328	1787	1564	1262
		Volume	um^3	1,26E+08	1,30E+08	1,33E+08	1,52E+08	1,56E+08
		Area	um^2	1,78E+07	1,64E+07	1,53E+07	1,59E+07	1,51E+07
	Run 2	Number		2960	2035	1868	1567	1408
		Volume	um^3	1,19E+08	1,13E+08	1,39E+08	1,52E+08	1,74E+08
		Area	um^2	1,68E+07	1,43E+07	1,59E+07	1,60E+07	1,69E+07
	Run 3	Number		1780	1389	1304	1210	1098
		Volume	um^3	7,18E+07	7,73E+07	9,70E+07	1,17E+08	1,36E+08
		Area	um^2	1,01E+07	9,76E+06	1,11E+07	1,23E+07	1,32E+07
Sample 2	Run 1	Number		1850	1539	1431	1198	948
		Volume	um^3	7,51E+07	8,71E+07	1,09E+08	1,20E+08	1,22E+08
		Area	um^2	1,05E+07	1,09E+07	1,24E+07	1,25E+07	1,17E+07
	Run 2	Number		1612	1422	1303	1159	985
		Volume	um^3	6,55E+07	8,05E+07	9,94E+07	1,16E+08	1,27E+08
		Area	um^2	9,18E+06	1,01E+07	1,13E+07	1,21E+07	1,21E+07
	Run 3	Number		1382	1284	1220	1109	1078
		Volume	um^3	5,61E+07	7,27E+07	9,31E+07	1,11E+08	1,39E+08
		Area	um^2	7,87E+06	9,13E+06	1,06E+07	1,15E+07	1,33E+07
Sample 3	Run 1	Number		1626	1498	1321	1094	856
		Volume	um^3	6,60E+07	8,48E+07	1,01E+08	1,10E+08	1,10E+08
		Area	um^2	9,26E+06	1,07E+07	1,15E+07	1,14E+07	1,05E+07
	Run 2	Number		1627	1488	1209	1111	974
		Volume	um^3	6,61E+07	8,42E+07	9,22E+07	1,11E+08	1,25E+08
		Area	um^2	9,26E+06	1,06E+07	1,05E+07	1,16E+07	1,20E+07
	Run 3	Number		1462	1236	1139	1053	940
		Volume	um^3	5,94E+07	6,99E+07	8,69E+07	1,05E+08	1,21E+08
		Area	um^2	8,32E+06	8,79E+06	9,88E+06	1,10E+07	1,16E+07

1,08E+07	1,12E+07	1,07E+07	1,06E+07	1,04E+07	9,23E+06	8,58E+06	8,55E+06	7,01E+06	7,00E+06	7,42E+06	5,99E+06
1,22E+08	1,35E+08	1,38E+08	1,47E+08	1,52E+08	1,43E+08	1,40E+08	1,46E+08	1,26E+08	1,31E+08	1,45E+08	1,22E+08
755	675	566	497	431	343	287	259	193	176	171	127
1,22E+07	1,06E+07	1,06E+07	9,61E+06	7,66E+06	8,23E+06	6,93E+06	6,31E+06	5,27E+06	5,53E+06	4,47E+06	4,20E+06
1,38E+08	1,29E+08	1,37E+08	1,32E+08	1,12E+08	1,27E+08	1,13E+08	1,08E+08	9,45E+07	1,04E+08	8,76E+07	8,58E+07
854	642	560	449	318	306	232	191	145	139	103	89
1,01E+07	1,09E+07	1,01E+07	8,05E+06	8,74E+06	6,86E+06	7,35E+06	6,44E+06	5,30E+06	6,09E+06	4,82E+06	5,00E+06
1,14E+08	1,32E+08	1,30E+08	1,11E+08	1,28E+08	1,06E+08	1,20E+08	1,10E+08	9,51E+07	1,14E+08	9,44E+07	1,02E+08
704	657	533	376	363	255	246	195	146	153	111	106
1,34E+07	1,38E+07	1,36E+07	1,41E+07	1,33E+07	1,07E+07	1,08E+07	9,87E+06	9,37E+06	7,76E+06	6,86E+06	7,17E+06
1,51E+08	1,68E+08	1,76E+08	1,94E+08	1,94E+08	1,65E+08	1,76E+08	1,69E+08	1,68E+08	1,46E+08	1,34E+08	1,47E+08
933	837	719	659	552	397	361	299	258	195	158	152
1,20E+07	1,13E+07	1,07E+07	1,05E+07	9,10E+06	7,80E+06	9,35E+06	7,36E+06	7,56E+06	6,64E+06	5,51E+06	5,99E+06
1,36E+08	1,37E+08	1,39E+08	1,44E+08	1,33E+08	1,20E+08	1,52E+08	1,26E+08	1,36E+08	1,25E+08	1,08E+08	1,22E+08
839	686	567	489	378	290	313	223	208	167	127	127
1,14E+07	1,03E+07	8,86E+06	8,95E+06	7,44E+06	6,75E+06	5,86E+06	5,48E+06	5,99E+06	5,57E+06	4,77E+06	3,02E+06
1,28E+08	1,24E+08	1,15E+08	1,23E+08	1,09E+08	1,04E+08	9,53E+07	9,38E+07	1,08E+08	1,05E+08	9,36E+07	6,17E+07
792	620	469	418	309	251	196	166	165	140	110	64
1,58E+07	1,64E+07	1,67E+07	1,80E+07	1,69E+07	1,68E+07	1,70E+07	1,42E+07	1,42E+07	1,24E+07	1,19E+07	9,90E+06
1,75E+08	1,96E+08	2,13E+08	2,43E+08	2,42E+08	2,54E+08	2,70E+08	2,39E+08	2,48E+08	2,28E+08	2,29E+08	1,98E+08
1131	1026	915	871	729	649	591	450	407	327	288	220
1,62E+07	1,67E+07	1,61E+07	1,47E+07	1,49E+07	1,26E+07	1,14E+07	8,74E+06	9,70E+06	8,67E+06	7,25E+06	6,07E+06
1,80E+08	1,99E+08	2,05E+08	1,99E+08	2,13E+08	1,91E+08	1,82E+08	1,46E+08	1,70E+08	1,59E+08	1,39E+08	1,21E+08
1161	1042	880	712	642	487	397	276	279	228	175	135
1,65E+07	1,47E+07	1,40E+07	1,32E+07	1,25E+07	1,00E+07	9,32E+06	8,07E+06	8,83E+06	8,06E+06	6,84E+06	6,84E+06
1,83E+08	1,75E+08	1,79E+08	1,79E+08	1,79E+08	1,52E+08	1,49E+08	1,35E+08	1,55E+08	1,48E+08	1,31E+08	1,37E+08
1182	915	768	639	540	388	325	255	254	212	165	152
65	70	75	80	85	90	95	100	105	110	115	120
6	7	8	9	10	11	12	13	14	15	16	17

5,11E+06	4,52E+06	5,17E+06	4,79E+06	4,72E+06	4,38E+06	3,98E+06	3,24E+06	2,73E+06	3,09E+06	2,28E+06	1,57E+06
1,09E+08	1,00E+08	1,19E+08	1,14E+08	1,16E+08	1,12E+08	1,04E+08	8,77E+07	7,63E+07	8,88E+07	6,74E+07	4,78E+07
100	82	87	75	69	60	51	39	31	33	23	15
4,50E+06	3,53E+06	3,15E+06	3,51E+06	3,14E+06	3,14E+06	2,10E+06	1,74E+06	1,85E+06	1,59E+06	2,77E+06	1,78E+06
9,56E+07	7,80E+07	7,22E+07	8,34E+07	7,74E+07	7,99E+07	5,53E+07	4,72E+07	5,17E+07	4,57E+07	8,20E+07	5,41E+07
88	64	53	55	46	43	27	21	21	17	28	17
4,55E+06	3,81E+06	3,51E+06	3,51E+06	3,21E+06	3,36E+06	2,34E+06	1,66E+06	2,03E+06	1,87E+06	2,28E+06	2,09E+06
9,67E+07	8,41E+07	8,04E+07	8,34E+07	7,90E+07	8,55E+07	6,14E+07	4,50E+07	5,66E+07	5,38E+07	6,74E+07	6,37E+07
89	69	59	55	47	46	30	20	23	20	23	20
5,88E+06	4,63E+06	5,23E+06	3,64E+06	2,32E+06	2,92E+06	2,96E+06	1,83E+06	1,85E+06	2,06E+06	1,58E+06	1,67E+06
1,25E+08	1,02E+08	1,20E+08	8,64E+07	5,72E+07	7,43E+07	7,78E+07	4,95E+07	5,17E+07	5,92E+07	4,69E+07	5,10E+07
115	84	88	57	34	40	38	22	21	22	16	16
5,36E+06	4,80E+06	4,75E+06	4,40E+06	3,56E+06	3,87E+06	3,04E+06	2,99E+06	2,38E+06	1,96E+06	2,47E+06	1,99E+06
1,14E+08	1,06E+08	1,09E+08	1,05E+08	8,75E+07	9,85E+07	7,98E+07	8,09E+07	6,65E+07	5,65E+07	7,33E+07	6,05E+07
105	87	80	69	52	53	39	36	27	21	25	19
3,12E+06	4,03E+06	3,21E+06	2,81E+06	2,94E+06	1,61E+06	1,56E+06	1,08E+06	1,50E+06	1,50E+06	1,58E+06	1,15E+06
6,63E+07	8,90E+07	7,36E+07	6,67E+07	7,23E+07	4,09E+07	4,09E+07	2,92E+07	4,19E+07	4,30E+07	4,69E+07	3,50E+07
61	73	54	44	43	22	20	13	17	16	16	11
1,14E+07	8,72E+06	8,93E+06	7,16E+06	6,56E+06	6,25E+06	5,25E+06	6,61E+06	3,85E+06	4,52E+06	2,72E+06	4,06E+06
2,37E+08	1,88E+08	2,00E+08	1,66E+08	1,57E+08	1,55E+08	1,34E+08	1,75E+08	1,05E+08	1,27E+08	7,83E+07	1,20E+08
234	166	158	118	101	90	71	84	46	51	29	41
6,62E+06	5,20E+06	4,30E+06	4,67E+06	5,00E+06	3,89E+06	3,48E+06	3,86E+06	3,68E+06	2,92E+06	3,19E+06	3,07E+06
1,38E+08	1,12E+08	9,61E+07	1,08E+08	1,20E+08	9,63E+07	8,90E+07	1,02E+08	1,00E+08	8,19E+07	9,18E+07	9,10E+07
136	99	76	77	77	56	47	49	44	33	34	31
7,45E+06	5,73E+06	5,09E+06	4,55E+06	3,96E+06	4,37E+06	3,77E+06	2,91E+06	3,26E+06	2,92E+06	2,91E+06	2,28E+06
1,55E+08	1,24E+08	1,14E+08	1,06E+08	9,50E+07	1,08E+08	9,66E+07	7,69E+07	8,87E+07	8,19E+07	8,37E+07	6,75E+07
153	109	90	75	61	63	51	37	39	33	31	23
125	130	135	140	145	150	155	160	165	170	175	180
18	19	20	21	22	23	24	25	26	27	28	29

2,32E+06	1,75E+06	2,21E+06	9,02E+05	1,49E+06	1,42E+06	4,46E+05	4,67E+05	1,30E+06	5,10E+05	7,09E+05	1,11E+06
7,25E+07	5,61E+07	7,26E+07	3,05E+07	5,15E+07	5,03E+07	1,62E+07	1,73E+07	4,93E+07	1,98E+07	2,81E+07	4,48E+07
21	15	18	7	11	10	3	3	8	3	4	6
1,33E+06	1,28E+06	1,59E+06	7,73E+05	8,12E+05	1,14E+06	2,97E+05	1,24E+06	6,50E+05	6,79E+05	5,32E+05	3,70E+05
4,14E+07	4,11E+07	5,25E+07	2,61E+07	2,81E+07	4,02E+07	1,08E+07	4,62E+07	2,47E+07	2,63E+07	2,11E+07	1,49E+07
12	11	13	6	6	8	2	8	4	4	3	2
2,87E+06	1,28E+06	1,47E+06	1,67E+06	1,35E+06	4,26E+05	2,97E+05	9,33E+05	4,88E+05	1,02E+06	7,09E+05	7,39E+05
8,98E+07	4,11E+07	4,84E+07	5,66E+07	4,68E+07	1,51E+07	1,08E+07	3,46E+07	1,85E+07	3,95E+07	2,81E+07	2,99E+07
26	11	12	13	10	3	2	6	3	6	4	4
1,10E+06	1,40E+06	1,35E+06	9,02E+05	2,71E+05	2,84E+05	4,46E+05	6,22E+05	3,25E+05	5,10E+05	0,00E+00	0,00E+00
3,45E+07	4,48E+07	4,44E+07	3,05E+07	9,36E+06	1,01E+07	1,62E+07	2,31E+07	1,23E+07	1,98E+07	0,00E+00	0,00E+00
10	12	11	7	2	2	3	4	2	3	0	0
1,44E+06	1,63E+06	7,35E+05	1,29E+06	1,22E+06	2,84E+05	7,43E+05	7,78E+05	9,76E+05	8,49E+05	0,00E+00	7,39E+05
4,49E+07	5,23E+07	2,42E+07	4,35E+07	4,21E+07	1,01E+07	2,70E+07	2,89E+07	3,70E+07	3,29E+07	0,00E+00	2,99E+07
13	14	6	10	9	2	5	5	6	5	0	4
1,10E+06	1,40E+06	1,10E+06	2,58E+05	1,35E+05	8,51E+05	5,95E+05	3,11E+05	1,63E+05	0,00E+00	3,54E+05	1,85E+05
3,45E+07	4,48E+07	3,63E+07	8,70E+06	4,68E+06	3,02E+07	2,16E+07	1,15E+07	6,17E+06	0,00E+00	1,40E+07	7,47E+06
10	12	9	2	1	6	4	2	1	0	2	1
2,20E+06	3,30E+06	1,97E+06	3,17E+06	2,05E+06	2,14E+06	2,67E+06	1,32E+06	1,69E+06	8,01E+05	1,34E+06	5,23E+05
6,68E+07	1,03E+08	6,31E+07	1,04E+08	6,88E+07	7,39E+07	9,40E+07	4,76E+07	6,22E+07	3,02E+07	5,14E+07	2,05E+07
21	30	17	26	16	16	19	9	11	5	8	3
2,61E+06	1,54E+06	2,09E+06	1,58E+06	1,41E+06	1,74E+06	1,26E+06	2,06E+06	1,07E+06	1,44E+06	1,34E+06	1,39E+06
7,95E+07	4,81E+07	6,68E+07	5,20E+07	4,73E+07	6,00E+07	4,45E+07	7,41E+07	3,96E+07	5,43E+07	5,14E+07	5,47E+07
25	14	18	13	11	13	9	14	7	9	8	8
1,88E+06	2,20E+06	1,51E+06	1,58E+06	1,28E+06	1,61E+06	1,83E+06	1,17E+06	1,23E+06	9,62E+05	1,67E+06	6,97E+05
5,72E+07	6,88E+07	4,83E+07	5,20E+07	4,30E+07	5,54E+07	6,43E+07	4,24E+07	4,53E+07	3,62E+07	6,43E+07	2,74E+07
18	20	13	13	10	12	13	8	8	6	10	4
185	190	195	200	205	210	215	220	225	230	235	240
30	31	32	33	34	35	36	37	38	39	40	41

3,85E+05	2,00E+05	2,08E+05	2,16E+05	8,99E+05	0,00E+00	0,00E+00	2,51E+05	2,60E+05	0,00E+00	0,00E+00	0,00E+00
1,59E+07	8,43E+06	8,94E+06	9,47E+06	4,01E+07	0,00E+00	0,00E+00	1,18E+07	1,25E+07	0,00E+00	0,00E+00	0,00E+00
2	1	1	1	4	0	0	1	1	0	0	0
1,92E+05	4,01E+05	0,00E+00	2,16E+05	8,99E+05	4,67E+05	0,00E+00	5,01E+05	0,00E+00	0,00E+00	5,56E+05	2,87E+05
7,94E+06	1,69E+07	0,00E+00	9,47E+06	4,01E+07	2,12E+07	0,00E+00	2,36E+07	0,00E+00	0,00E+00	2,76E+07	1,45E+07
1	2	0	1	4	2	0	2	0	0	2	1
7,70E+05	2,00E+05	4,17E+05	4,33E+05	2,25E+05	2,33E+05	2,42E+05	2,51E+05	0,00E+00	2,69E+05	0,00E+00	2,87E+05
3,18E+07	8,43E+06	1,79E+07	1,90E+07	1,00E+07	1,06E+07	1,12E+07	1,18E+07	0,00E+00	1,31E+07	0,00E+00	1,45E+07
4	1	2	2	1	1	1	1	0	1	0	1
1,92E+05	2,00E+05	2,08E+05	0,00E+00	0,00E+00	2,33E+05	2,42E+05	0,00E+00	0,00E+00	0,00E+00	5,56E+05	0,00E+00
7,94E+06	8,43E+06	8,94E+06	0,00E+00	0,00E+00	1,06E+07	1,12E+07	0,00E+00	0,00E+00	0,00E+00	2,76E+07	0,00E+00
1	1	1	0	0	1	1	0	0	0	2	0
1,92E+05	4,01E+05	4,17E+05	2,16E+05	0,00E+00	2,33E+05	2,42E+05	0,00E+00	0,00E+00	0,00E+00	2,78E+05	0,00E+00
7,94E+06	1,69E+07	1,79E+07	9,47E+06	0,00E+00	1,06E+07	1,12E+07	0,00E+00	0,00E+00	0,00E+00	1,38E+07	0,00E+00
1	2	2	1	0	1	1	0	0	0	1	0
3,85E+05	2,00E+05	0,00E+00	2,16E+05	0,00E+00	2,33E+05	0,00E+00	2,51E+05	0,00E+00	0,00E+00	5,56E+05	2,87E+05
1,59E+07	8,43E+06	0,00E+00	9,47E+06	0,00E+00	1,06E+07	0,00E+00	1,18E+07	0,00E+00	0,00E+00	2,76E+07	1,45E+07
2	1	0	1	0	1	0	1	0	0	2	1
9,07E+05	3,78E+05	1,96E+05	2,04E+05	6,35E+05	8,79E+05	9,11E+05	2,36E+05	4,89E+05	2,53E+05	5,23E+05	8,12E+05
3,64E+07	1,54E+07	8,18E+06	8,67E+06	2,75E+07	3,88E+07	4,09E+07	1,08E+07	2,27E+07	1,20E+07	2,52E+07	3,97E+07
5	2	1	1	3	4	4	1	2	1	2	3
1,09E+06	5,67E+05	1,96E+05	4,08E+05	1,48E+06	8,79E+05	4,56E+05	2,36E+05	4,89E+05	1,01E+06	5,23E+05	2,71E+05
4,36E+07	2,32E+07	8,18E+06	1,73E+07	6,42E+07	3,88E+07	2,05E+07	1,08E+07	2,27E+07	4,79E+07	2,52E+07	1,32E+07
6	3	1	2	7	4	2	1	2	4	2	1
5,44E+05	5,67E+05	1,37E+06	2,04E+05	8,47E+05	4,40E+05	9,11E+05	4,72E+05	2,45E+05	0,00E+00	5,23E+05	2,71E+05
2,18E+07	2,32E+07	5,73E+07	8,67E+06	3,67E+07	1,94E+07	4,09E+07	2,16E+07	1,14E+07	0,00E+00	2,52E+07	1,32E+07
3	3	7	1	4	2	4	2	1	0	2	1
245	250	255	260	265	270	275	280	285	290	295	300
42	43	44	45	46	47	48	49	50	51	52	53

0,00E+00	0,00E+00	3,17E+05	9,80E+05	3,37E+05	3,47E+05	0,00E+00	0,00E+00	3,79E+05	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	1,68E+07	5,27E+07	1,84E+07	1,93E+07	0,00E+00	0,00E+00	2,20E+07	0,00E+00	0,00E+00	0,00E+00
0	0	1	3	1	1	0	0	1	0	0	0
0,00E+00	0,00E+00	3,17E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	1,68E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	0	0	0	0	0	0	0	0	0
2,97E+05	0,00E+00	0,00E+00	3,27E+05	0,00E+00	0,00E+00	3,58E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1,52E+07	0,00E+00	0,00E+00	1,76E+07	0,00E+00	0,00E+00	2,01E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	1	0	0	1	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,79E+05	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,20E+07	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	1	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	3,17E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	1,68E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	0	0	0	0	0	0	0	0	0
5,59E+05	0,00E+00	8,94E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,57E+05	0,00E+00	0,00E+00	0,00E+00
2,78E+07	0,00E+00	4,59E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,00E+07	0,00E+00	0,00E+00	0,00E+00
2	0	3	0	0	0	0	0	1	0	0	0
0,00E+00	0,00E+00	8,94E+05	6,15E+05	3,17E+05	0,00E+00	6,73E+05	0,00E+00	3,57E+05	0,00E+00	3,77E+05	0,00E+00
0,00E+00	0,00E+00	4,59E+07	3,20E+07	1,68E+07	0,00E+00	3,67E+07	0,00E+00	2,00E+07	0,00E+00	2,18E+07	0,00E+00
0	0	3	2	1	0	2	0	1	0	1	0
2,80E+05	2,89E+05	2,98E+05	6,15E+05	6,34E+05	3,27E+05	0,00E+00	3,46E+05	0,00E+00	0,00E+00	1,13E+06	3,88E+05
1,39E+07	1,46E+07	1,53E+07	3,20E+07	3,36E+07	1,76E+07	0,00E+00	1,92E+07	0,00E+00	0,00E+00	6,54E+07	2,27E+07
1	1	1	2	2	1	0	1	0	0	3	1
305	310	315	320	325	330	335	340	345	350	355	360
54	55	56	57	58	59	60	61	62	63	64	65

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,93E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,58E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	2	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	4,60E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	2,93E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	1	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,72E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,05E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	1	0	0	0	0	0	0	0
0,00E+00	0,00E+00	4,48E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	2,82E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	0	0	0	0	0	0	0	0	0
3,99E+05	4,10E+05	0,00E+00	4,32E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2,37E+07	2,46E+07	0,00E+00	2,67E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	1	0	1	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,78E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,11E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	1	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,78E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,11E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	1	0	0	0	0
365	370	375	380	385	390	395	400	405	410	415	420
66	67	68	69	70	71	72	73	74	75	76	77

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	5,64E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	3,99E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	0	0	0	0	0	0	0	0	0
5,39E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,30E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
3,72E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,71E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	0	0	0	0	1	0	0	0	0
425	430	435	440	445	450	455	460	465	470	475	480
78	79	80	81	82	83	84	85	86	87	88	89

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,51E+05	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,38E+07	0,00E+00
0	0	0	0	0	0	0	0	0	0	1	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	7,15E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	5,68E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	0	0	0	0	0	0	0	0	0
485	490	495	500	505	510	515	520	525	530	535	540
90	91	92	93	94	95	96	97	98	99	100	101

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	
0	0	0	0	0	0	0	0	0	0	0	
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,99E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,38E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	1	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
545	550	555	560	565	570	575	580	585	590	595	600
102	103	104	105	106	107	108	109	110	111	112	113

0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00
0	0	0
0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00
0	0	0
0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00
0	0	0
605	610	615
114	115	116

Appendix C

Fraction 3: Smaller than 100 µm

Multisizer 4	11.05.15 13:33
Control mode:	Volumetric, 2000 uL
Acquired:	11.05.15 13:30
Size bins:	114
From	4
To	120

	Number					
			1	2	3	4
		and up)	4	5	6	7
Sample 1	**Run 1**	Number		24562	10101	5174	2854
		Volume	um^3	1,22E+06	9,15E+05	7,73E+05	6,55E+05
		Area	um^2	1,59E+06	9,77E+05	7,00E+05	5,15E+05
	Run 2	Number		24470	10376	5096	2987
		Volume	um^3	1,22E+06	9,40E+05	7,61E+05	6,85E+05
		Area	um^2	1,58E+06	1,00E+06	6,90E+05	5,39E+05
	Run 3	Number		23067	10201	5111	2798
		Volume	um^3	1,15E+06	9,24E+05	7,64E+05	6,42E+05
		Area	um^2	1,49E+06	9,87E+05	6,92E+05	5,05E+05
Sample 2	**Run 1**	Number		8661	3864	2083	1125
		Volume	um^3	4,29E+05	3,45E+05	3,05E+05	2,52E+05
		Area	um^2	5,58E+05	3,70E+05	2,78E+05	2,00E+05
	Run 2	Number		8511	3852	1961	1142
		Volume	um^3	4,21E+05	3,44E+05	2,87E+05	2,56E+05
		Area	um^2	5,48E+05	3,69E+05	2,62E+05	2,03E+05
	Run 3	Number		8509	3709	1991	1062
		Volume	um^3	4,21E+05	3,31E+05	2,91E+05	2,38E+05
		Area	um^2	5,48E+05	3,55E+05	2,66E+05	1,89E+05
Sample 3	**Run 1**	Number		11224	4875	2634	1462
		Volume	um^3	5,55E+05	4,35E+05	3,85E+05	3,27E+05
		Area	um^2	7,23E+05	4,67E+05	3,52E+05	2,60E+05
	Run 2	Number		15539	5621	2618	1423
		Volume	um^3	7,69E+05	5,02E+05	3,83E+05	3,19E+05
		Area	um^2	1,00E+06	5,39E+05	3,50E+05	2,53E+05
	Run 3	Number		11088	4970	2542	1450
		Volume	um^3	5,49E+05	4,44E+05	3,72E+05	3,25E+05
		Area	um^2	7,14E+05	4,76E+05	3,39E+05	2,57E+05

2,02E+05	1,58E+05	1,23E+05	1,06E+05	8,06E+04	8,37E+04	7,61E+04	4,76E+04	4,97E+04	3,76E+04	4,30E+04	4,06E+04
2,88E+05	2,51E+05	2,17E+05	2,03E+05	1,69E+05	1,89E+05	1,84E+05	1,23E+05	1,37E+05	1,10E+05	1,33E+05	1,32E+05
887	554	355	254	164	146	115	63	58	39	40	34
2,07E+05	1,58E+05	1,20E+05	1,21E+05	1,03E+05	8,60E+04	6,55E+04	5,59E+04	4,37E+04	4,62E+04	3,12E+04	2,87E+04
2,95E+05	2,51E+05	2,11E+05	2,32E+05	2,16E+05	1,94E+05	1,59E+05	1,45E+05	1,20E+05	1,35E+05	9,64E+04	9,34E+04
909	554	346	290	210	150	99	74	51	48	29	24
2,05E+05	1,65E+05	1,23E+05	9,78E+04	9,69E+04	8,66E+04	6,94E+04	5,82E+04	5,22E+04	5,58E+04	2,58E+04	3,71E+04
2,92E+05	2,63E+05	2,16E+05	1,88E+05	2,02E+05	1,95E+05	1,68E+05	1,51E+05	1,44E+05	1,63E+05	7,97E+04	1,21E+05
900	580	354	235	197	151	105	77	61	58	24	31
1,57E+05	1,25E+05	9,55E+04	8,53E+04	8,41E+04	5,96E+04	5,49E+04	5,74E+04	3,42E+04	4,24E+04	3,98E+04	2,27E+04
2,24E+05	1,99E+05	1,68E+05	1,64E+05	1,76E+05	1,35E+05	1,33E+05	1,49E+05	9,43E+04	1,24E+05	1,23E+05	7,39E+04
688	440	275	205	171	104	83	76	40	44	37	19
1,63E+05	1,26E+05	9,34E+04	7,91E+04	6,34E+04	6,82E+04	5,09E+04	4,61E+04	4,02E+04	3,95E+04	3,44E+04	2,39E+04
2,33E+05	2,01E+05	1,64E+05	1,52E+05	1,33E+05	1,54E+05	1,23E+05	1,19E+05	1,11E+05	1,15E+05	1,06E+05	7,78E+04
716	444	269	190	129	119	77	61	47	41	32	20
1,57E+05	1,30E+05	1,13E+05	8,53E+04	7,47E+04	6,19E+04	5,56E+04	5,36E+04	3,51E+04	3,37E+04	3,55E+04	3,35E+04
2,24E+05	2,07E+05	1,98E+05	1,64E+05	1,56E+05	1,40E+05	1,35E+05	1,39E+05	9,67E+04	9,85E+04	1,10E+05	1,09E+05
690	457	325	205	152	108	84	71	41	35	33	28
4,02E+05	3,30E+05	2,70E+05	2,35E+05	2,10E+05	1,77E+05	1,46E+05	1,40E+05	1,27E+05	9,79E+04	1,08E+05	9,34E+04
5,78E+05	5,30E+05	4,80E+05	4,57E+05	4,44E+05	4,05E+05	3,59E+05	3,66E+05	3,53E+05	2,90E+05	3,39E+05	3,08E+05
1731	1136	761	551	417	302	216	180	144	99	98	76
3,98E+05	3,18E+05	2,79E+05	2,50E+05	1,90E+05	1,67E+05	1,61E+05	1,52E+05	1,22E+05	1,29E+05	6,97E+04	1,19E+05
5,74E+05	5,11E+05	4,96E+05	4,86E+05	4,01E+05	3,83E+05	3,94E+05	3,99E+05	3,41E+05	3,81E+05	2,18E+05	3,93E+05
1717	1096	786	587	377	285	237	196	139	130	63	97
4,23E+05	3,36E+05	2,65E+05	2,45E+05	2,02E+05	1,75E+05	1,75E+05	1,43E+05	1,13E+05	1,29E+05	1,15E+05	8,60E+04
6,08E+05	5,40E+05	4,71E+05	4,77E+05	4,28E+05	3,99E+05	4,29E+05	3,74E+05	3,14E+05	3,81E+05	3,60E+05	2,84E+05
1821	1158	747	576	402	297	258	184	128	130	104	70
8	9	10	11	12	13	14	15	16	17	18	19
5	6	7	8	9	10	11	12	13	14	15	16

3,83E+04	3,20E+04	2,71E+04	3,65E+04	2,26E+04	3,07E+04	1,99E+04	1,43E+04	1,53E+04	8,20E+03	1,17E+04	3,12E+03
1,31E+05	1,15E+05	1,02E+05	1,43E+05	9,25E+04	1,30E+05	8,78E+04	6,54E+04	7,28E+04	4,04E+04	5,95E+04	1,64E+04
29	22	17	21	12	15	9	6	6	3	4	1
2,51E+04	2,32E+04	1,43E+04	2,60E+04	2,26E+04	2,66E+04	8,83E+03	1,43E+04	1,79E+04	1,37E+04	1,75E+04	1,25E+04
8,59E+04	8,34E+04	5,38E+04	1,02E+05	9,25E+04	1,13E+05	3,90E+04	6,54E+04	8,49E+04	6,73E+04	8,92E+04	6,55E+04
19	16	9	15	12	13	4	6	7	5	6	4
3,17E+04	3,05E+04	2,55E+04	2,78E+04	2,64E+04	1,63E+04	2,43E+04	2,14E+04	2,30E+04	1,91E+04	2,05E+04	1,87E+04
1,08E+05	1,09E+05	9,56E+04	1,09E+05	1,08E+05	6,95E+04	1,07E+05	9,81E+04	1,09E+05	9,42E+04	1,04E+05	9,83E+04
24	21	16	16	14	8	11	9	9	7	7	6
2,64E+04	2,62E+04	2,23E+04	2,08E+04	1,70E+04	1,23E+04	3,31E+04	1,43E+04	1,28E+04	1,64E+04	2,05E+04	1,56E+04
9,04E+04	9,38E+04	8,36E+04	8,17E+04	6,94E+04	5,22E+04	1,46E+05	6,54E+04	6,07E+04	8,07E+04	1,04E+05	8,19E+04
20	18	14	12	9	6	15	6	5	6	7	5
2,77E+04	2,47E+04	1,91E+04	2,08E+04	3,02E+04	2,45E+04	1,32E+04	2,14E+04	1,79E+04	1,64E+04	2,05E+04	1,87E+04
9,49E+04	8,86E+04	7,17E+04	8,17E+04	1,23E+05	1,04E+05	5,85E+04	9,81E+04	8,49E+04	8,07E+04	1,04E+05	9,83E+04
21	17	12	12	16	12	6	9	7	6	7	6
3,04E+04	3,34E+04	2,39E+04	2,08E+04	2,45E+04	2,25E+04	1,99E+04	2,14E+04	1,53E+04	1,09E+04	1,17E+04	1,56E+04
1,04E+05	1,20E+05	8,96E+04	8,17E+04	1,00E+05	9,56E+04	8,78E+04	9,81E+04	7,28E+04	5,38E+04	5,95E+04	8,19E+04
23	23	15	12	13	11	9	9	6	4	4	5
8,56E+04	9,42E+04	7,37E+04	7,50E+04	8,93E+04	7,16E+04	8,64E+04	7,59E+04	5,00E+04	4,79E+04	4,82E+04	1,93E+04
2,97E+05	3,43E+05	2,81E+05	2,98E+05	3,70E+05	3,09E+05	3,87E+05	3,53E+05	2,41E+05	2,39E+05	2,49E+05	1,03E+05
63	63	45	42	46	34	38	31	19	17	16	6
9,78E+04	6,43E+04	9,01E+04	6,25E+04	6,80E+04	5,05E+04	5,00E+04	3,92E+04	3,16E+04	4,51E+04	4,22E+04	1,93E+04
3,39E+05	2,34E+05	3,43E+05	2,49E+05	2,82E+05	2,18E+05	2,24E+05	1,82E+05	1,52E+05	2,25E+05	2,18E+05	1,03E+05
72	43	55	35	35	24	22	16	12	16	14	6
9,65E+04	7,77E+04	8,02E+04	1,00E+05	6,99E+04	5,26E+04	5,46E+04	5,63E+04	5,79E+04	7,05E+04	2,41E+04	3,86E+04
3,35E+05	2,83E+05	3,06E+05	3,98E+05	2,90E+05	2,27E+05	2,45E+05	2,62E+05	2,79E+05	3,52E+05	1,24E+05	2,06E+05
71	52	49	56	36	25	24	23	22	25	8	12
20	21	22	23	24	25	26	27	28	29	30	31
17	18	19	20	21	22	23	24	25	26	27	28

2,32E+04	1,06E+04	3,74E+03	7,92E+03	2,09E+04	8,84E+03	1,40E+04	9,81E+03	2,58E+04	1,62E+04	2,27E+04	5,95E+03
1,26E+05	5,91E+04	2,15E+04	4,69E+04	1,27E+05	5,53E+04	8,97E+04	6,46E+04	1,74E+05	1,12E+05	1,61E+05	4,31E+04
7	3	1	2	5	2	3	2	5	3	4	1
6,64E+03	1,06E+04	1,12E+04	7,92E+03	8,37E+03	8,84E+03	9,32E+03	4,90E+03	2,06E+04	1,62E+04	1,14E+04	1,19E+04
3,60E+04	5,91E+04	6,45E+04	4,69E+04	5,10E+04	5,53E+04	5,98E+04	3,23E+04	1,39E+05	1,12E+05	8,04E+04	8,62E+04
2	3	3	2	2	2	2	1	4	3	2	2
1,33E+04	7,05E+03	1,12E+04	3,96E+03	8,37E+03	1,33E+04	4,66E+03	4,90E+03	2,06E+04	5,41E+03	5,68E+03	1,19E+04
7,19E+04	3,94E+04	6,45E+04	2,34E+04	5,10E+04	8,29E+04	2,99E+04	3,23E+04	1,39E+05	3,74E+04	4,02E+04	8,62E+04
4	2	3	1	2	3	1	1	4	1	1	2
1,66E+04	7,05E+03	1,12E+04	1,98E+04	1,26E+04	8,84E+03	1,40E+04	4,90E+03	1,55E+04	0,00E+00	5,68E+03	0,00E+00
8,99E+04	3,94E+04	6,45E+04	1,17E+05	7,64E+04	5,53E+04	8,97E+04	3,23E+04	1,04E+05	0,00E+00	4,02E+04	0,00E+00
5	2	3	5	3	2	3	1	3	0	1	0
6,64E+03	1,41E+04	1,12E+04	0,00E+00	1,67E+04	2,65E+04	0,00E+00	4,90E+03	5,15E+03	0,00E+00	1,70E+04	1,19E+04
3,60E+04	7,88E+04	6,45E+04	0,00E+00	1,02E+05	1,66E+05	0,00E+00	3,23E+04	3,48E+04	0,00E+00	1,21E+05	8,62E+04
2	4	3	0	4	6	0	1	1	0	3	2
1,33E+04	7,05E+03	2,24E+04	1,19E+04	8,37E+03	8,84E+03	9,32E+03	4,90E+03	1,03E+04	5,41E+03	5,68E+03	5,95E+03
7,19E+04	3,94E+04	1,29E+05	7,03E+04	5,10E+04	5,53E+04	5,98E+04	3,23E+04	6,96E+04	3,74E+04	4,02E+04	4,31E+04
4	2	6	3	2	2	2	1	2	1	1	1
3,08E+04	4,73E+04	3,09E+04	3,27E+04	2,16E+04	2,28E+04	2,88E+04	4,05E+04	1,60E+04	1,68E+04	4,10E+04	2,45E+04
1,69E+05	2,68E+05	1,80E+05	1,96E+05	1,33E+05	1,45E+05	1,88E+05	2,71E+05	1,09E+05	1,18E+05	2,95E+05	1,81E+05
9	13	8	8	5	5	6	8	3	3	7	4
4,11E+04	6,18E+04	1,16E+04	4,90E+04	4,32E+04	4,56E+03	4,81E+04	4,05E+04	3,19E+04	1,12E+04	2,93E+04	1,84E+04
2,26E+05	3,51E+05	6,76E+04	2,95E+05	2,67E+05	2,89E+04	3,13E+05	2,71E+05	2,19E+05	7,85E+04	2,11E+05	1,36E+05
12	17	3	12	10	1	10	8	6	2	5	3
4,79E+04	4,73E+04	3,09E+04	2,86E+04	2,16E+04	2,28E+04	1,92E+04	4,05E+04	2,13E+04	2,79E+04	1,17E+04	1,84E+04
2,64E+05	2,68E+05	1,80E+05	1,72E+05	1,33E+05	1,45E+05	1,25E+05	2,71E+05	1,46E+05	1,96E+05	8,43E+04	1,36E+05
14	13	8	7	5	5	4	8	4	5	2	3
32	33	34	35	36	37	38	39	40	41	42	43
29	30	31	32	33	34	35	36	37	38	39	40

0,00E+00	0,00E+00	6,79E+03	2,13E+04	7,39E+03	0,00E+00	0,00E+00	8,33E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	5,27E+04	1,68E+05	5,98E+04	0,00E+00	0,00E+00	7,15E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	3	1	0	0	1	0	0	0	0
6,22E+03	1,30E+04	1,36E+04	7,09E+03	0,00E+00	0,00E+00	8,01E+03	0,00E+00	0,00E+00	0,00E+00	1,87E+04	9,68E+03
4,62E+04	9,87E+04	1,05E+05	5,61E+04	0,00E+00	0,00E+00	6,75E+04	0,00E+00	0,00E+00	0,00E+00	1,70E+05	8,95E+04
1	2	2	1	0	0	1	0	0	0	2	1
6,22E+03	6,51E+03	6,79E+03	7,09E+03	7,39E+03	7,70E+03	1,60E+04	8,33E+03	8,66E+03	8,99E+03	0,00E+00	0,00E+00
4,62E+04	4,93E+04	5,27E+04	5,61E+04	5,98E+04	6,35E+04	1,35E+05	7,15E+04	7,58E+04	8,02E+04	0,00E+00	0,00E+00
1	1	1	1	1	1	2	1	1	1	0	0
6,22E+03	6,51E+03	0,00E+00	7,09E+03	7,39E+03	0,00E+00	0,00E+00	8,33E+03	0,00E+00	0,00E+00	9,33E+03	0,00E+00
4,62E+04	4,93E+04	0,00E+00	5,61E+04	5,98E+04	0,00E+00	0,00E+00	7,15E+04	0,00E+00	0,00E+00	8,48E+04	0,00E+00
1	1	0	1	1	0	0	1	0	0	1	0
1,24E+04	0,00E+00	6,79E+03	0,00E+00	7,39E+03	0,00E+00	8,01E+03	0,00E+00	8,66E+03	0,00E+00	0,00E+00	0,00E+00
9,23E+04	0,00E+00	5,27E+04	0,00E+00	5,98E+04	0,00E+00	6,75E+04	0,00E+00	7,58E+04	0,00E+00	0,00E+00	0,00E+00
2	0	1	0	1	0	1	0	1	0	0	0
6,22E+03	1,30E+04	1,36E+04	2,13E+04	1,48E+04	0,00E+00	0,00E+00	2,50E+04	0,00E+00	1,80E+04	9,33E+03	1,94E+04
4,62E+04	9,87E+04	1,05E+05	1,68E+05	1,20E+05	0,00E+00	0,00E+00	2,15E+05	0,00E+00	1,60E+05	8,48E+04	1,79E+05
1	2	2	3	2	0	0	3	0	2	1	2
1,93E+04	1,34E+04	7,01E+03	2,93E+04	2,29E+04	1,59E+04	0,00E+00	6,02E+04	2,68E+04	1,86E+04	2,89E+04	4,00E+04
1,45E+05	1,03E+05	5,52E+04	2,36E+05	1,88E+05	1,33E+05	0,00E+00	5,25E+05	2,39E+05	1,68E+05	2,67E+05	3,76E+05
3	2	1	4	3	2	0	7	3	2	3	4
1,93E+04	4,03E+04	2,81E+04	2,20E+04	2,29E+04	2,38E+04	1,65E+04	1,72E+04	2,68E+04	1,86E+04	2,89E+04	1,00E+04
1,45E+05	3,10E+05	2,21E+05	1,77E+05	1,88E+05	2,00E+05	1,42E+05	1,50E+05	2,39E+05	1,68E+05	2,67E+05	9,40E+04
3	6	4	3	3	3	2	2	3	2	3	1
0,00E+00	0,00E+00	2,81E+04	0,00E+00	2,29E+04	7,95E+03	2,48E+04	1,72E+04	2,68E+04	0,00E+00	9,64E+03	2,00E+04
0,00E+00	0,00E+00	2,21E+05	0,00E+00	1,88E+05	6,66E+04	2,12E+05	1,50E+05	2,39E+05	0,00E+00	8,90E+04	1,88E+05
0	0	4	0	3	1	3	2	3	0	1	2
44	45	46	47	48	49	50	51	52	53	54	55
41	42	43	44	45	46	47	48	49	50	51	52

2,01E+04	0,00E+00	1,08E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,43E+04
1,89E+05	0,00E+00	1,05E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,61E+05
2	0	1	0	0	0	0	0	0	0	0	1
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,38E+04	1,23E+04	0,00E+00	1,31E+04	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,44E+05	1,28E+05	0,00E+00	1,41E+05	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	2	1	0	1	0	0	0
0,00E+00	1,04E+04	1,08E+04	0,00E+00	1,15E+04	3,56E+04	0,00E+00	1,27E+04	2,61E+04	0,00E+00	0,00E+00	0,00E+00
0,00E+00	9,96E+04	1,05E+05	0,00E+00	1,16E+05	3,65E+05	0,00E+00	1,34E+05	2,81E+05	0,00E+00	0,00E+00	0,00E+00
0	1	1	0	1	3	0	1	2	0	0	0
1,00E+04	1,04E+04	0,00E+00	0,00E+00	0,00E+00	1,19E+04	0,00E+00	0,00E+00	0,00E+00	1,35E+04	0,00E+00	0,00E+00
9,45E+04	9,96E+04	0,00E+00	0,00E+00	0,00E+00	1,22E+05	0,00E+00	0,00E+00	0,00E+00	1,47E+05	0,00E+00	0,00E+00
1	1	0	0	0	1	0	0	0	1	0	0
1,00E+04	1,04E+04	1,08E+04	0,00E+00	1,15E+04	1,19E+04	0,00E+00	1,27E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
9,45E+04	9,96E+04	1,05E+05	0,00E+00	1,16E+05	1,22E+05	0,00E+00	1,34E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	1	1	0	1	1	0	1	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	1,11E+04	0,00E+00	0,00E+00	2,45E+04	2,53E+04	0,00E+00	0,00E+00	0,00E+00	4,29E+04
0,00E+00	0,00E+00	0,00E+00	1,10E+05	0,00E+00	0,00E+00	2,56E+05	2,68E+05	0,00E+00	0,00E+00	0,00E+00	4,83E+05
0	0	0	1	0	0	2	2	0	0	0	3
1,04E+04	1,07E+04	0,00E+00	2,30E+04	2,38E+04	3,68E+04	2,54E+04	2,62E+04	2,70E+04	0,00E+00	0,00E+00	1,48E+04
9,92E+04	1,05E+05	0,00E+00	2,32E+05	2,44E+05	3,84E+05	2,69E+05	2,82E+05	2,95E+05	0,00E+00	0,00E+00	1,69E+05
1	1	0	2	2	3	2	2	2	0	0	1
1,04E+04	2,15E+04	1,11E+04	0,00E+00	4,75E+04	0,00E+00	1,27E+04	0,00E+00	4,05E+04	0,00E+00	1,44E+04	1,48E+04
9,92E+04	2,09E+05	1,10E+05	0,00E+00	4,87E+05	0,00E+00	1,34E+05	0,00E+00	4,43E+05	0,00E+00	1,62E+05	1,69E+05
1	2	1	0	4	0	1	0	3	0	1	1
3,11E+04	4,29E+04	2,22E+04	1,15E+04	2,38E+04	2,46E+04	1,27E+04	2,62E+04	1,35E+04	1,39E+04	0,00E+00	1,48E+04
2,97E+05	4,18E+05	2,20E+05	1,16E+05	2,44E+05	2,56E+05	1,34E+05	2,82E+05	1,48E+05	1,55E+05	0,00E+00	1,69E+05
3	4	2	1	2	2	1	2	1	1	0	1
56	57	58	59	60	61	62	63	64	65	66	67
53	54	55	56	57	58	59	60	61	62	63	64

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,70E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,08E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	1	0	0	0	0	0	0
0,00E+00	1,52E+04	0,00E+00	0,00E+00	3,30E+04	0,00E+00	0,00E+00	0,00E+00	1,84E+04	0,00E+00	1,94E+04	0,00E+00
0,00E+00	1,76E+05	0,00E+00	0,00E+00	3,99E+05	0,00E+00	0,00E+00	0,00E+00	2,34E+05	0,00E+00	2,53E+05	0,00E+00
0	1	0	0	2	0	0	0	1	0	1	0
0,00E+00	0,00E+00	1,56E+04	0,00E+00	1,65E+04	1,70E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	1,83E+05	0,00E+00	2,00E+05	2,08E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	1	0	1	1	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,30E+04	0,00E+00	0,00E+00	0,00E+00	3,68E+04	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,99E+05	0,00E+00	0,00E+00	0,00E+00	4,69E+05	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	2	0	0	0	2	0	0	0
0,00E+00	1,57E+04	1,61E+04	1,66E+04	0,00E+00	0,00E+00	1,80E+04	0,00E+00	0,00E+00	0,00E+00	2,00E+04	0,00E+00
0,00E+00	1,85E+05	1,93E+05	2,01E+05	0,00E+00	0,00E+00	2,27E+05	0,00E+00	0,00E+00	0,00E+00	2,66E+05	0,00E+00
0	1	1	1	0	0	1	0	0	0	1	0
0,00E+00	1,57E+04	3,23E+04	0,00E+00	0,00E+00	0,00E+00	1,80E+04	0,00E+00	0,00E+00	1,95E+04	2,00E+04	4,10E+04
0,00E+00	1,85E+05	3,86E+05	0,00E+00	0,00E+00	0,00E+00	2,27E+05	0,00E+00	0,00E+00	2,56E+05	2,66E+05	5,53E+05
0	1	2	0	0	0	1	0	0	1	1	2
0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,41E+04	0,00E+00	0,00E+00	1,85E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,19E+05	0,00E+00	0,00E+00	2,37E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	2	0	0	1	0	0	0	0
68	69	70	71	72	73	74	75	76	77	78	79
65	66	67	68	69	70	71	72	73	74	75	76

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	2,19E+04	0,00E+00	0,00E+00	2,35E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	3,05E+05	0,00E+00	0,00E+00	3,39E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	1	0	0	1	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,30E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,27E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	1	0	0	0	0	0	0
0,00E+00	2,09E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,35E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	2,83E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,39E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	0	0	0	1	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,46E+04	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,63E+05	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	1	0	0	0
0,00E+00	0,00E+00	0,00E+00	2,19E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,46E+04	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	3,05E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,63E+05	0,00E+00	0,00E+00	0,00E+00
0	0	0	1	0	0	0	0	1	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,49E+04	2,54E+04	0,00E+00	2,66E+04	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,69E+05	3,82E+05	0,00E+00	4,08E+05	0,00E+00
0	0	0	0	0	0	0	1	1	0	1	0
0,00E+00	0,00E+00	2,21E+04	4,53E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,72E+04
0,00E+00	0,00E+00	3,09E+05	6,41E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,22E+05
0	0	1	2	0	0	0	0	0	0	0	1
80	81	82	83	84	85	86	87	88	89	90	91
77	78	79	80	81	82	83	84	85	86	87	88

0,00E+00	2,75E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	4,28E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	1	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,93E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,71E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	1	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,11E+04	0,00E+00	0,00E+00	3,30E+04	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,16E+05	0,00E+00	0,00E+00	5,64E+05	0,00E+00
0	0	0	0	0	0	0	1	0	0	1	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
2,69E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
4,14E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	0	0	0	0	0	0	0	0	0
2,78E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
4,36E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
92	93	94	95	96	97	98	99	100	101	102	103
89	90	91	92	93	94	95	96	97	98	99	100

0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,77E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,87E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	1	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,70E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,69E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	1	0	0	0	0	0	0	0
3,43E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,05E+04	0,00E+00	0,00E+00
5,98E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,66E+05	0,00E+00	0,00E+00
1	0	0	0	0	0	0	0	0	1	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,91E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,26E+05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	1	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0	0	0	0	0	0	0	0	0
104	105	106	107	108	109	110	111	112	113	114	115
101	102	103	104	105	106	107	108	109	110	111	112

0,00E+00	0,00E+00	0,00E+00	4,49E+04
0,00E+00	0,00E+00	0,00E+00	8,94E+05
0	0	0	1
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0,00E+00	0,00E+00	0,00E+00	0,00E+00
0	0	0	0
116	117	118	119
113	114	115	116