DISPERSION MODELING, RESOURCE MAPPING AND ENVIRONMENTAL ASSESSMENT

Johan Sverdrup

Statoil Petroleum AS

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ABBREVATIONS

CTS:	Cuttings Transport System
DREAM:	Dose Related Risk and Effects Assessment Model
EBSA:	Ecological and Biological Significant Areas
EIF:	Environmental Impact Factor
HC:	Hydrocarbons
IMR:	Institute of Marine Research
MOD:	Environmental Monitoring Database (Miljøovervåking Database)
NCS:	Norwegian Continental Shelf
OBM:	Oil Based Mud
OSPAR:	Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo and Paris Convention)
PEC:	Predicted Environmental Concentration
PNEC:	Predicted No Effect Concentration
SSD:	Species Sensitive Distribution
TCC:	Thermo mechanical Cuttings Cleaner Technology
WAF:	Water Accommodated Fraction
WBM:	Water Based Mud

EXECUTIVE SUMMARY

DNV GL and SINTEF have on behalf of Statoil ASA performed the following tasks related to the planned development of the Johan Sverdrup field:

- EIF (Environmental Impact Factor) modelling of produced water discharges.
- Dispersion and sedimentation modelling of drill cuttings and fluid from drilling operations including EIF calculations for discharges of drill cuttings and fluids.
- Environmental assessment of the discharges based on the result of the dispersion modelling, updated knowledge of environmental effects of produced water and drilling discharges (literature review), and based on knowledge of the resources at the Johan Sverdrup field.

In general the main tasks have been to model dispersion of produced water and drilling discharges, by use of the DREAM model, and to perform environmental assessment of those discharges. A set of criteria (Ecological and Biological significant areas – EBSA criteria) have been applied to identify ecologically or biologically important areas relevant for the Johan Sverdrup field. The environmental assessment has then been focused on those areas and as such been site specific.

The environmental assessment has been done by use of the environmental impact factor (EIF) a risk factor based on PEC/PNEC considerations which is part of the DREAM modelling system.

In addition a literature review has been done on selected substances based on the EIF results. This has been done in order to get new information on effect values and assess site specific environmental risk based on this information.

<u>Ecological and biological significant areas assessment for Johan Sverdrup</u>

A system is described and used in order to evaluate presence of valuable environmental resources and areas in the area of Johan Sverdrup. The system is transparent and first initiated at a high end level, by the Convention on Biological Diversity (CBD COP 9 Decision IX/20). A set of seven so called EBSA (Ecological and Biological Significant Areas) criteria have been used to identify ecologically or biologically important areas:

- Uniqueness or rarity
- Special importance for life-history stages of species
- Importance for threatened, endangered or declining species and/or habitats
- Biological productivity
- Biological diversity
- Vulnerability, fragility, sensitivity, or slow recovery
- Naturalness

The data sources used to assess these criteria are mainly OSPAR, Norwegian Red list for Species, Havmiljø.no, Mareano program (Mareano.no) and MOD database (Environmental Monitoring database).

In general the following valuable resources and areas are identified as relevant for the Johan Sverdrup area:

- The benthic species *Apherusa bispinosa*, *Eteone suecica*, *Tellimya tenella*, *Thyasira dunbari* all listed in the Norwegian Red List for Species under Data Deficiency (DD). *Arctica islandica,* defined

by OSPAR being a species under threat and/or in decline within the Greater North Sea (OSPAR Region II).
- Sand eel areas (spawning and foraging area)
- Spawning ground for North sea cod
- Mackerel spawning area
- North Sea herring larvae and juvenile area

Produced water

Modelling results: The EIF modelling results for Johan Sverdrup results in a max EIF of 269 and a time averaged EIF of 91, covering water volumes over 2 km from the discharge point. The max EIF is related to a single time step with the highest EIF during the whole simulation period. Compared with the general experience from the water column monitoring where effects are measured 0.5-1 km from the discharge point (1.6 km in one instance) it may be that the risk calculated for Johan Sverdrup is over-estimated.

The main contributor to the risk of the produced water at the Johan Sverdrup field is the H_2S scavenger planned for use (components named H_2S K1 and K2), dispersed oil, and 2-3 ring PAHs. The contributions from phenols and alkyl phenols are relatively small and from metals almost negligible, except for copper which contributes 7% to the overall risk.

Summary literature review: Lethal exposure concentrations cited in the literature are in general significantly higher than the PNEC (Predicted No Effect Concentration) used in risk modelling and acute effects are therefore not expected within the modelled influence area. The literature study shows effects of sub lethal parameters in both adults and fish larvae at oil concentrations down to 10 µg/l. However, low effect levels reported from controlled laboratory experiments where fish have been exposed to stable oil concentrations (either in a flow-through system, or in static assays with regular water exchange) are not directly transferrable to a field exposure situation. The Water Column Monitoring programme (WCM), which made use of Atlantic cod held in cages at various distances from the produced water outlet and which was carried out at various oil fields in the North Sea during a period of 10 years, has demonstrated that exposure to potentially toxic oil concentrations in the field is transient due to currents and tides. Consequently biomarkers of effect (irreversible damage scored e.g. as histological changes), which are the result of exposure over extended time periods, have not been detected in the field even at close distance to the discharge point. Reversible effects have been detected as biomarkers of exposure (e.g. scored as increased levels of detoxification enzymes, or bile PAH-metabolites) downstream of the discharge point on some occasions, reflecting a high sensitivity of these biomarkers but not reflecting impact on fish populations. In conclusions therefore, water column effects resulting from produced water discharges at Johan Sverdrup are predicted to be comparable to what has been demonstrated around other oil fields in the North Sea; small and not measurable on the population level.

Based on the literature some effect levels for effect related to fish in general are suggested:

- Dispersed oil: 40.4 µg/l => Used PNEC in DREAM is 40.4 µg/l (same)
- 2-3 rings PAH: 1.4 µg/l => Used PNEC in DREAM is 0.15 µg/l
- Naphthalene: 2.4 µg/l => Used PNEC in DREAM is 2.1 µg/l

Valuable resources within the area of potential risk: There are no overlaps between the risk areas modelled (EIF) and the valuable resources and areas identified; indicating that these identified resources and areas should not be directly affected by the discharges of produced water.

For dispersed oil, 2-3 rings PAH and naphthalene, there are only modeled concentrations above the suggested effect levels, given above, in the range up to 400 m from the discharge point (Field center) and in the upper part of the water column. There are no overlaps between concentrations above the suggested threshold values and the Ecological and biological significant areas identified.

Drilling – Water column

Modelling results: A summary of the potential risk, expressed as EIF, and the contribution of the modelled substances to the overall risk in the water column is presented in table below.

Overall modelling results indicate potential risk within the order of some kilometres from the discharge point. It is important to underline that potential risk in the water column is time dependent and related to a short period of time when the actual discharges are taking place. After the discharges stop, the potential risk declines quickly due to dispersion and dilution of the particles in the water column.

There are no clear differences between the Base Case (simulation 1-8) and Alternative Case (simulation 1 and 4-10) with respect to overall risks. In general the risk is associated with bentonite and barite except for simulation 2 and 3 were TCC powder contributes most to the overall risk.

Simulation nr.	**EIF Water**	**Contribution (%)**						
	Max/time averaged	TCC Aliph-atic HC	TCC aromatic HC	TCC powder	TCC PAH	Bari-te	Bento-nite	Cuttings
1. Floater. CTS. Field center	4632/267	n.r	n.r	n.r	n.r	39	61	0
2. Integrated rig. 24" from rig. TCC. Field center	9492/1680	0.22	0.08	58.81	0.82	16	23.55	0.03
3. Integrated rig.24" from rig. TCC. Avaldsnes	9377/1654	0.22	0.09	60.33	0.022	15.73	22.75	0.03
4. Floater 42". CTS. E-template	3502/102	n.r	n.r	n.r	n.r	37.49	62.48	0.03
5. Floater 42". CTS. F-template	4267/107	n.r	n.r	n.r	n.r	36.72	63.25	0.04
6. Floater 42". CTS. G-template	4833/104	n.r	n.r	n.r	n.r	37.36	62.6	0.04
7. Floater 42". CTS. Kvitsøy	6498/225	n.r	n.r	n.r	n.r	37.23	62.73	0.03

8. Floater 42". CTS. Geitungen	6497/210	n.r	n.r	n.r	n.r	35.93	64.04	0.02
9. Integrated rig. 24" from rig. Field center	9578/2181	n.r	n.r	n.r	n.r	39.86	60.07	0.07
10. Integrated rig.24" from rig. Avaldsnes	9585/2164	n.r	n.r	n.r	n.r	40.1	59.83	0.07

n.r: Not relevant

Summary literature review: The literature review has focused on fish in general because fish are identified as valuable resources in the Johan Sverdrup area (cod, mackerel, sand eel and herring), and because it is considered most relevant in relation to effects of particles in the water column. Based on the studies cited, the following effect levels of lethal and sub lethal effects of particles (including behavioural effects) have been identified in adult/juvenile fish, and fish eggs/larvae:

- Lethal effects adults/juveniles: 400 mg/l (Newcombe, 2003)
- Lethal effects eggs/juveniles: 100 mg/l (Van Dalfsen, 1999)
- Sublethal effects adults/juveniles: 7 mg/l (Newcombe, 2003)
- Sublethal effects eggs/juveniles: 3.5 mg/l (estimated 50% of adult threshold)

The influence area will be significantly smaller, and the exposure time to potentially toxic particle concentrations will be significantly shorter, if the effect levels listed for fish (see above) are used, including effect levels of behavioural changes related to feeding and spawning. The effect levels in adult/juvenile fish are conservatively related to an exposure time of up to 2 weeks (Newcombe, 2003). Although these effect levels are mainly related to experiments performed on salmon species, there are no indications in the literature that other pelagic species including cod are more sensitive to suspended mineral particles.

Valuable resources within the area of potential risk: The modelled EIF results indicate an overlap between the discharges posing a potential risk in the water column and the North Sea cod spawning area. For the other identified valuable resources there is no overlap; indicating that these identified resources and areas will not be directly affected by the planned drilling operations, when considering suspended particles in the water column.

Based on the suggested effect values for fish from the literature review, concentration fields of particles was extracted from the model at the time with maximum risk. An overall conclusion is that no concentrations above 100 mg/l are modelled, meaning no concentrations above the suggested effect levels for lethal effects on adult fish, juveniles nor eggs. There are only modelled concentrations in the range corresponding to sub lethal effects, but it is important to underling that this is for a limited period of time and within a limited water volume. With regards to identified valued resources in the area there are no overlap between the particle concentrations in the sub lethal range (3.5 – 100 mg/l). A summary of the main findings for each simulation is presented in the table below. In the table, distance is an approximate value (km) of the longest distance the different concentrations interval is modelled and the volume of water (mill m^3) of those concentrations intervals.

	Particle concentration interval (mg/l)								Max (mg/l)
Simulation nr.	3.5-7		7-100		100-400		>400		
	Dist. (km)	Vol. (mill. m^3)	Dist. (km)	Vol. (mill. m^3)	Dist. (km)	Vol. (mill. m^3)	Dist. (km)	Vol. (mill. m^3)	
1	2.7	3.4	1.4	1.3	n.r.	n.r.	n.r.	n.r.	32
2	3	6	2.7	4.7	n.r.	n.r.	n.r.	n.r.	34
3	5	9.5	2.5	3	n.r.	n.r.	n.r.	n.r.	26
4	1.4	8.6	0.9	2.5	n.r.	n.r.	n.r.	n.r.	39
5	2.1	2.6	1.4	1	n.r.	n.r.	n.r.	n.r.	16
6	2.5	2.7	2.2	0.9	n.r.	n.r.	n.r.	n.r.	15
7	2.3	10	2	4	n.r.	n.r.	n.r.	n.r.	46
8	3.5	9.1	2.8	1.5	n.r.	n.r.	n.r.	n.r.	57
9	5.5	6.6	2.2	2.3	n.r.	n.r.	n.r.	n.r.	21
10	5	3.8	2.1	2.6	n.r.	n.r.	n.r.	n.r.	25

n.r. Not relevant

Drilling – sediment

Modelling results: The parameter assessed for sediments in relation to drilling is sedimentation of particles. Currently a PNEC of 6.5 mm is applied in the DREAM model. All results are therefore based on the sediment area where modelled sedimentation is >6.5 mm. The results are summarized in the table below, presenting the area for each simulation where sedimentation is >6.5 mm and the longest approximate distance from the discharge points such rates are modelled.

In general are areas above a PNEC of 6.5 mm local and within 150 – 500 m from the discharge point. Overall there is modelled that Base case will affect a sediment area of 180 000 m^2 more than Alternative case.

Simulation nr.	Case	Area (m^2) >6.5 mm	Approximate largest distance (m) from discharge point covered by >6.5 mm/Direction
1	Base & alternative	67 500	300/south
2	Base	277 500	500/south
3	Base	237 500	500/south
4	Base & alternative	40 000	180/south east
5	Base & alternative	30 000	150/south east
6	Base & alternative	30 000	180/south
7	Base & alternative	47 500	250/south to south east
8	Base & alternative	95 000	350 south
9	Alternative	177 500	500/south
10	Alternative	150 000	400/south
Base case		790 000	
Alternative case		610 000	

Summary literature review: There are strong evidences to conclude that sedimentation of particles onto the seafloor has only local and short term effects on the sediment fauna. This conclusion is supported by experiments and by the extensive monitoring performed on the NCS. This is partly due to the fact that sedimentation levels in the order of a few millimetres are usually the case in the vicinity of the discharge point, for example at distances less than 250 m. Regional monitoring has generally not revealed any effects on the macro faunal community structure closer than 20-250 m from discharge point. DNV GL has assessed the PNEC if 6.5 mm currently used in DREAM. There was no data found that supported the use of an alternative effect level than 6.5 mm.

Valuable resources within the area of potential risk: There are in general no overlap between the areas with sedimentation rates >6.5 mm and the identified valuable fishery resources.

Regarding the two benthic species, the mussels *Arctica islandica* and *Tellimya tenella,* it cannot be ruled out that individuals of these species may be affected by the drilling operations. The abundance of these species at the Johan Sverdrup field are however uncertain. *Tellimya tenella* is mentioned because it is listed in the Norwegian Red List as DD – data deficient. There are no data on presence of this species within Johan Sverdrup, but data from the regional survey carried out in 2012 revealed some scattered densities in the region with the highest density far west. The category data deficient does not necessarily mean that this is a rare or vulnerable species but the simply that there are lack of data to assess it properly.

1 INTRODUCTION

DNV GL and SINTEF have on behalf of Statoil ASA performed the following tasks related to the planned development of the Johan Sverdrup field:

- EIF (Environmental Impact Factor) modelling of produced water discharges.
- Dispersion and sedimentation modelling of drill cuttings and fluids from drilling operations including EIF calculations.
- Environmental assessment of the discharges based on the modelled EIF factor, updated knowledge of environmental effects of produced water and drilling discharges, and based on knowledge of the resources at the Johan Sverdrup field.

This report is made of the following main chapters:

- 2 presents a general introduction to the dispersion model (DREAM) and the EIF methodology
- 3 presents the modelling set up or input parameters such as simulations run, discharge regimes, current data, discharge localities and more. More details regarding input to the model are attached in Appendix A and Appendix B.
- 4 presents an overview of the different sources used in order to assess resources and areas considered as valuable in the Johan Sverdrup field area
- 5 presents and discusses the results in general.

1.1 The Johan Sverdrup field

Johan Sverdrup field includes production licenses 501, 502 and 265 in the North Sea, see Figure 1-1. The field has an area of approximately 200 km^2. The distance to the Grane field in the north is about 40 km, and the Sleipner field in the southwest about 65 km. The water depth in the area is 110-120 m. The shortest distance to shore (Karmøy) is approximately 150 km. The total recoverable petroleum resources at Johan Sverdrup field are currently estimated to be between 1.8 and 2.9 billion barrels of oil equivalent, of which approximately 97 % oil / NGL and about 3% gas. The field will be developed in several phases. The first phase of the plan for development and operation (PDO) includes establishment of a field center, consisting of four platforms:

- A process platform,
- A drilling platform,
- A riser platform and
- An accommodation platform.

Three subsea water injection installations for maintaining reservoir pressure are also planned. Production capacity in the first phase will be designed to 315 000 barrels of oil equivalents per day. The schedule for development is subject to approval of the PDO in Parliament's spring session in 2015. Installation of templates can happen in Q2 2015, drilling operations can commence in 2016, installation of suspension of drilling platform in 2018 and the start of production expected in Q4 of 2019.

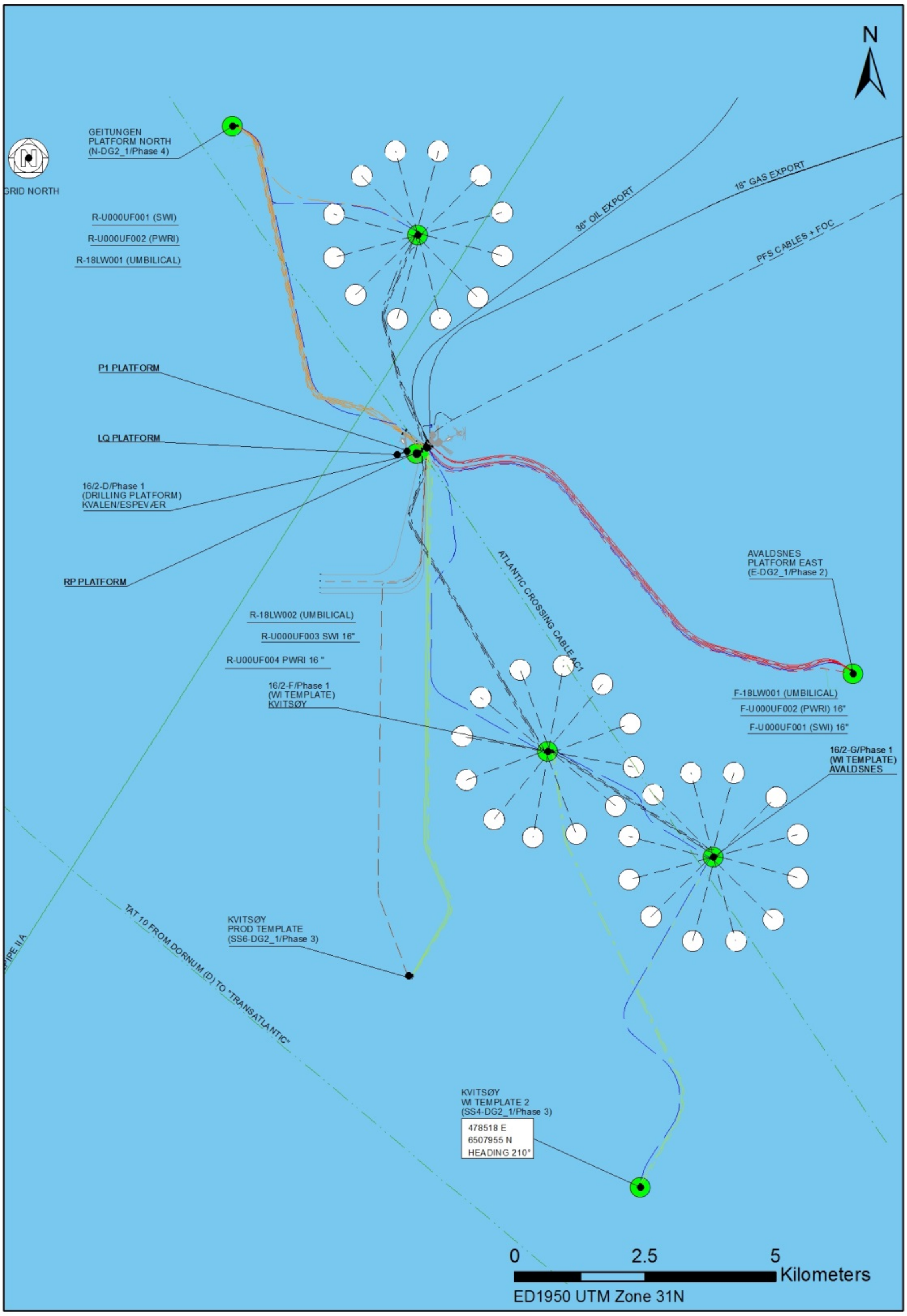


Figure 1-1 Development plan for the Johan Sverdrup field.

2 DISPERSION MODELING AND EIF METHODOLOGY

The operators on the Norwegian Continental Shelf (NCS) have agreed with the Norwegian Authorities to work towards a reduction of the environmental impacts from produced water releases and from drill cuttings and drilling fluids release down to a level of “zero harmful effects”. To more clearly define this goal, the EIF (Environmental Impact Factor) is applied as an indicator of the potential impacts from produced water releases and drilling discharges. The EIF is used as an indicator of the environmental benefit achieved when alternate measures are considered for reducing environmental impacts.

The EIF approach is based on PEC (Predicted Environmental Concentration) and PNEC (Predicted No Effect Concentration) considerations. The PEC/PNEC ratio is used as an indicator of potential risk, termed the Risk Quotient. PNEC values are selected for the most sensitive species and it is assumed that ecosystem sensitivity depends on the most sensitive species, and that protecting ecosystem structure protects community function.

Common practice is to consider water concentrations of potentially toxic compounds corresponding to a PEC:PNEC ratio < 1 as environmentally safe (Karman et al. 1996). This is illustrated in Figure 2-1. Furthermore, the PNEC is set to protect 95% of all aquatic species (globally), which means that 5% of all species are potentially impacted at a water concentration corresponding to PEC:PNEC =1. As a consequence of this PNEC values are not resource specific or site specific but can be interpreted as a “global” effect limit protecting 95% of all species in the aquatic environment.

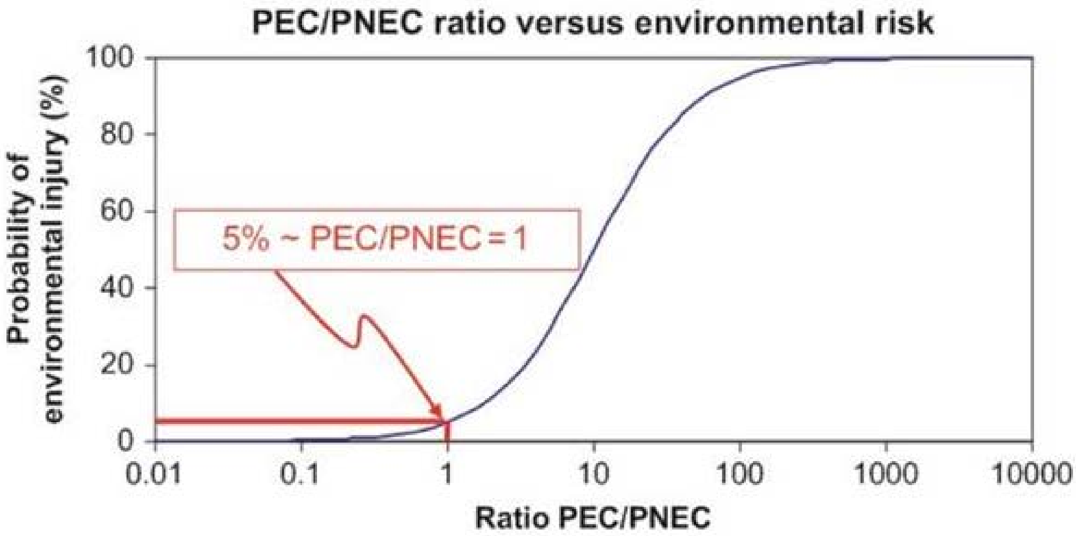


Figure 2-1 Relation between PEC/PNEC level and potential risk level (in %) for impact on biota (based on Karman et al. 1996). Common practice is to accept a PEC/PNEC ratio ≤ 1.

PNEC values are derived from laboratory experiments that typically result in values for LC_{50} (Lethal Concentration) and NOEC (No Observed Effect Concentration). The LC_{50} is the concentration where 50% of the tested sample population dies in an experiment. NOEC is the highest concentration to which organisms are exposed in a full life-life cycle (long term) or partial life- cycle (short term) test, which causes no observable adverse effects on the test organisms. Depending on the number of toxicity tests available for a particular compound, the lowest observed effect level is divided by an assessment factor (AF) 10-10,000 (EU, 2003). If for compound X the only available toxicity test is LC_{50} from one or several fish species, the lowest LC_{50} is divided by AF 10,000 to obtain the PNEC for compound X; e.g. lowest LC50 = 1 mg/l renders a PNEC of 0.1 µg/l for compound X. If for compound Y both acute and chronic toxicity tests are available for at least one alga, one crustacean and one fish species, the lowest observed effect concentration is divided by AF 10 to obtain the PNEC for compound Y; e.g. lowest LOEC = 1 mg/l renders a PNEC of 0.1 mg/l for compound Y.

The relationship between risk expressed and PEC/PNEC ≥1 in the DREAM model, is that 5% risk corresponds to a PEC/PNEC>=1. With respect to the unit EIF (Environmental Impact Factor) 1 EIF for the water column corresponds to a volume with dimensions 100x100x10 m where PEC/PNEC ≥1. For sediments, the EIF has dimensions 100x100 m.

The method has the advantage that it gives a quantitative measure of the potential environmental risks involved in discharges to the sea, and is thus able to form a basis for reduction of impacts in a systematic and a quantitative manner.

Calculations of the EIF is made using the numerical model DREAM (Dose related Risk and Effect Assessment Model) developed by SINTEF, with financial support from Statoil, Norsk Hydro, ENI, Total, ExxonMobil, Petrobras, ConocoPhillips, and Shell.

DREAM is a three-dimensional Lagrangian particle model (Reed and Hetland, 2002) and based on:

- A generalized transport equation, accounting for advection and turbulent diffusion
- Several transformative processes such as sinking, dissolution, sedimentation and biodegradation.

The numerical solution of the transport equation uses the Lagrangian frame of reference, with numerical parcels following the ocean current. For a continuous release of produced water or cuttings and mud, the numerical parcels are created with fraction of the released mass, and then tracked through the water column, while being subject to the physio-chemical processes. Essential parameters of the released material, including grain size distribution, adsorbed substances are similarly tracked.

DREAM can account simultaneously for up to 200 chemical components, with different release profiles for 50 or more different sources. Each chemical component in an effluent mixture is described by a set of physical, chemical, and toxicological parameters.

Because petroleum hydrocarbons constitute a significant fraction of many industrial releases, DREAM incorporates a complete surface slick model, in addition to the processes governing pollutant behavior and fates in the water column. The model can also calculate exposure, uptake, depuration, and effects for fish and zooplankton simultaneously with physical-chemical transport and fates.

In this project the produced water module for simulations of dispersion and potential risk associated with produced water discharges is applied. In addition the par track module used for particle modelling and for assessing the associated potential risk in the water column and sediment is used in relation to discharge of cuttings and mud.

3 DREAM MODELLING SET UP

A general description related to the produced water discharges and drilling discharges modelling are described below. More details are given in Appendix A (produced water) and B (drilling).

3.1 Scenarios

3.1.1 Produced water discharges

Produced water is planned to be re-injected into the reservoir for controlling pressure. The injection technology is planned with a high degree of regularity and today's estimates are that about 98 % of produced water will be re-injected each year. In theory produced water discharged to the water column will most likely be related to testing of valves on the wells, which in theory have duration of a few hours.

As a conservative approach/worst case scenario the rate of produced water discharges to the water column was based on a scenario where one of the injection pumps was not operating. In the case of one pump not operating it is expected that this will only be for a relatively short period of time. Based on the theoretical availability of the injection system, max annual discharge of produced water could be in the range of 1 - 2 mill m^3 when water production is on top.This amount will probably be distributed unevenly during a year as batches during valve tests or, more unlikely, during periods were an injection pump is not operating. An injection pump has a capacity of about 30 000 m^3/day.

As a worst case scenario or conservative approach it was decided to set a discharge rate of 30 000 m^3/day for 8 days.

Details related to the discharge used in the simulation are attached in Appendix A.

3.2 Drilling discharges

Drilling campaigns at Johan Sverdrup are planned with the use of different drilling platforms with different discharge regimes. In general drilling campaigns are planned with the use of:

- Floating drilling platforms with the well head on platform or sub-sea
- Integrated platform with well head at platform

Based on details regarding planned drilling campaigns, 4 different drilling strategies were identified, each with a characteristic discharge regime. See Table 3-1 for discharge details related to each of the 4 drilling strategies.

Table 3-1. Discharge regimes for the 4 identified drilling strategies.

Drilling strategy	42"	36"	24"	17,5"	12,25"	9,5"
1	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Discharges of cuttings and WBM from rig	Discharges of cuttings with hydrocarbons from TCC from rig.	Discharges of cuttings with hydrocarbons from TCC from rig.	Discharges of cuttings with hydrocarbons from TCC from rig.
2	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Discharges of cuttings and WBM from rig	No discharges	No discharges	No discharges
3	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	No discharges	No discharges	No discharges
4	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor.	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	No discharges	No discharges	No discharges

n.a: Not Applicable

TCC: Thermo mechanical Cuttings Cleaner Technology

A total of 84 wells distributed between 7 localities are planned to be drilled at Johan Sverdrup. Based on the identified drilling strategies, number and localities of wells, 10 modelling simulations were identified, see Table 3-2.

Table 3-2. Modelling scenarios.

Simulation nr./type	Drilling strategy	Number of wells	Locality	Discharge points
1/Floater with well head on platform (dry)	3	6	Field center	1: (CTS)
2/Integrated rig with well-head on platform. Discharges of cleaned cuttings 25 m below sea surface	1	27	Field center	2: (CTS) + discharges from rig
3/ Integrated rig with well head on platform. Discharges of cleaned cuttings 25 m below sea surface	1	24	Avaldsnes	2: (CTS) + discharges from rig
4/ Floater with well head sub-sea (wet)	4	4	E-template	1: (CTS)
5/ Floater with well head sub-sea (wet)	4	4	F-template	1: (CTS)
6/ Floater with well head sub-sea (wet)	4	4	G-template	1: (CTS)
7/ Floater with well head sub-sea (wet	4	6	Kvitsøy	1: (CTS)
8/ Floater with well head sub-sea (wet)	4	9	Geitungen	1: (CTS)
9/ Integrated rig with well head on platform. (dry) OBM cuttings shipped to shore	2	27	Field center	2 (CTS)+ discharges from rig
10/ Integrated rig with well head on platform. (dry) OBM cuttings shipped to shore	2	24	Avaldsnes	2 (CTS)+ discharges from rig

Based on these 10 simulations two overall cases are assessed:

1. Simulation number 1-8 in Table 3-2 => referred to as Base Case.
2. Simulation number 1 and 4-10 in Table 3-2 => referred to as Alternative Case. The difference between the two cases is that cleaned cuttings are discharged to sea instead of being shipped to shore to be cleaned with the same technology as used on rig.

Details related to the discharges used in the simulations are attached inAppendix A and Appendix B.

3.3 Metocean data

Common for both produced water discharges and drilling discharges are that the same metocean data (current, wind and stratification) are used. The development at the Johan Sverdrup field will be over a period of years, with drilling in different years and different seasons. It was therefore chosen to use ocean and current for the period 2012-2013, produced by the numerical ocean model SINMOD (developed by SINTEF since 1987). Wind data for the same period is also provided by Sintef. In order to capture time dependency in the ocean current data, simulations were set up in such a way that they included seasonally variation. The spatial resolution is 4 km and the temporal resolution is 2 hours.

Details regarding the different periods the wells were drilled in the simulations are presented in Appendix B.

The temperature and salinity profile in the model is fixed meaning that no time dependent variation is included in the simulations. The temperature and salinity profiles used in the model are given in Table 3-3.

Table 3-3. Temperature and salinity profile used for the Johan Sverdrup field.

Depth (m)	Spring/Summer conditions	
	Temperature (°C)	Salinity
0	14.51	34.10
10	14.22	34.30
20	13.09	34.70
30	10.78	35.00
40	9.52	35.00
50	8.25	35.10
60	7.97	35.10
70	7.68	35.10
80	7.46	35.20
90	7.32	35.20
100	7.18	35.20
110	7.17	35.20

4 RESOURCE DATA FROM THE AREA

Data regarding resources are from the following sources:

Norwegian Environment Agency:

- Administrative areas
  - Downloaded from http://kartkatalog.miljodirektoratet.no/map_catalog_dataset.asp?datasetid=700&download=yes
- Particularly Valuables areas
  - Downloaded from http://kartkatalog.miljodirektoratet.no/map_catalog_dataset.asp?datasetid=703&download=yes&language=

Havmiljø – Environmental values in Norwegian marine areas (http://www.havmiljo.no/):

- Data on herring – Larvae, April
- Herring – 0 group
- Mackerel spawning area
- Sandeel areas

Institute of Marine Research - Mareano project

- North Sea Cod Spawning Area
  - Source: Institute of Marine Research
  - Downloaded from http://maps.imr.no/geoserver/web/;jsessionid=923iu6j94lyf?wicket:bookmarkablePage=:org.geoserver.web.demo.MapPreviewPage

MOD (Environmental Monitoring Database):

- Data on benthos form the Norwegian continental shelf

5 RESULTS AND DISCUSSION

5.1 Ecological and Biological Significant areas (EBSA) assessment for Johan Sverdrup

For the purpose of evaluating presence of environmental resources in the area of Johan Sverdrup, a transparent approach has been applied, first initiated at a high end level, by the Convention on Biological Diversity (CBD COP 9 Decision IX/20). A set of seven criteria have been used to identify ecologically or biologically important areas (see Appendix C for complete description on the EBSA (Ecological and Biological Significant Areas) criteria):

- Uniqueness or rarity
- Special importance for life-history stages of species
- Importance for threatened, endangered or declining species and/or habitats
- Biological productivity
- Biological diversity
- Vulnerability, fragility, sensitivity, or slow recovery
- Naturalness

These criteria are used for environmental value assessment in Havmiljø.no. According to Havmiljø.no, criterion 2, especially important areas for life-history stages of species, is used as the basis for the environmental values system, and the areas can be up-weighted if they are important for endangered species, key species in the ecosystem, or form habitats that are important for the rest of the biological diversity. There are also important environmental components which cannot be quantified in this way. The environmental value assessments must therefore be supplemented with information about the PVAs (Particularly Valuable Areas).

For the Johan Sverdrup case, the criteria are used to document:

- sources of information on species and habitats which fulfils the different criteria
- data sources used for generating distribution maps of given species and habitats
- Identified species

Based on the collaboration of data from Region II, areas fulfilling criteria (i) uniqueness or rarity, (ii) special importance for life-history stages of species, and (iii) Importance for threatened, endangered or declining species and/or habitats, have been identified, see Table 5-1 and Figure 5-1. The region is considered to have a low degree of naturalness due to especially shipping-, fishing- and petroleum activity.

Regarding the category DD (data deficient) used in the Norwegian Red list for Species. Data deficient does not necessarily mean that it is a rare or vulnerable species but the simply that there are lack of data to assess it properly. The species listed as DD in Table 5-1 has been treated as rare or unique as a precautionary approach.

Table 5-1 Evaluated sources of information on species and habitats which fulfils the different criteria, data sources used for generating distribution maps of given species and habitats, and identified species.

Criteria	Identified criteria used	Data sources used	Identified species and areas	EBSA within Region II
Uniqueness or rarity	• OSPAR • Norwegian Red List for Species • Norwegian Red List for Habitats • Havmiljø.no	MOD 2012 Havmiljø.no Mareano.no	**Benthic compartment:** Apherusa bispinosa (DD) Eteone suecica (DD)[1)] Tellimya tenella (DD) Thyasira dunbari (DD) Sand Eel **Pelagic compartment:** None	X
Special importance for life-history stages of species	• Norwegian Red List for Habitats • Norwegian Red List for Species • St meld 37	Havmiljø.no Mareano.no	**Benthic compartment:** Sand Eel **Pelagic compartment:** North Sea Cod Mackerel Herring	X
Importance for threatened, endangered or declining species and/or habitats	• Norwegian Red List for Habitats • Norwegian Red List for Species • OSPAR	MOD 2012 Havmiljø.no Mareano.no	**Benthic compartment:** Arctica islandica **Pelagic compartment:** North Sea Cod	X
Vulnerability, fragility, sensitivity, or slow recovery	• Norwegian Red List for Habitats • OSPAR • Havmiljø.no	MOD 2012 Havmiljø.no Mareano.no	**Benthic compartment:** None **Pelagic compartment:** None	-
Biological productivity	• Havmiljø.no	Havmiljø.no	**Benthic compartment:** Sand Eel **Pelagic compartment:** None	X
Biological diversity	NA	MOD 2012	**Benthic compartment:** None **Pelagic compartment:** None	-
Naturalness	• St meld 37	St meld 37	**Benthic compartment:** Fishing and petroleum activity **Pelagic compartment:** Fishing and petroleum activity	-

1) DD: Data deficiency.

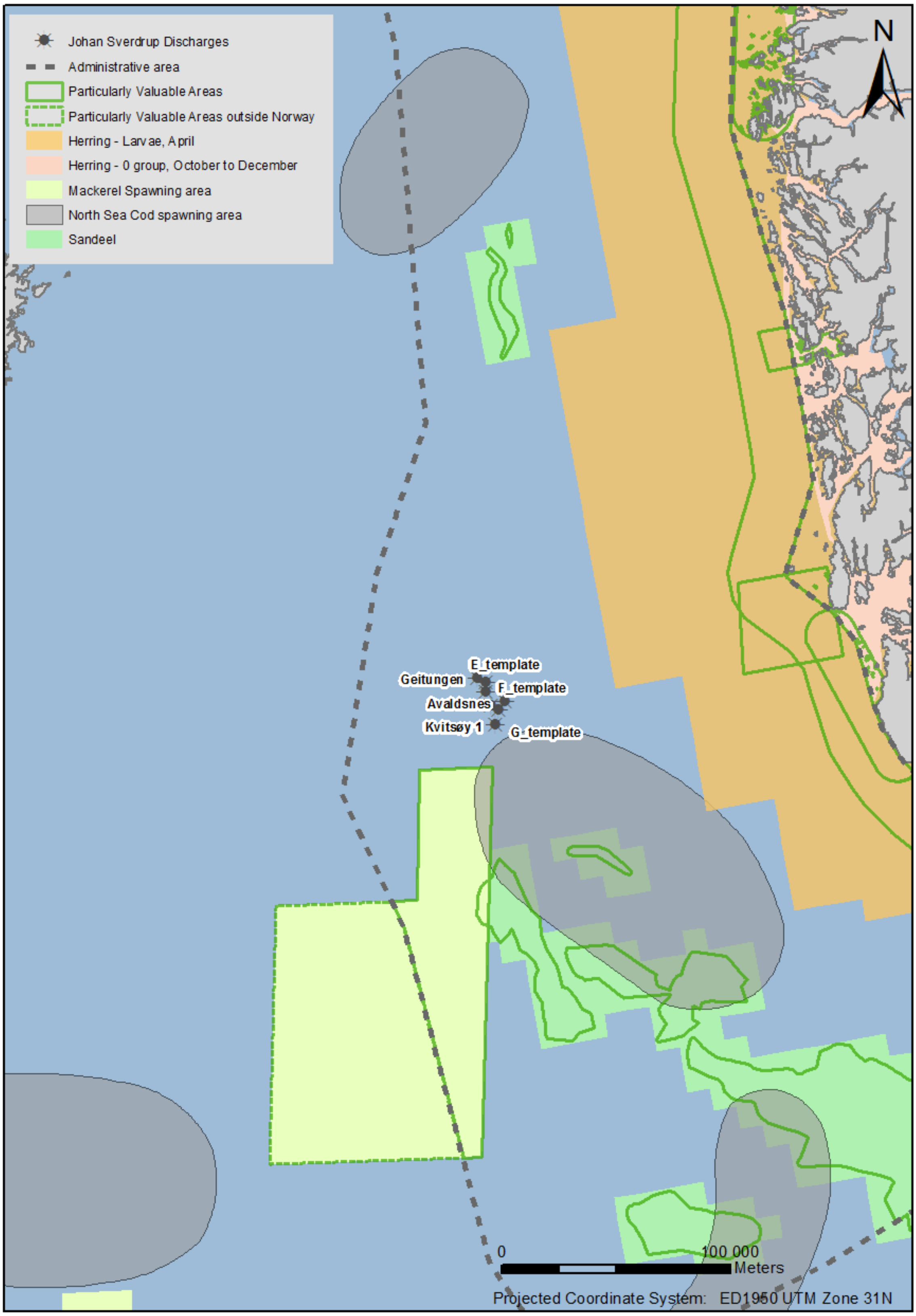


Figure 5-1 The Johan Sverdrup field and identified environmental resources of concern.

5.1.1 Valuable species and habitats relevant for the Johan Sverdrup field

5.1.1.1 Arctica islandica

The mussel ocean quahog (*Arctica islandica*), is not listed in the Norwegian Red List for Species, but has been defined by OSPAR being a species under threat and/or in decline within the Greater North Sea (OSPAR Region II). There are no data on presence of A. islandica within the Johan Sverdrup field, but the data from the regional survey carried out in 2012, revealed highest densities north west of the Geitungen location (4 ind per 0.5m^2). The results may indicate a patchy distribution (Figure 5-2), related to preferred grain size of medium to fine grain sand, sandy mud and silty sand, at depths where suspension feeding on phytoplankton is possible (Cargnelli *et al.* 1999).

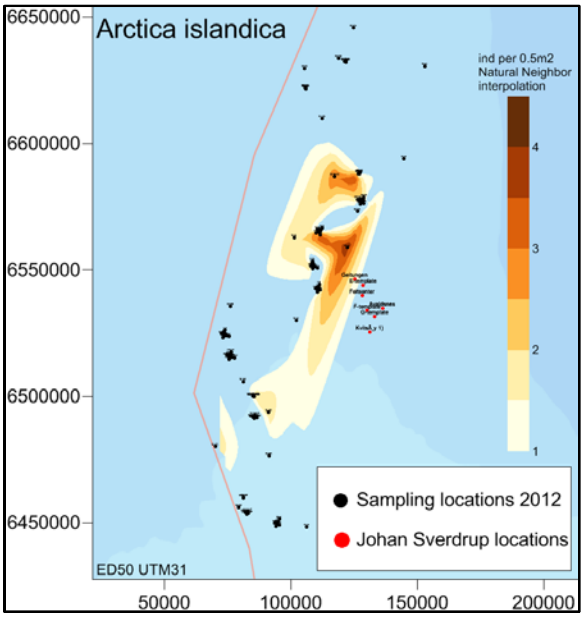


Figure 5-2 Distribution map of Arctica islandica based on data from 2012 regional survey. Data has been interpolated by use of Natural Neighbor.

5.1.1.2 Thyasira dunbari

Only three specimens of the bivalve has been recorded on one station (R2-10) located far North West in Region II. Listed as data deficient in Norwegian Red List for Species.

5.1.1.3 Tellimya tenella

The mussel *Tellimya tenella*, is listed as a data deficient species in the Norwegian Red List for Species. According to Marine Species Identification Portal its distribution within OSPAR Region II is limited to the Scandinavian shelf. There are no data on presence of *T. tenella* within the Johan Sverdrup field, but the data from the regional survey carried out in 2012, revealed highest densities far west in the Norwegian economic zone, and if at all, single to few specimens at the other sampled locations (

).

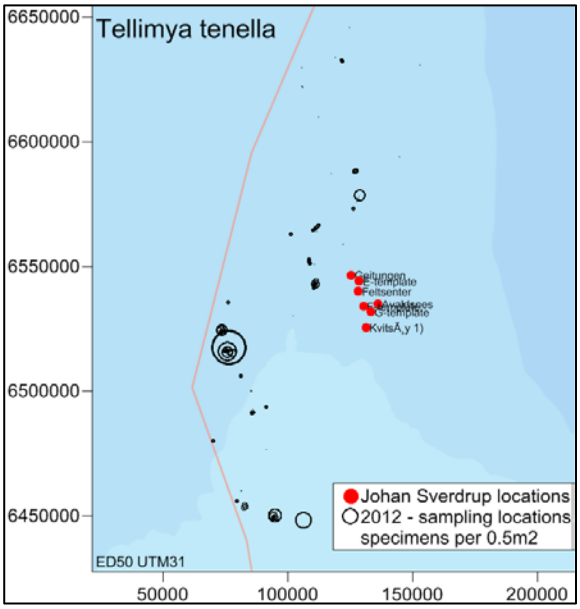


Figure 5-3 Distribution map of Tellimya tenella based on data from 2012 regional survey.

5.1.1.4 Eteone suecica

Only two specimens of the polychaet have been recorded at Sleipner A and Volve south West of Johan Sverdrup. Listed as data deficient in Norwegian Red List for Species.

5.1.1.5 Apherusa bispinosa

Only one specimen of the amphipod have been recorded at Dag far West in Region II. Listed as data deficient in Norwegian Red List for Species.

5.1.1.6 Sand Eel

High fishing intensity on sand eel over the last decades has resulted in negative impacts on the spawning population. As a consequence, area specific management plans were implemented in 2010 to secure a sustainable spawning population at all historical important sand eel locations. Sand eels are known to be grain size selective, and in addition to fishing pressure, also vulnerable to activities resulting in altering the grain size composition.

5.1.1.7 North Sea Cod

The Norwegian Red List for Species classifies the cod population (including the North Sea population) to be in very good to good ecological condition, resistant to influence without risk of significantly change. However, according to Stortingsmelding 37, the North Sea Cod stock has over a long period of time been over exploited and the population is considered to be below critical spawning size (Figure 5-4). Hence, the North Sea cod has been included in the assessment due to an identified spawning area south of the Johan Sverdrup field.

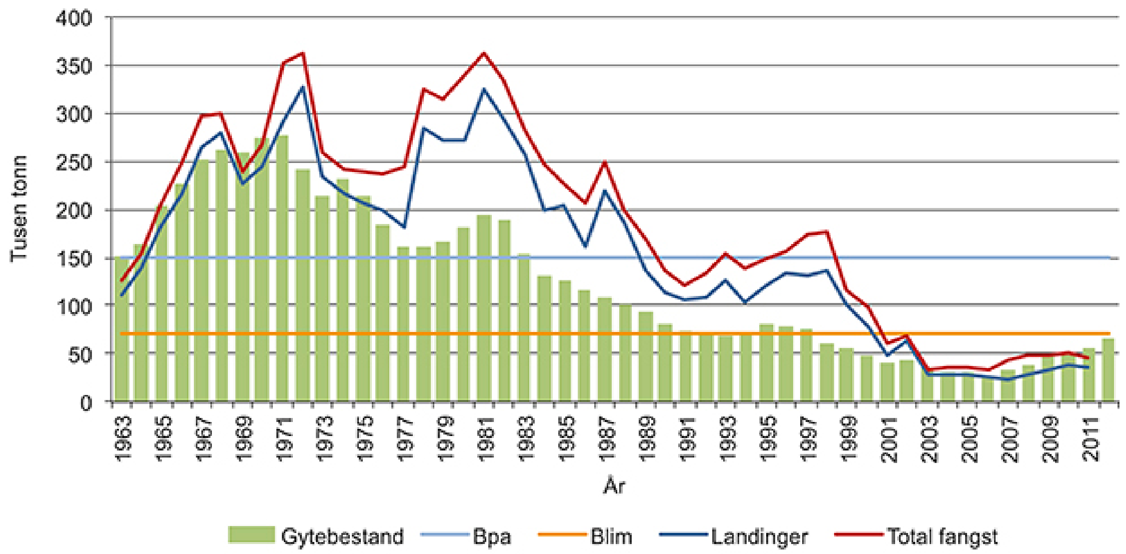


Figure 5-4 Development of the spawning population and catches of North Sea cod (Source: IMR)

5.1.1.8 Mackerel

The North Sea mackerel is the smallest stock of the Atlantic population. The spawning grounds are located in Skagerak and central North Sea. During the 70's the population was over exploited and has yet to recover. As a consequence, strict regulations and prohibited fishing areas south west of the Johan Sverdrup field have been implemented.

5.1.1.9 North Sea herring

The autumn spawning herring dominates the North Sea and is considered as key specie both as predator and prey. High exploitation and low recruiting over many years led to strict regulations. The areas of larvae and juvenile fish are both defined closer to shore east of the Johan Sverdrup field.

5.1.2 Naturalness

Figure 5-5 shows different use of the area, used as an input to conclude that the region is considered to have a low degree of naturalness due to especially shipping-, fishing- and petroleum activity.

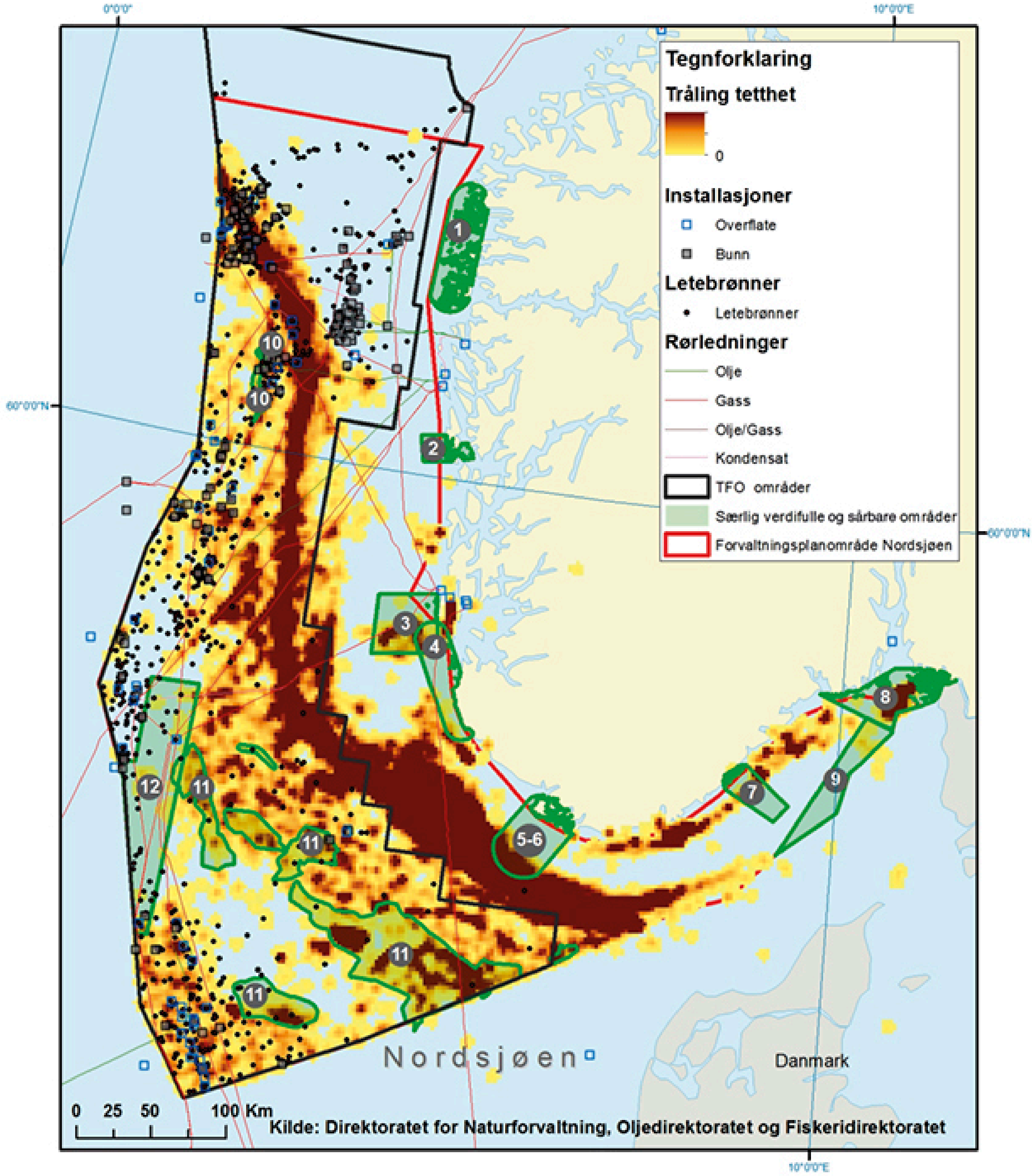


Figure 5-5 Different types of use of the area and sea floor influence.

5.1.3 Summary of EBSAs at Johan Sverdrup

A total of four EBSA criteria have been identified within Region II. When carrying out overlay analysis between identified environmental resources and DREAM simulation results a more refined picture is revealed (Table 5-2).

Sediment deposition may influence the bivalves *Tellimya tenella* and *Arctica islandica*. There are great uncertainties linked to presence of these two species at the Johan Sverdrup field, and apparently they are quite common throughout the area. The other benthic species identified are only registered with a few specimens far from the Johan Sverdrup field. Hence, they are not expected to be present and are not further assessed.

Table 5-2 Identification of species at potential risk revealed from overlay analysis between EBSA identified and DREAM simulation results for the Johan Sverdrup field

EBSA Criteria	EBSA within Region II	Overlay analysis between EBSA identified and simulation results (see chapt) for the Johan Sverdrup field				
		Benthic compartment		Pelagic compartment		
		Base case Sediment deposition	Alt. case Sediment deposition	Base case Suspended solids	Alt. case Suspended solids	Produced water
Uniqueness or rarity	X	Tellimya tenella	Tellimya tenella	-	-	-
Special importance for life-history stages of species	X	-	-	North Sea Cod	North Sea Cod	-
Importance for threatened, endangered or declining species and/or habitats	X	Arctica islandica	Arctica islandica	North Sea Cod	North Sea Cod	-
Vulnerability, fragility, sensitivity, or slow recovery	-	-	-	-	-	-
Biological productivity	X	-	-	-	-	-
Biological diversity	-	-	-	-	-	-
Naturalness	-	-	-	-	-	-

5.2 Produced water

Formation water brought up with the hydrocarbons (produced water) and rock cuttings and drilling mud from drilling operations are the major sources of contaminants entering the sea from regular oil & gas operations. This has been the case for more than 40 years of oil & gas activities at the Norwegian Continental Shelf (NCS). Drilling waste and produced water are cleaned with different technologies and regulations put strict limits on levels of contaminants which can be discharged to the sea.

Over the years different efforts have been taken in order to reduce the overall discharges, such as re-injection of produced water, chemical substitution and implementation of cleaning technologies.

In 2012 about 130 million m^3 of produced water were discharged to sea at NCS (Bakke *et al.* 2013). The highest average discharge from a single field was 76 700 m^3/day in 2012. A variety of chemicals may be discharged with produced water that varies in concentration between wells and over the life time of a well. Greatest concern is probably related to discharges of alkyl phenols due to their documented hormone disrupting effects. In 2012 the total amount of phenol and alkyl phenols (C1-C9) discharged to the NCS was 206 and 316 tons respectively. Total phenols contain mainly phenol and C1-C3 alkyl phenols, typically 90-98 % in North Sea produced water discharges (OGP, 2005). It is established that C6-C9 phenols have estrogenic effects in fish (Neff, 2002). The concentrations in produced water discharges however are too low to have an estrogenic effect in a field exposure situation (Beyer *et al.*, 2012).

Some concern is also related to discharges of 2-6 rings PAH. There are a great number of studies documenting different effects of PAH (Aas *et al* 2000, Sturve *et al* 2006, Carls *et al* 2008). In 2012 the concentration of 4-6 rings PAH in produced water discharges varied between 0.4-12 µg/l. BTEX (benzene, toluene, ethyl benzene and xylenes) and rarely considered as a major concern since they evaporate rapidly from sea water. Similarly metals are of lesser concern because dilution and chemical processes will reduce the concentration of inorganic elements when entering the sea. The amount of dispersed oil in produced water discharges amounted to 1535 tons in 2012, a relatively high amount historically which can be explained by well ageing and a rising number of producing fields.

At the Johan Sverdrup field produced water are planned re injected. It is estimated by Statoil that 246 769 m^3 of produced water may be discharged each year. Discharges will be associated with periods of maintenance such as valve testing and as such will be limited in duration. Compared with the largest average daily discharge of 76 700 m^3 from a single field in 2012 (Bakke *et al* 2013) the discharges from Johan Sverdrup are relatively small and limited to a short period. The amount of planned produced water discharge for Johan Sverdrup corresponds to 0.2 % of the total volume discharged in 2012 (130 million m^3) at the NCS. The amount of dispersed oil in produced water (estimated at 10 mg/l) corresponds to 2.4 tons/year which is 0.15% of the total amount discharged in 2012 at the NCS (Bakke *et al.* 2013). Regarding phenols and alkyl phenols, with an estimated concentration of 1.86 mg/l in the produced water discharge, this corresponds to 0.05 tons a year or 0.02% of the reported discharges of phenols in 2012, or 0.015% of the reported discharges of alkyl phenols (whole NCS).

Monitoring surveys focusing on the effects of produced water were first performed at the NCS in 1997 and surveys have been repeated almost annually up to the present. Monitoring during these years includes direct field measurements of contaminants in the water column, analysis of contaminant body burden, and biomarkers in Atlantic cod and blue mussel (*Mytilus edulis*) caged for 6 weeks at various distances from the produced water outlet. The surveys have mostly detected exposure to PAH and alkylphenols from produced water and biomarkers responses no further than 0.5-1 km from discharge points, except for one study where effects out to 1.6 km were detected (Sundt *et al* 2008). There is however still a debate about the methods and how local the effects are.

5.2.1 Risk results

Table 5-3 and Figure 5-6 show the contribution of each substance to the EIF. The EIF modelling results for Johan Sverdrup results in a max EIF of 269 and a time averaged EIF of 91. The max EIF is a related to as single time step with the highest EIF during the whole simulation period and is achieved after about 8 days with a discharge rate of 30 000 m^3/d. The average EIF of 91 better reflects the whole modelled time period. The modelled results indicate that a total of 26 900 000 m^3 of water volume are at potential risk, in terms of EIF, for a very short period of time or on average 9 100 000 m^3 for the whole discharge period. Overall the potential risk is limited to the upper part of the water column and reaches a vertical distribution of some kilometres. Compared with the general experience from the water column monitoring where effects are measured 0.5-1 km from the discharge point (1.6 km in one instance) it seems that the potential risk calculated for Johan Sverdrup is over-estimated.

The main contributor to the potential risk of the produced water at the Johan Sverdrup field is the H_2S scavenger named K1 (13%) and K2 (26%), dispersed oil (10%), and 2-3 ring PAHs (22%). The contributions from phenols and alkyl phenols are relatively small and from metals almost negligible, except for copper which contributes 7% to the overall potential risk.

Table 5-3 EIF results for discharges of produced water from the Riser platform at Johan Sverdrup. The applied PNECs are also listed.

Computed max. EIF:	**269**								
Time averaged EIF:	91								
Components	Product	Rel.Tons/ day	Concentration ppm	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total		31050							293
BTEX			3.8619	17	2.16	5.806674	1	5.806674	
Napthalene			0.9786	2.1	7.95	21.37178625	1	21.37178625	
PAH 2-3 rings			0.1421	0.15	23.87	64.16912425	1	64.16912425	
PAH 4+ rings			0.0036	0.05	1.35	3.62917125	2	7.2583425	
Phenol C0-C3			1.7827	10	2.5	6.7206875	1	6.7206875	
Phenol C4-C5			0.0882	0.36	5.1	13.7102025	1	13.7102025	
Phenol C6+			0.004	0.04	1.96	5.269019	2	10.538038	
Disp.oil			10	40.4	5.37	14.43603675	2	28.8720735	
Zinc			0.00026	0.46	0.01	0.02688275	1	0.02688275	
Copper			0.0063	0.02	7.16	19.248049	1	19.248049	
Nickel			0.0029	1.22	0.03	0.08064825	1	0.08064825	
Cadmium			0.00011	0.028	0.05	0.13441375	1	0.13441375	
Lead			0.00063	0.182	0.04	0.107531	1	0.107531	
Mercury			0.00004	0.008	0.07	0.18817925	1	0.18817925	
Dem 6 KI			0.053	21.8	0.03	0.08064825	1	0.08064825	
Dem 6 KII			0.57	1000	0.01	0.02688275	1	0.02688275	
Dem 6 KIII			1.13	55.6	0.32	0.860248	1	0.860248	
Dem 6 KIV			0.42	50	0.12	0.322593	2	0.645186	
Dem 6 KV			1.13	39.5	0.47	1.26348925	1	1.26348925	
Floc 1 KI			0.1	1334	0	0	1	0	
MEG			4.34	19235	0	0	1	0	
DF 5 KI			0.0087	69	0	0	1	0	
DF 5 KII			0.000082	1000	0	0	2	0	
SI 14 KI			1	430	0.03	0.08064825	1	0.08064825	
AI 3 KI			0.000013	1000	0	0	2	0	
AI 3 KII			0.013	25	0	0	1	0	
AI 3 KIII			0.00034	51	0	0	1	0	
H2S-K1			30	51	13.63	36.64118825	1	36.64118825	
H2S-K2			30	27	27.78	74.6802795	1	74.6802795	

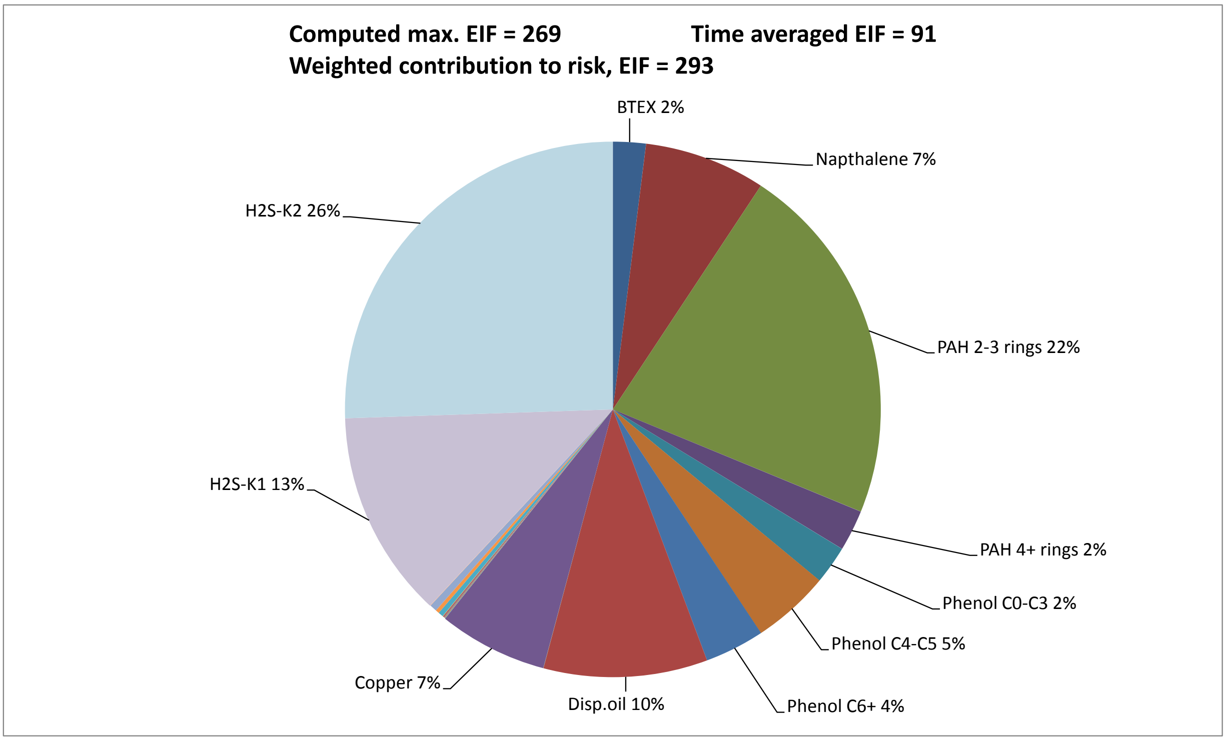


Figure 5-6 Pie chart of contribution of each substance in the produced water discharge to the overall EIF.

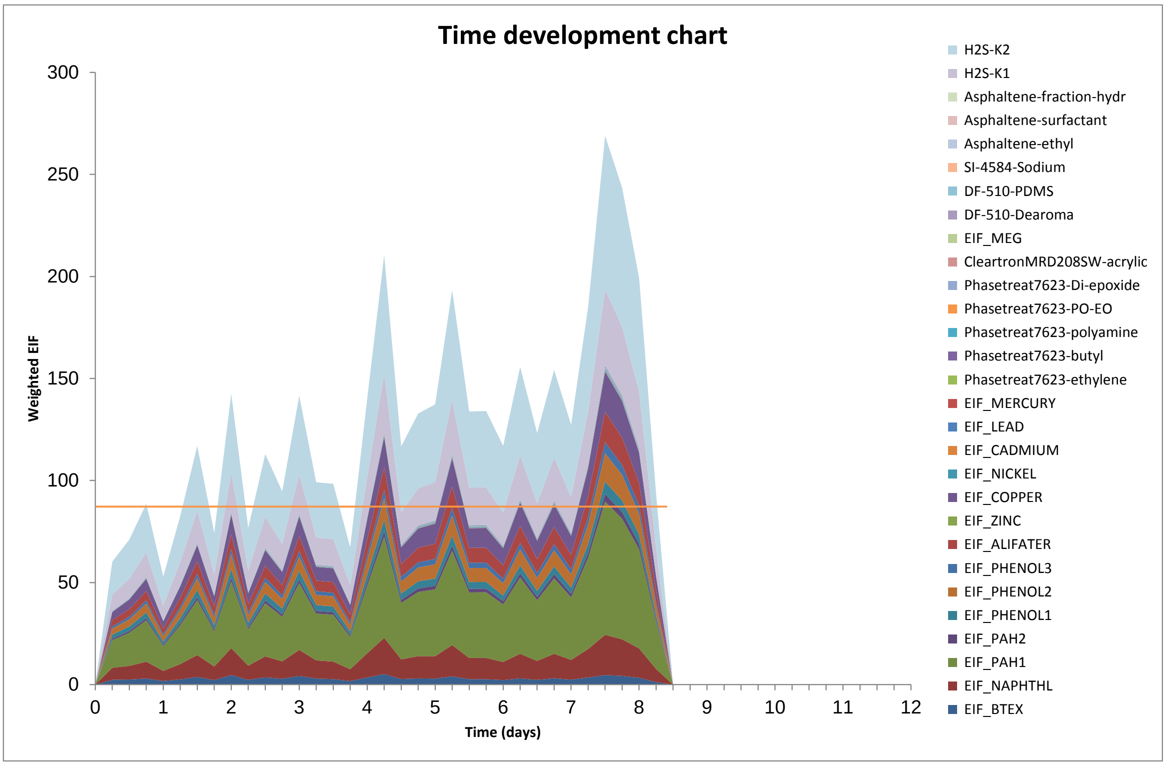


Figure 5-7 Time development of EIF for the water column over 30 days simulation for Johan Sverdrup. Orange line marks time averaged EIF of 91.

5.2.2 Valuable resources in the area in relation to discharges

In Figure 5-8 the time step with the maximum potential risk of produced water is shown together with identified valuable resources and areas identified in the area of the Johan Sverdrup field. There are no overlaps between the potential risk areas and the valuable resources and areas identified; indicating that these identified resources and areas should not be directly affected by the discharges of produced water. Sand eel spawning areas have been identified north and south of the Johan Sverdrup field, as well as mackerel and cod spawning areas south of the field. It cannot be ruled out that during periods of spawning eggs and larvae may drift from the spawning areas into the areas defined by the Johan Sverdrup field. Considering that discharges of produced water are most likely limited to a relatively short period of time and that spawning periods will cover a much larger time span it is considered unlikely that the produced water discharges have an effect at the population level. More likely is that individual larvae and eggs may be affected if the discharges overlap periods of spawning.

The risk calculations in the DREAM model are based on PEC/PNEC relationship. PNEC values are not species specific but a "generic" value with the aim of protecting 95 % of the species in the modeled domain. As such the potential risk associated with produced water is mostly relevant for "all other" species than those identified as valuable in the Johan Sverdrup area.

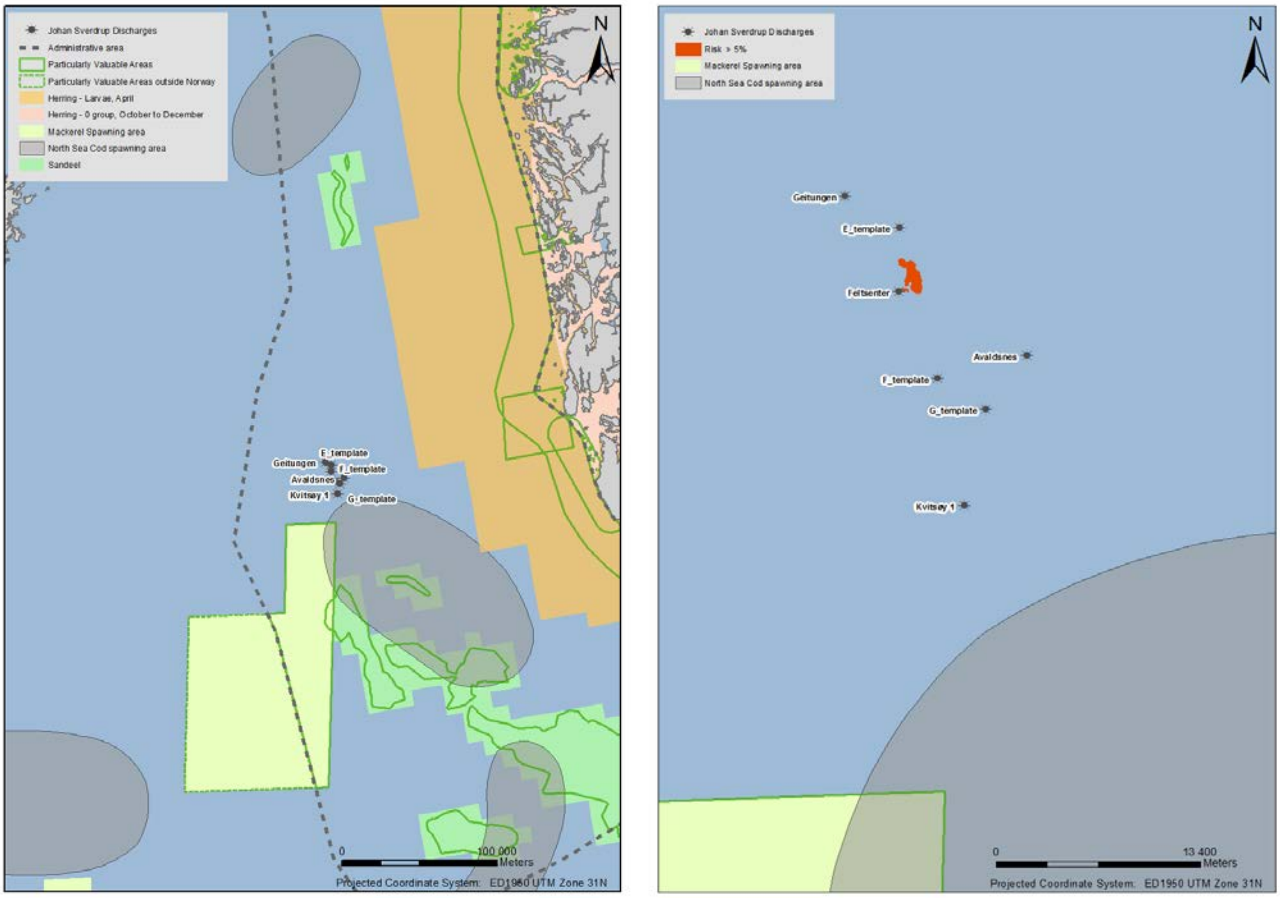


Figure 5-8 Right: Identified valued resources and areas in the area of the Johan Sverdrup field together with the time step where the distribution of the potential risk (risk >5% or PEC/PNEC>1) is largest. Left: Zoomed in figure.

5.2.3 Literature review

DNV GL has looked into the literature for additional information regarding the compounds contributing most to the EIF in produced water according to the model. This is done in order to supplement the risk results, and the corresponding PNEC values used in order to calculate potential risk from the DREAM model. The focus on the literature review has been fish in general because this is regarded as most relevant based on the valuable recourses identified and that produced water is most relevant for water column organisms.

Regarding the H_2S scavenger DNV GL has no information on the chemical identities the two compounds part of this product with high contribution to total EIF. The assessment is therefore based on the three consecutive compound groups: 2-3 ring PAHs (22% of total EIF), dispersed oil (10%) and naphthalene (7%). The assessment of 2-3 ring PAHs is made for phenanthrene, the representative compound of this group in DREAM modelling with a modelled PNEC of 0.15 µg/l in water. The compound group “naphthalene” is considered consisting of both alkylated and non-alkylated forms.

The lethal concentration of naphthalene and alkylated naphthalenes in Atlantic cod *eggs* is approximately 1 mg/l, with reported 100% mortality in the range 2.0-3.3 mg/l (Sætre *et al.*, 1984; Falk-Petersen *et al.*, 1982). Impaired development of *eggs* from the same species has been reported after exposure to 2-methylnaphthalene at 300 µg/l (Stene & Lonning, 1984). In experiments with Atlantic cod *larvae*, phenanthrene has been shown to bioaccumulate at a concentration of 125 µg/l (Petersen & Kristensen, 1998).

Increased mortality related to exposure to pure heptane, representative of aliphatic compounds (“dispersed oil”), has been reported down to 100 mg/l in Coho salmon (Morrow *et al.*, 1975). Lethal exposure concentrations of small PAHs (2-3 rings) in adult and juvenile fish have not been identified in the literature, whereas sub lethal exposure experiments where adults/juveniles have been exposed to pure naphthalene or phenanthrene fractions have not been identified in the literature. The vast majority of published results have instead used crude oil in exposure experiments, either as water accommodated fraction (WAF) or as dispersed oil droplets.

Impaired growth of early larval stages of Atlantic cod has been reported at a measured exposure concentration of 19 µg/l (nominal 50 µg/l), whereas 100 µg/l (nominal 250 µg/l) affected feeding behaviour after exposure to the WAF of Ekofisk crude oil (Tilseth *et al.*, 1984). Adults of the same species exhibit reduced growth rate and organ weights over total body weight as a result of chronic exposure (3 weeks) to nominal 12 µg/l (Kiceniuk & Khan, 1987).

The lowest reported, sublethal effect levels in other fish species include 10 µg/l for accumulation in juvenile Australian bass (*Macquaria novemaculeata*; Cohen *et al.*, 2001), 25 µg/l for histological effects in juvenile pink salmon (*Oncorhynchus gorbuscha*; Brand *et al.*, 2001), 10 µg/l for growth of Pacific Herring hatchlings (*Clupea pallasi*; Kocan *et al.*, 1996), and 30 µg/l for morphological and histological effects in larvae of the same species (Carls, 1987).

The above cited results demonstrate that comparable exposure concentrations of 10-30 µg/l may induce sub lethal effects in both larvae and adults as a result of exposure over several days. This is in contrast to lethal exposure concentrations, being significantly higher in adults over eggs and larvae. Effect levels of specific compounds, including naphthalene(s), phenanthrene(s) and aliphatics are rather difficult to address from these studies. It is however worth underlining that the Norwegian Environment Agency operates with a quality standard for phenanthrene in marine waters of 1.4 µg/l compared to 0.15 µg/l used in risk modelling. For naphthalene, the quality criteria is 2.4 µg/l, compared to the modelled PNEC of 2.1 µg/l. These quality criteria have been derived from species sensitivity distributions (SSDs) and are benchmarks of marine water quality in Norway. As such they appear to represent relevant effect levels.

In this context, it is also important to emphasize that laboratory exposure studies represent continuous exposure to a certain oil load over extended periods. The perhaps most important conclusion from the Water Column Monitoring programme in the Norwegian sector of the North Sea is that laboratory results cannot be transferred directly to a field exposure situation (Resource council of Norway, 2012). In the field, fish will be subject to transient hydrocarbon exposure even if held in cages at close distance to the produced water discharge, resulting in small or non-measurable effects in fish (Sundt *et al.*, 2012).

Lethal exposure concentrations are significantly higher than the PNEC used in risk modelling. The literature study shows effects of sub lethal parameters in both adults and fish larvae at oil concentrations down to 10 µg/l. However, the WCM programme has clearly shown that laboratory results cannot be directly transferred to a field exposure situation where water column resources will be subject to transient exposure to potentially toxic oil concentrations, and at close distance to the discharge point. It is concluded that produced water discharges from Johan Sverdrup will result in small effects in a restricted water volume close to the discharge point. It is considered unlikely that these effects will be measurable at the population level.

Based on the literature some effect levels related to fish in general are suggested:

- Dispersed oil: 40.4 µg/l => Used PNEC in DREAM is 40.4 µg/l (same)
- 2-3 rings PAH: 1.4 µg/l => Used PNEC in DREAM is 0.15 µg/l
- Naphthalene: 2.4 µg/l => Used PNEC in DREAM is 2.1 µg/l

Based on the effect levels above a snapshot of the plume for the 3 components (dispersed oil, 2-3 ring PAHs and naftalen) from the time step with the highest overall potential risk is exported from the model. The concentration gradients in the figures are shown with two colors corresponding to values below and above the suggested threshold values. Based on this a potential risk picture for each of the components are visualized (see Figure 5-9 to Figure 5-11).

The concentration gradient for dispersed oil is presented in Figure 5-9. Concentrations above the threshold value of 40.4 µg/l are limited to the upper part of the water column and within a distance of 400 m from the Field center. Overall a volume corresponding to 900 000 m^3 have concentrations above the threshold value at this time step.

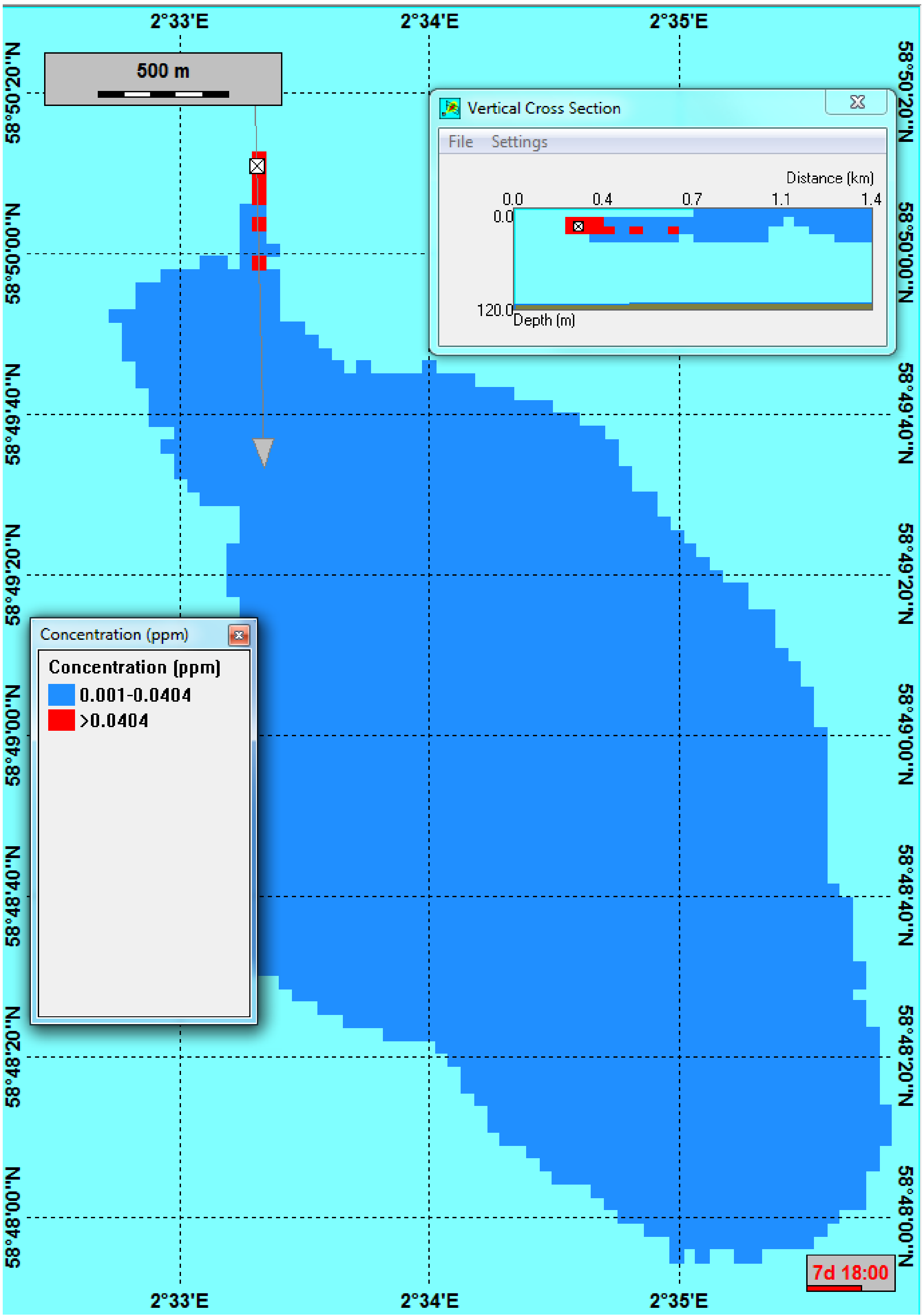


Figure 5-9 Concentrations below and above the suggested threshold value (40.4 µg/l) for dispersed oil at the time step with overall maximum potential risk. Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field centre.

The concentration gradient of 2-3 rings PAH is presented in Figure 5-10. There are no modelled concentrations above the suggested threshold value of 1.4 µg/l, in the time step of max EIF. Concentrations above 1.4 µg/l are only modelled in some time steps very close to the discharge point.

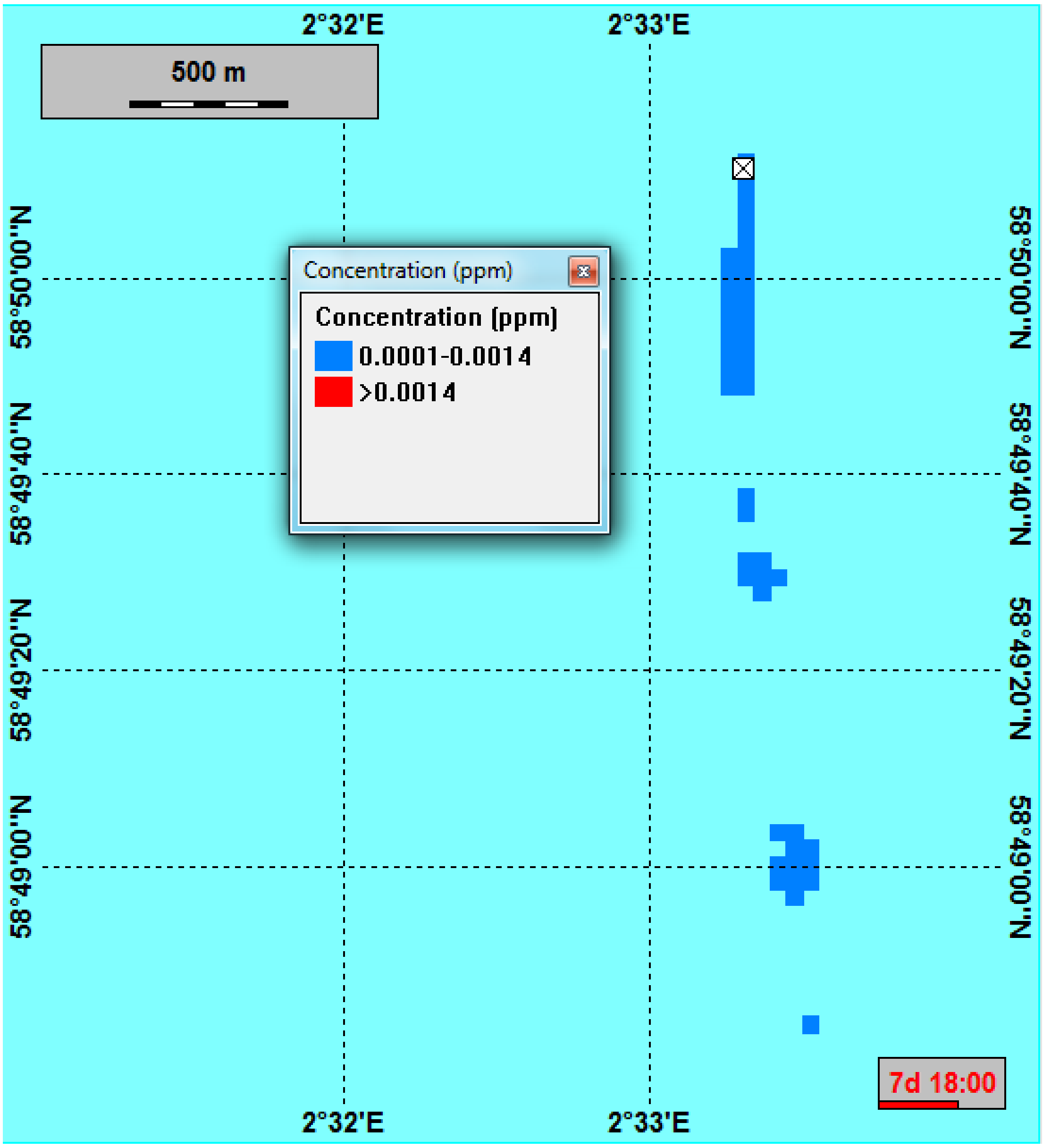


Figure 5-10 Concentrations below and above the suggested threshold value (1.4 µg/l) for 2-3 rings PAH at the time step with overall maximum potential risk. Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field centre.

The concentration gradient of naphthalene is presented in Figure 5-11. Concentrations above the suggested threshold value of 2.4 µg/l are only modelled within 350 m south of the discharge.

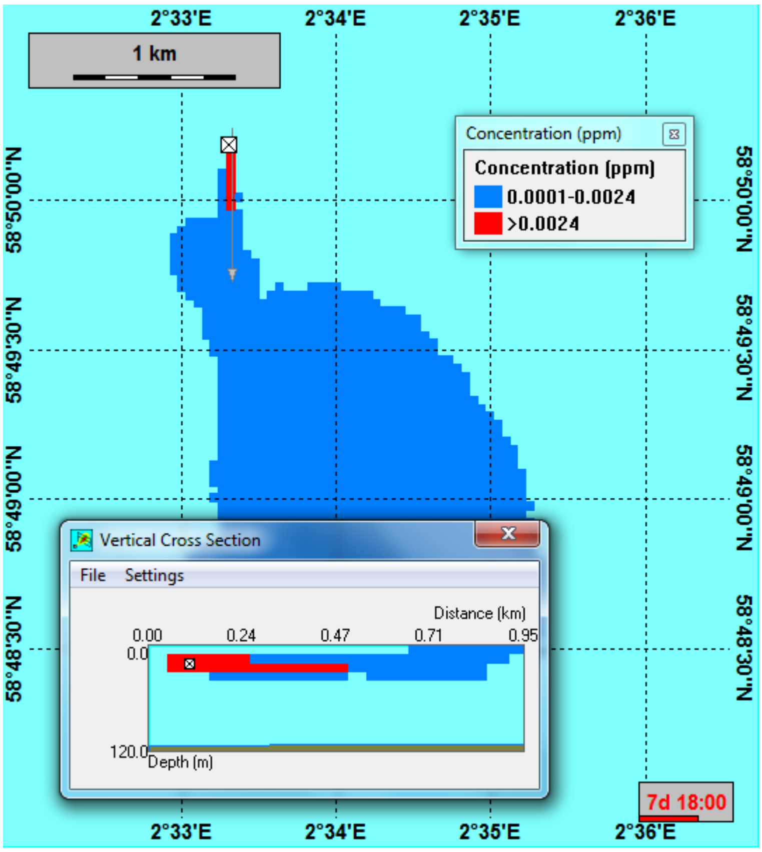


Figure 5-11 Concentrations below and above the suggested threshold value (2.4 µg/l) for naphthalene at the time step with overall maximum potential risk. Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field centre.

5.3 Drilling – water column

Drilling operations today are mainly performed with water based mud (WBM) and only occasionally oil based mud (OBM). Oil can be discharged to sea if oil adhered to cuttings is not more than 1 %. The use of synthetic mud is more or less non-existent today, and has been rarely used after 2001 (Bakke *et al.,* 2013). There exists a vast literature on acute toxicity of WBM components but in general the acute toxicity of WBM is low. This is, amongst other reasons, due to the fact that most chemicals used as additives are mostly classified as PLONOR (Pose Little or No Effects to the Environment).

This section presents the results for the water column impact from the planned drilling operation. The results are presented in a set of figures. The following figures are shown:

- Table and pie chart for the risk contributors
- Time series of EIF value
- Instantaneous (maximum) and accumulated potential risks calculated for the water column, including vertical cross section profiles. Note that maximum potential risk is related to a short time step (hours duration) compared to the whole period modelled (months).

For simulations 2-3, and 9-10, one well is simulated to represent the influence in the water column. The simulations have been run for four different months of the year to show seasonal variations.

5.3.1 Simulation 1

Simulation 1 includes drilling of 6 wells at the Field Center.

Table 5-4 and Figure 5-12 show the contribution of each substance to the EIF in the water column. Computed max EIF is 4632 and time averaged EIF is 267. Since 1 EIF corresponds to a water volume of 100 000 m^3 (100m*100m*10m) a max EIF of 4632 corresponds to a water volume of 463 200 000 m^3 and an averaged EIF of 267 corresponds to water volume of 26 700 000 m^3.

The EIF is dominated by bentonite and barite which contribute 61% and 39% to the total potential risk respectively.

Max EIF of 4632 is related to drilling of well 3 in the month of May (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated in Figure 5-13 the potential risk varies from about 3500 (well 1- drilled in February) to 4632 (well 3 - May) and is only related to a relatively short period when the different wells are drilled, and to the lower 10-20 m of the water column (Figure 5-14).

Table 5-4. EIF results for the water column from drilling – Simulation 1: 6 wells at the Field center.

Computed max. EIF:	**4632**						
Time averaged EIF:	267						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							4632
Cuttings		100000	0.04	1.8526138	1	1.8526138	
Bentonite		88	61.47	2847.004257	1	2847.004257	
Barite		200	38.5	1783.140783	1	1783.140783	

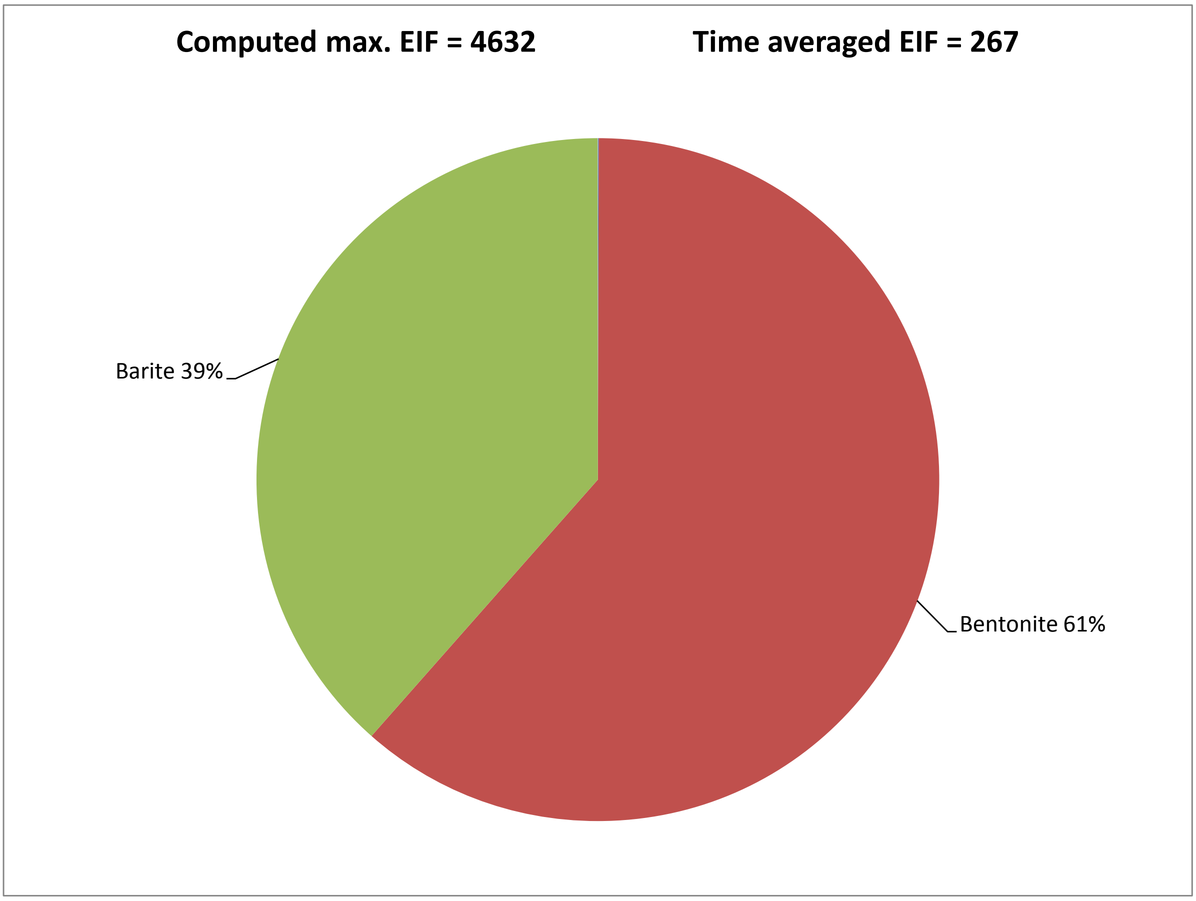


Figure 5-12 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, simulation 1.

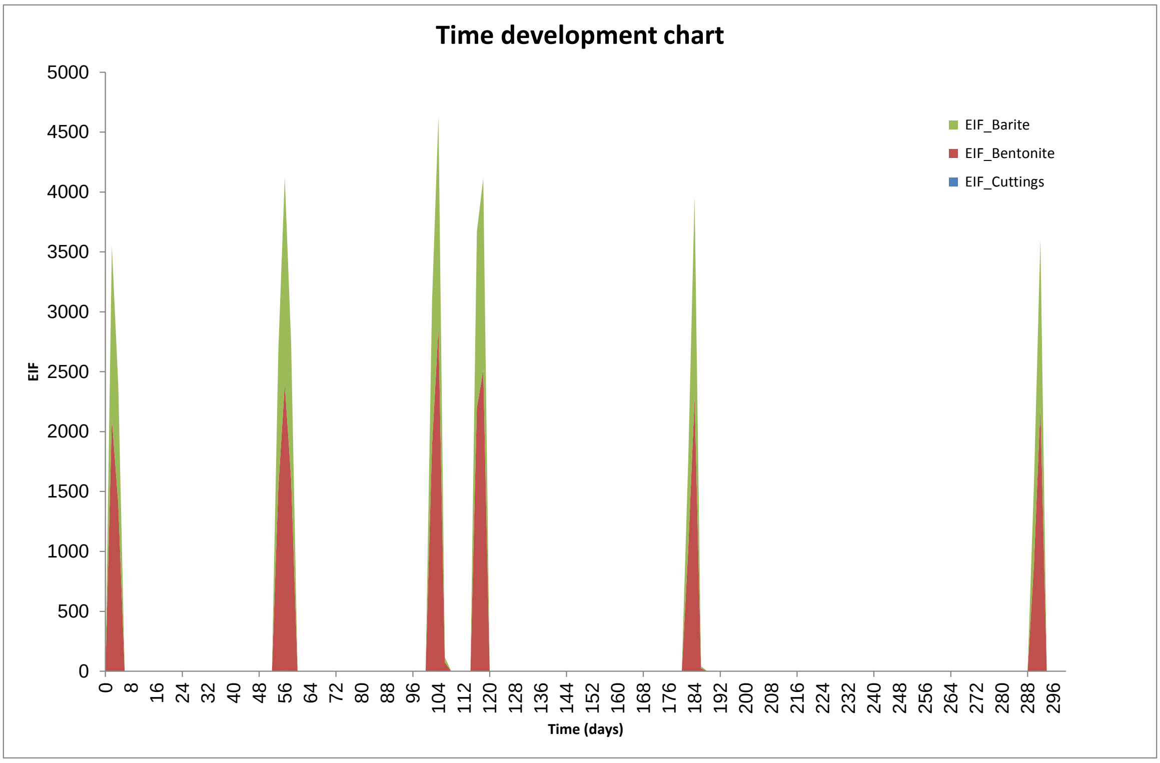


Figure 5-13 Time development of the EIF for the water column for Simulation 1: discharge from 6 wells at Field-center.

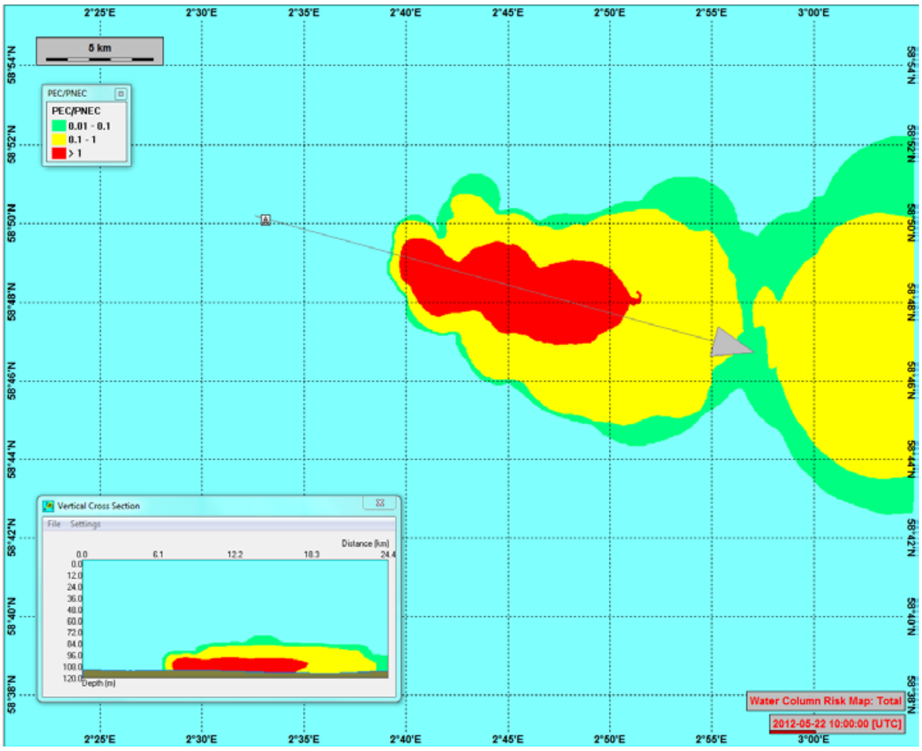


Figure 5-14 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 1: discharge from 6 wells at Field-center. Location of the Field center is marked as a square in the main figure. The vertical cross section figure represents the arrow starting at the Field center.

5.3.2 Simulation 2

Simulation 2 includes drilling of 27 wells at the Field Center.

Due to technical limits Simulation 2 – water column was performed for one well in four different seasons, February, May, August, November respectively. For sediments drilling of all 27 wells were simulated.

Table 5-5 shows the contribution of each substance to the EIF in the water column. Computed max EIF vary from 6401 in May to 9492 in February.

The EIF is dominated by TCC powder, barite and bentonite, see Figure 5-15.

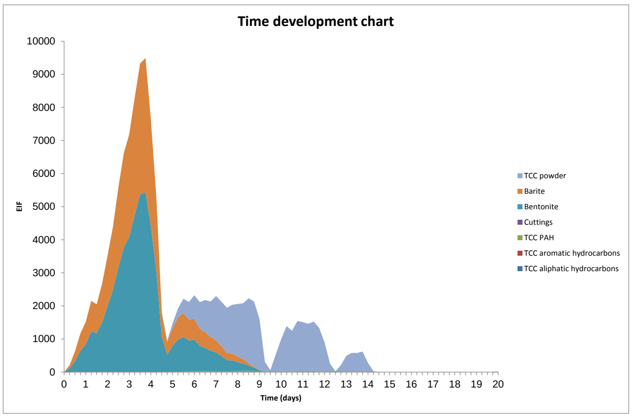
As illustrated in Figure 5-16, potential risk is only related to a relatively short period when the drilling is carried out. The footprint of the plume and areas with potential risk are exemplified in Figure 5-17 (August), and as can be seen there is a potential risk in more or less the whole water column, because of discharges both from surface and subsurface, in a short period of time.

Table 5-5 EIF results for the water column from drilling – Simulation 2, discharges from a well at the Field center in four different seasons.

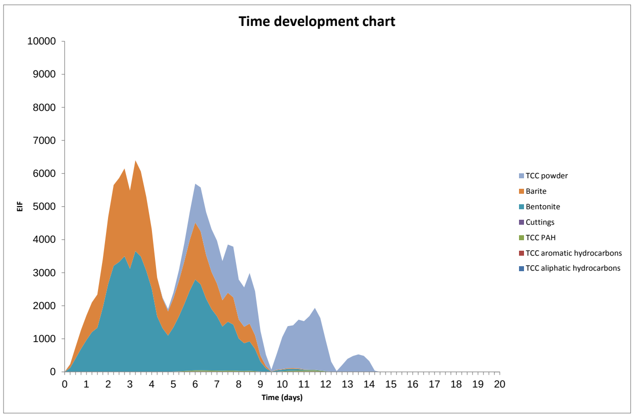
	Month				
		May	**August**	**November**	**February**
Computed max EIF		6401	9310	8791	9492
Time averaged EIF		1883	2773	2205	1680
Components	**PNEC ppb**	**Contribution EIF**			
TCC aliphatic	70.5	10.88	21.41	17.58	20.88
TCC aromatic	2	4.48	3.72	3.51	7.59
TCC PAH	0.022	41.6	83.79	66.81	77.83
Cuttings	100.000	1.92	1.86	1.75	2.85
Bentonite	88	2171.84	1339.71	2011.45	2235.46
Barite	200	1416.53	898.42	1325.73	1565.28
TCC powder	150	2753.70	6961.12	5364.46	5582.42

Figure 5-15 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column in 4 different seasons.

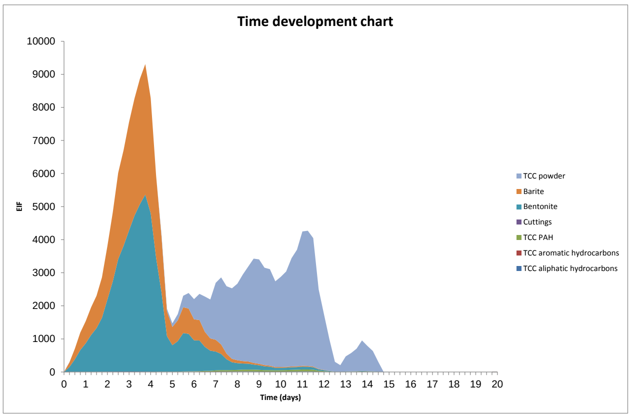
February



May



August



November

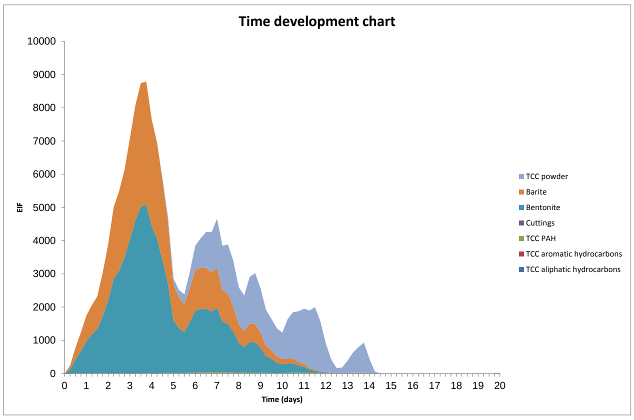


Figure 5-16 Time development of the EIF for the water column for Simulation 2, discharge from a well at Field-center in four different seasons.

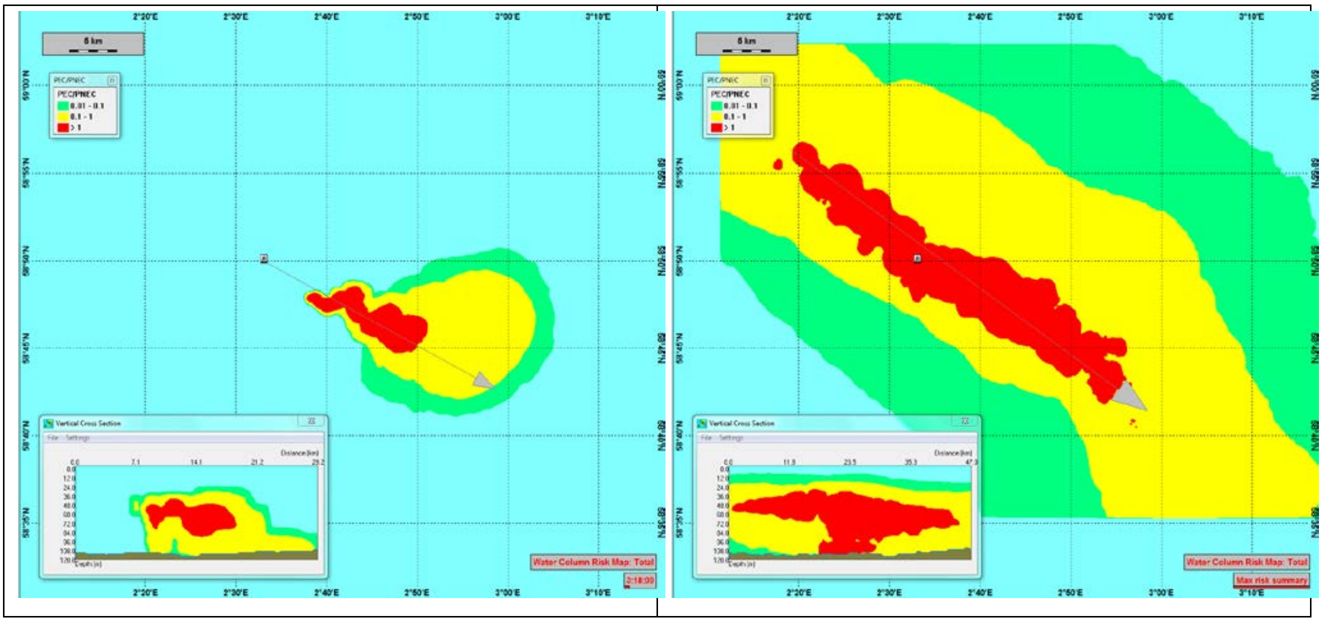


Figure 5-17 Snapshot showing Left: the time instant with maximum potential risk. Right: accumulated maximum potential risk for the whole simulation period (foot-print) for the water column for Simulation 2. Discharge from 1 well at Field-center (CTS + rig), wind and current data for August.

5.3.3 Simulation 3

Simulation 3 includes drilling of 24 wells at Avaldsnes.

Due to technical limits Simulation 3 – water column was performed for one well in four different seasons, February, May, August and November respectively. For sediments drilling of all 24 wells were simulated.

Table 5-6 shows the contribution of each substance to the EIF in the water column. Computed max EIF vary from 6698 in May to 9377 in February.

The EIF is dominated by TCC powder, barite and bentonite, see Figure 5-18.

As illustrated in Figure 5-19 potential risk is only related to a relatively short period when the drilling is carried out. The footprint of the plume and areas with potential risk are exemplified in Figure 5-20 (August), and as can be seen there is a potential risk in more or less the whole water column, because of discharges both from near the sea surface and just above the sea bottom.

Table 5-6 EIF results for the water column from drilling – Simulation 3, discharges from a well at Avaldsnes in four different seasons.

		Month			
		May	**August**	**November**	**February**
Computed max EIF		6698	9106	7751	9377
Time averaged EIF		1739	2212	2180	1654
Components	**PNEC ppb**	**Contribution EIF**			
TCC aliphatic	70.5	12.06	20.94	15.10	20.63
TCC aromatic	2	4.68	3.64	3.02	8.44
TCC PAH	0.022	44.88	81.04	58.14	79.70
Cuttings	100.000	2.01	1.82	1.51	2.81
Bentonite	88	2216.29	1166.46	1634.85	2133.19
Barite	200	1450.73	807.69	1057.18	1474.95
TCC powder	150	2967.78	7024.27	4781.47	5656.94

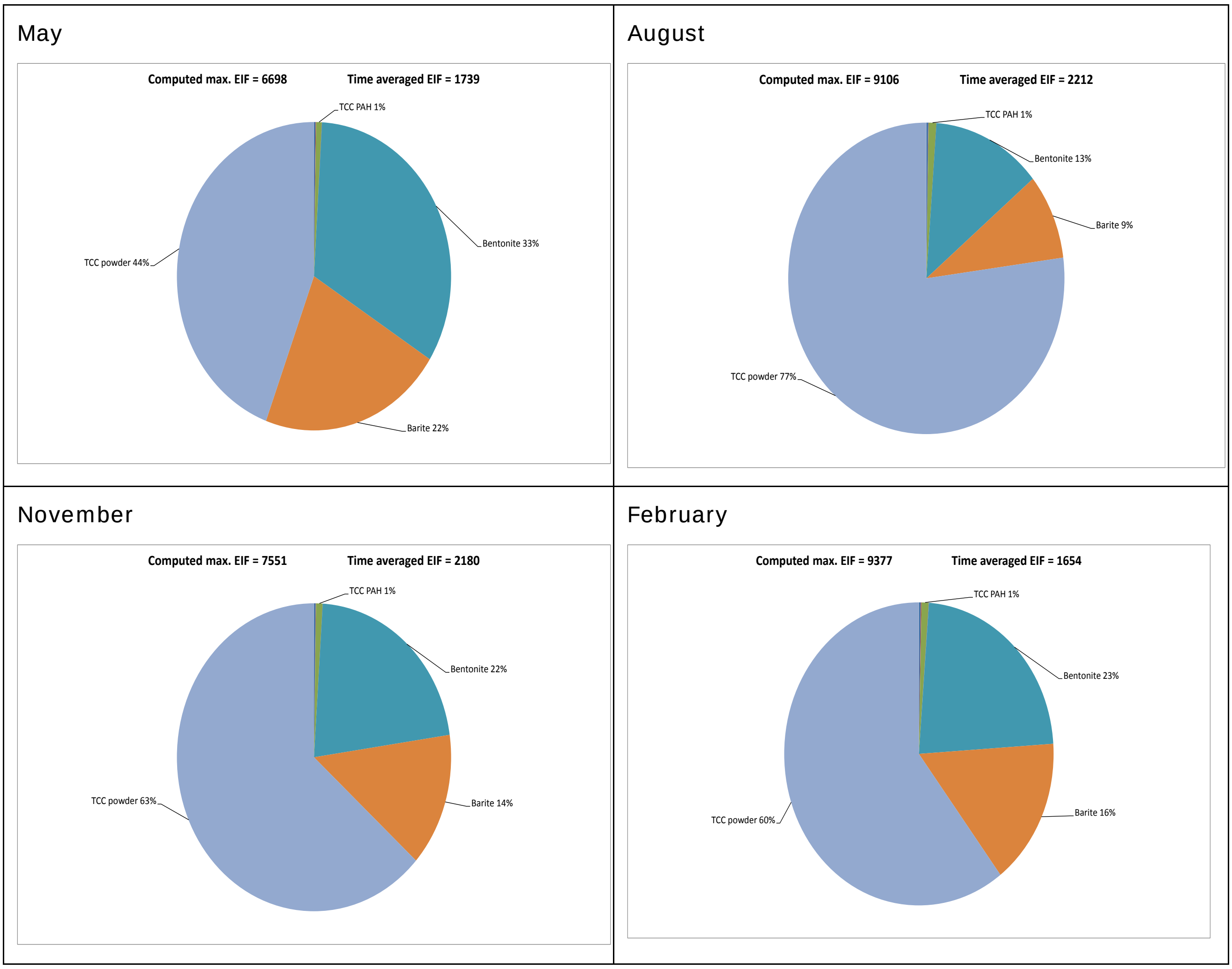


Figure 5-18 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column in 4 different seasons, simulation 3, discharges from a well at Avaldsnes in four different seasons.

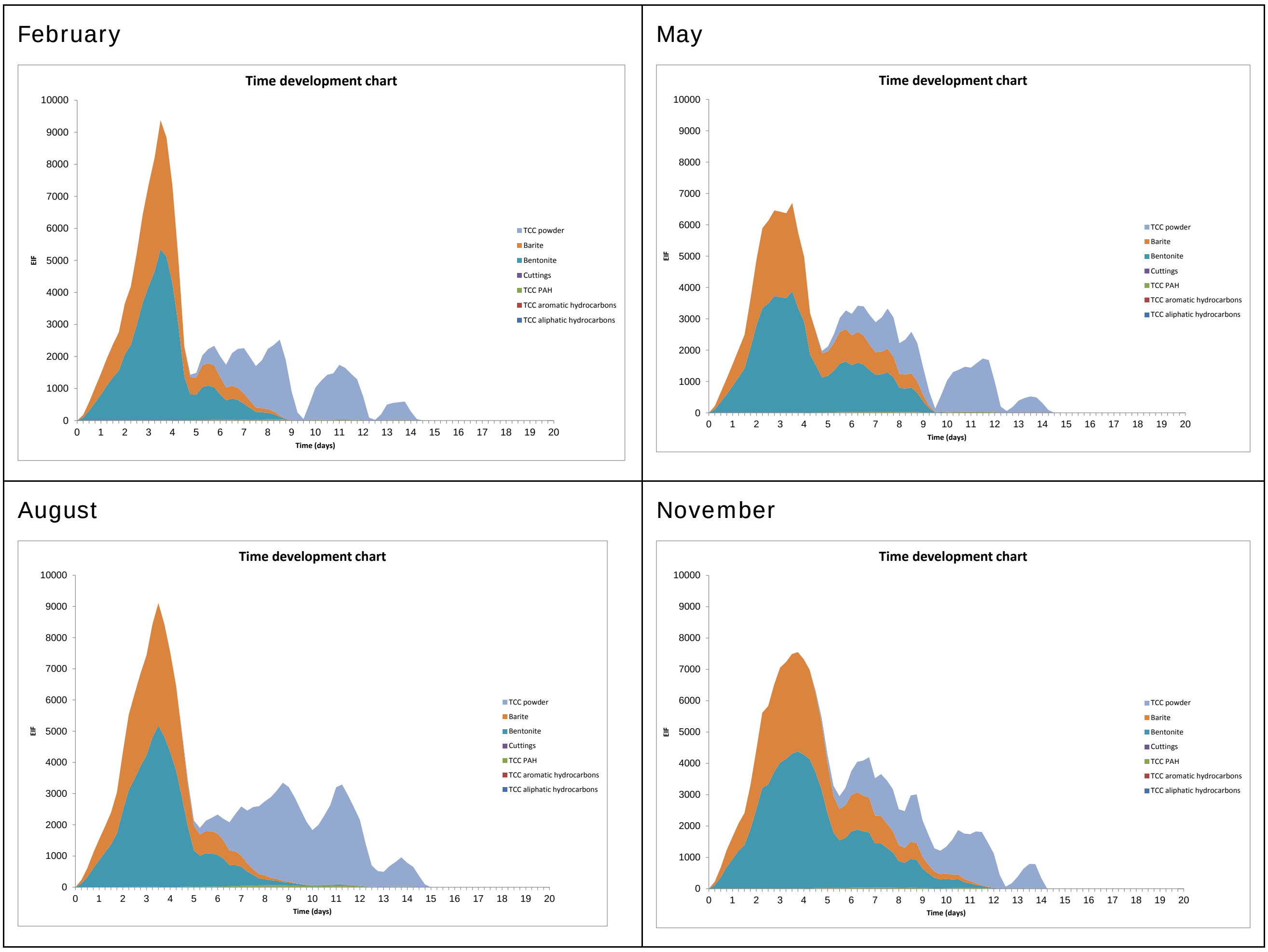


Figure 5-19 Time development of the EIF for the water column for Simulation 3, discharge from a well at Avaldsnes in four different seasons.

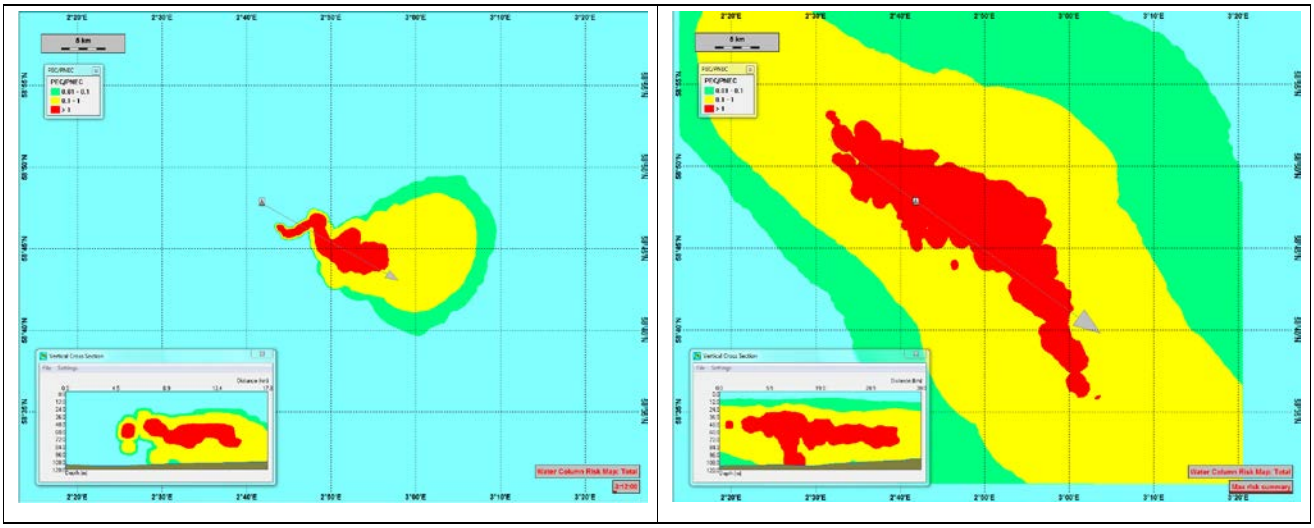


Figure 5-20 Snapshot showing Left: the time instant with maximum potential risk. Right: accumulated maximum potential risk for the whole simulation period (foot-print) for the water column for Simulation 3: Discharge from a well at Avaldsnes (CTS + rig), wind and current data for August.

5.3.4 Simulation 4

Simulation 4 includes drilling of 4 wells at the E-template.

Table 5-7 and Figure 5-21 show the contribution of each substance to the EIF in the water column. Computed max EIF is 3502 and time averaged EIF is 102. Since 1 EIF corresponds to a water volume of 100 000 m^3 (100m*100m*10m) a max EIF of 3502 corresponds to a water volume of 350 200 000 m^3 and an averaged EIF of 102 corresponds to water volume of 10 200 000 m^3.

The EIF is dominated by bentonite and barite which contribute 62% and 38% to the total potential risk respectively.

Max EIF of 3502 is related to drilling of well 2 in June (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated Figure 5-22 the potential risk vary from about 2500 (well 1- drilled in February) to 3502 (well 2 - June) and are only related to a relatively short period when the different wells are drilled and to the lower 10-20 m of the water column (Figure 5-23).

Table 5-7 EIF results for the water column from drilling – Simulation 4, discharges 4 wells at Template E.

Computed max. EIF:	**3502**						
Time averaged EIF:	102						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							3502
Cuttings		100000	0.03	1.05055686	1	1.05055686	
Bentonite		88	62.48	2187.959754	1	2187.959754	
Barite		200	37.49	1312.845889	1	1312.845889	

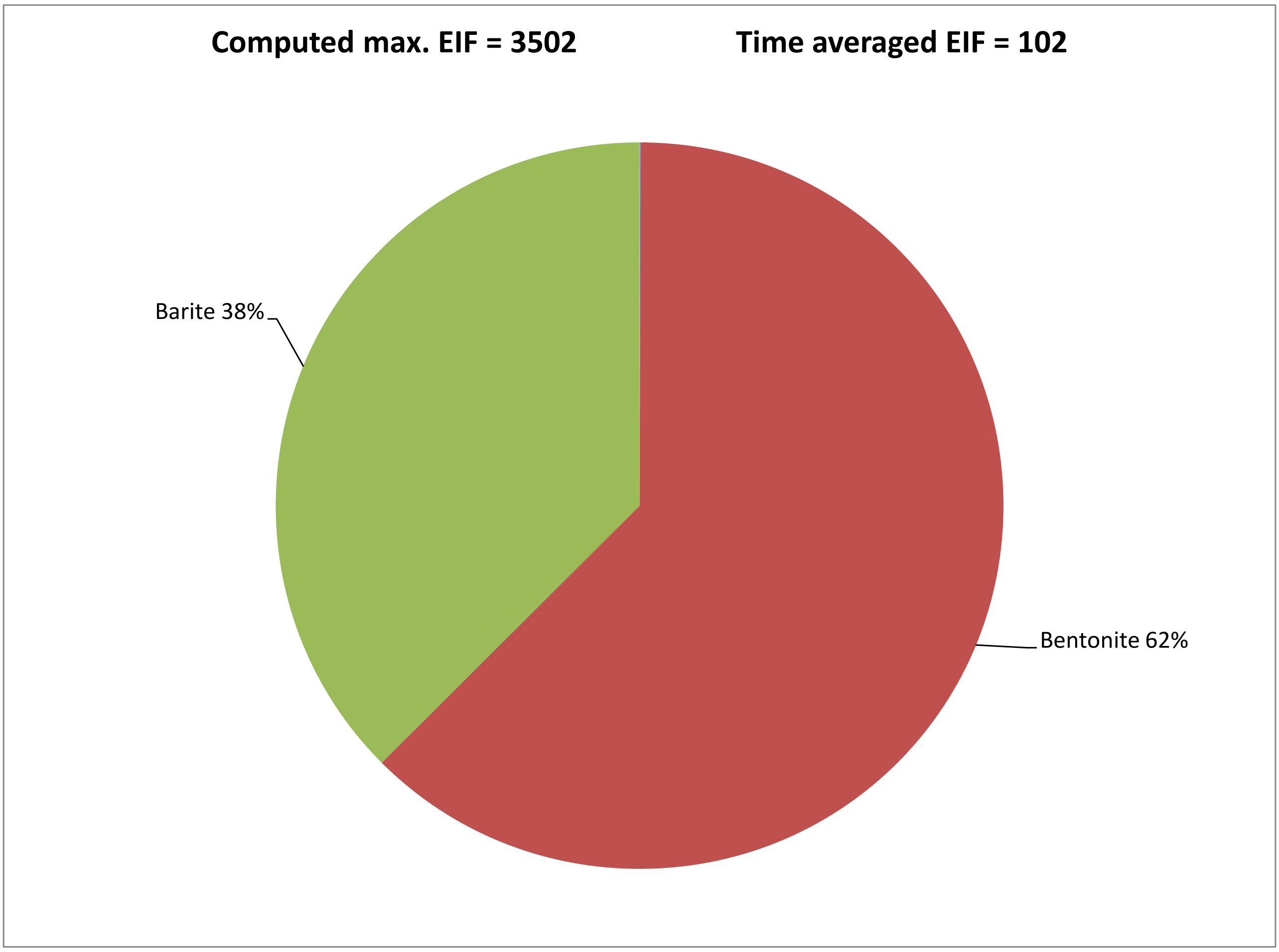


Figure 5-21 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, Simulation 4, discharge from 4 wells at Template E.

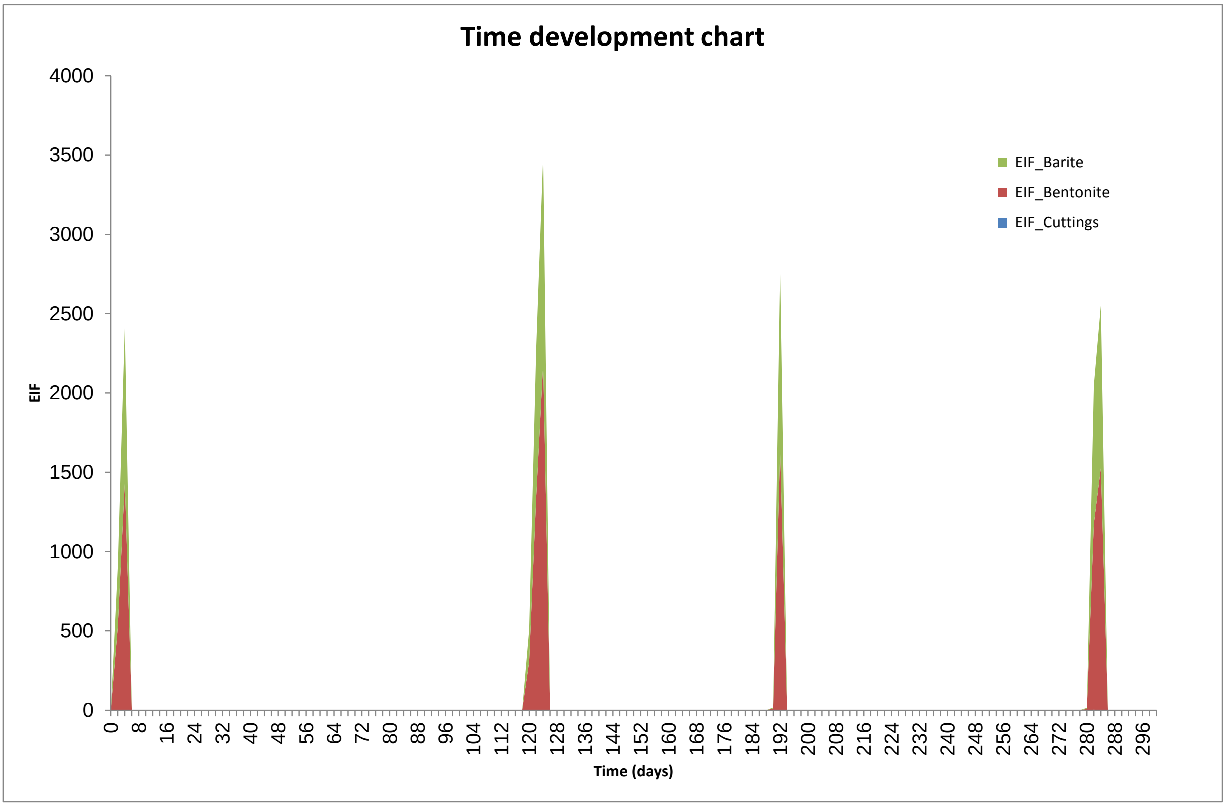


Figure 5-22 Time development of the EIF for the sediment for Simulation 4, discharge from 4 wells at Template E.

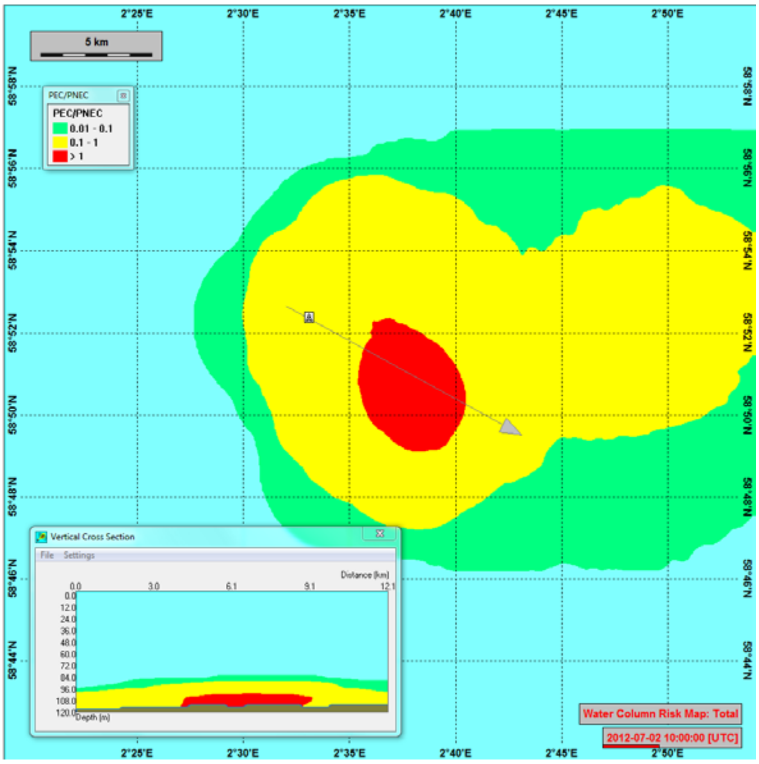


Figure 5-23 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 4: discharge from 4 wells at Template E.

5.3.5 Simulation 5

Simulation 5 includes drilling of 4 wells at F-template.

Table 5-8 and Figure 5-24 shows the contribution of each substance to the EIF in the water column. Computed max EIF is 4267 and time averaged EIF is 107. Since 1 EIF corresponds to a water volume of 100 000 m^3 (100m*100m*10m) a max EIF of 4267 corresponds to a water volume of 426 700 000 m^3 and an averaged EIF of 107 corresponds to water volume of 10 700 000 m^3.

The EIF is dominated by bentonite and barite which contribute 63% and 37% to the total potential risk respectively.

Max EIF of 4267 is related to drilling of well 3 in the month of September (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated in Figure 5-25 the potential risk varies from about 1600 (well 4- drilled in December) to 4267 (well 3 - September) and is only related to a relatively short period when the different wells are drilled, and to the lower 10-20 m of the water column (Figure 5-26).

Table 5-8 EIF results for the water column from drilling – Simulation 5, discharges 4 wells at Template F.

Computed max. EIF:	**4267**						
Time averaged EIF:	107						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							4267
Cuttings		100000	0.04	1.70673796	1	1.70673796	
Bentonite		88	63.25	2698.779399	1	2698.779399	
Barite		200	36.72	1566.785447	1	1566.785447	

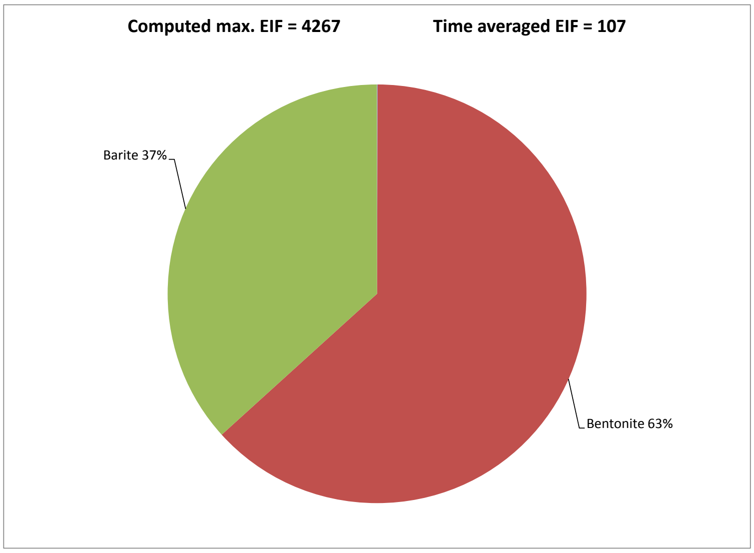


Figure 5-24 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, Simulation 5, discharge from 4 wells at Template F.

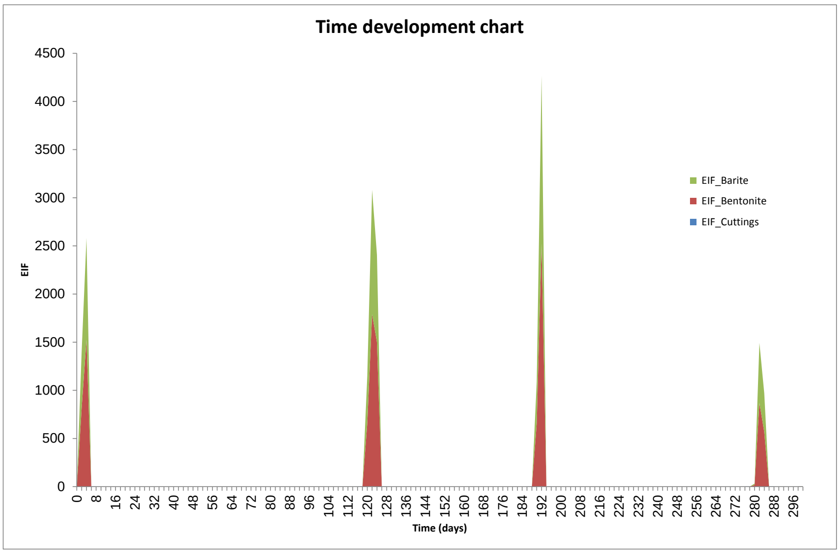


Figure 5-25 Time development of the EIF for the water column for Simulation 5, discharge from 4 wells at F-template.

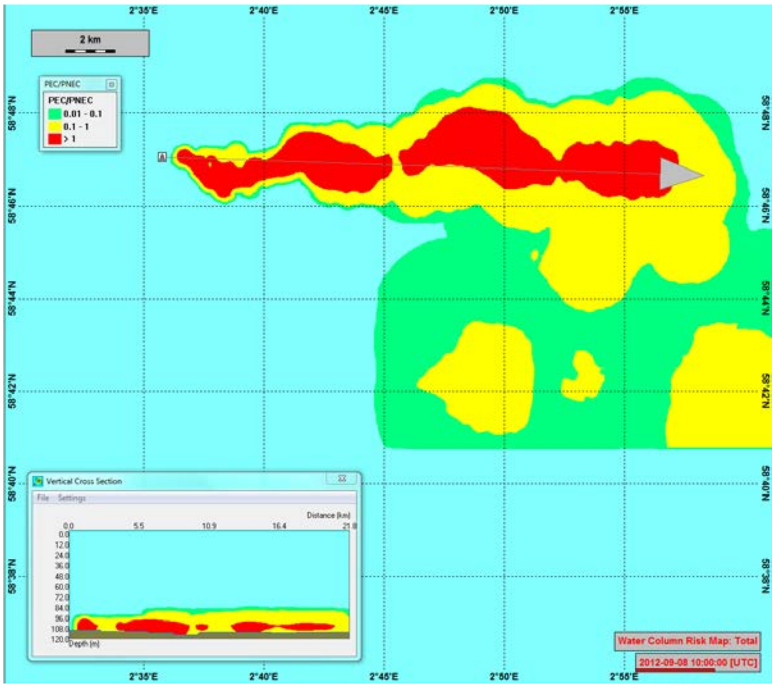


Figure 5-26 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 5, discharge from 4 wells at F-template.

5.3.6 Simulation 6

Simulation 6 includes drilling of 4 wells at G-template.

Table 5-9 and Figure 5-27 shows the contribution of each substance to the EIF in the water column. Computed max EIF is 4833 and time averaged EIF is 104. Since 1 EIF corresponds to a water volume of 100 000 m^3 (100m*100m*10m) a max EIF of 4833 corresponds to a water volume of 483 300 000 m^3 and an averaged EIF of 104 corresponds to water volume of 10 400 000 m^3.

The EIF is dominated by bentonite and barite which contribute 63% and 37% to the total potential risk respectively.

Max EIF of 4833 is related to drilling of well 4 in December (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated Figure 5-28 the potential risk varies from about 2000 (well 1- drilled in January) to 4833 (well 4 - December) and is only related to a relatively short period when the different wells are drilled, and to the lower 10-20m of the water column (Figure 5-29).

Table 5-9 EIF results for the water column from drilling – Simulation 6, discharges 4 wells at Template G.

Computed max. EIF:	**4833**						
Time averaged EIF:	104						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							4833
Cuttings		100000	0.04	1.93309008	1	1.93309008	
Bentonite		88	62.6	3025.285975	1	3025.285975	
Barite		200	37.36	1805.506135	1	1805.506135	

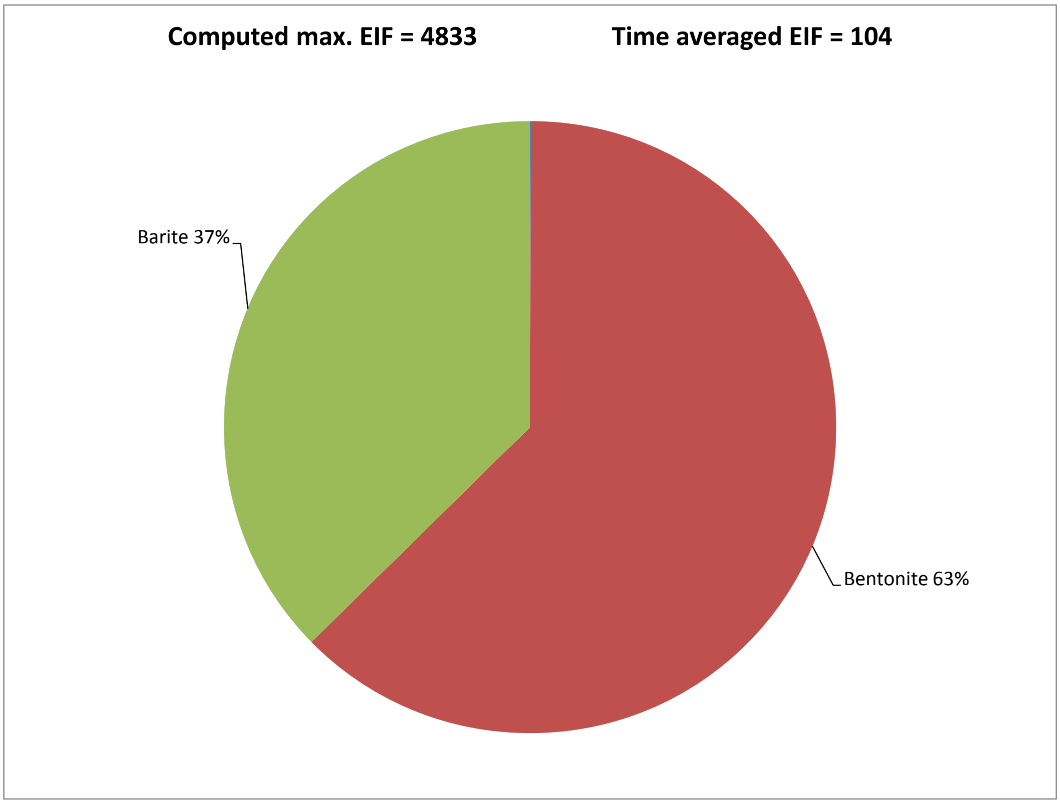


Figure 5-27 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, Simulation 6, discharge from 4 wells at Template G.

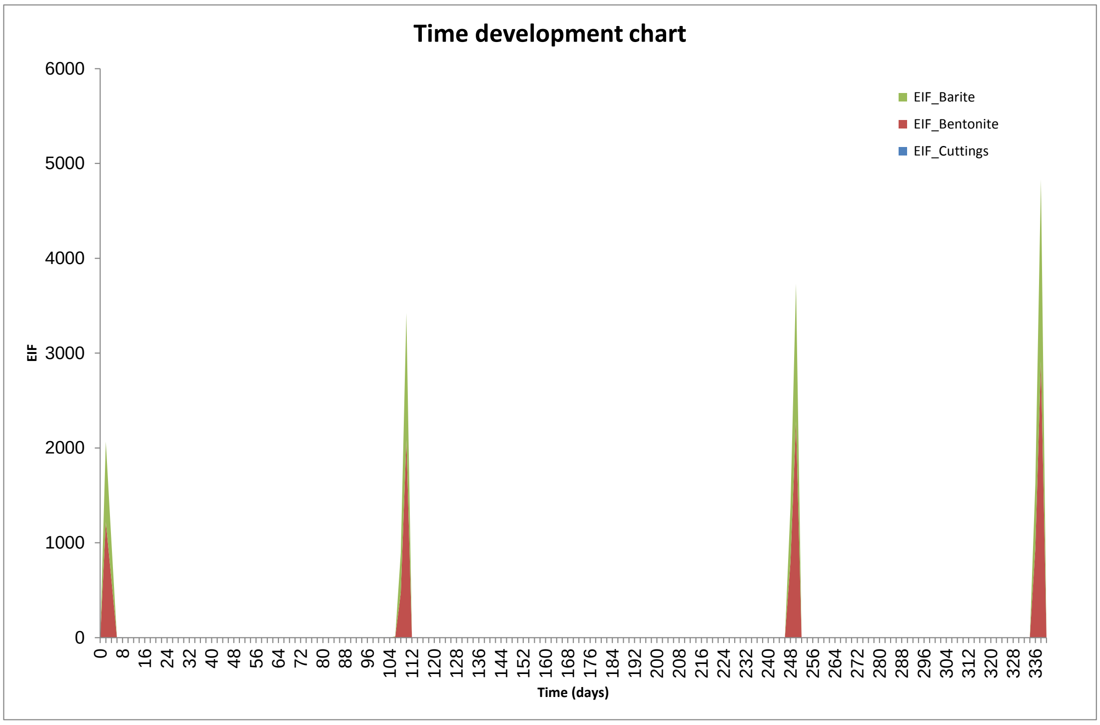


Figure 5-28 Time development of the EIF for the water column for Simulation 6, discharge from 4 wells at the G-template.

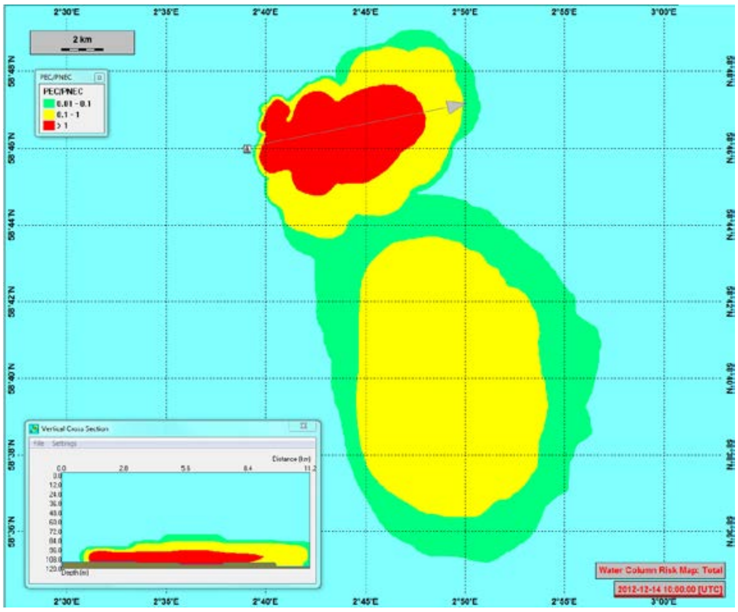


Figure 5-29 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 6, discharge from 4 wells at the G-template.

5.3.7 Simulation 7

Simulation 7 includes drilling of 6 wells at Kvitsøy.

Table 5-10 and Figure 5-30 shows the contribution of each substance to the EIF in the water column. Computed max EIF is 6498 and time averaged EIF is 225. Max EIF of 6498 corresponds to a water volume of 649 800 000 m^3 and an averaged EIF of 225 corresponds to water volume of 22 500 000 m^3.

The EIF is dominated by bentonite and barite which contribute 63% and 37% to the total potential risk respectively.

Max EIF of 6498 is related to drilling of well 4 in July (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated Figure 5-31 the potential risk varies from just below 2000 (well 1- drilled in January) to 6498 (well 4 - July) and are only related to a relatively short period when the different wells are drilled, and to the lower part of the water column (Figure 5-32).

Table 5-10 EIF results for the water column from drilling – Simulation 7, discharges 6 wells at Kvitsøy.

Computed max. EIF:	**6498**						
Time averaged EIF:	225						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							6497
Cuttings		100000	0.03	1.94943276	1	1.94943276	
Bentonite		88	62.73	4076.263901	1	4076.263901	
Barite		200	37.23	2419.246055	1	2419.246055	

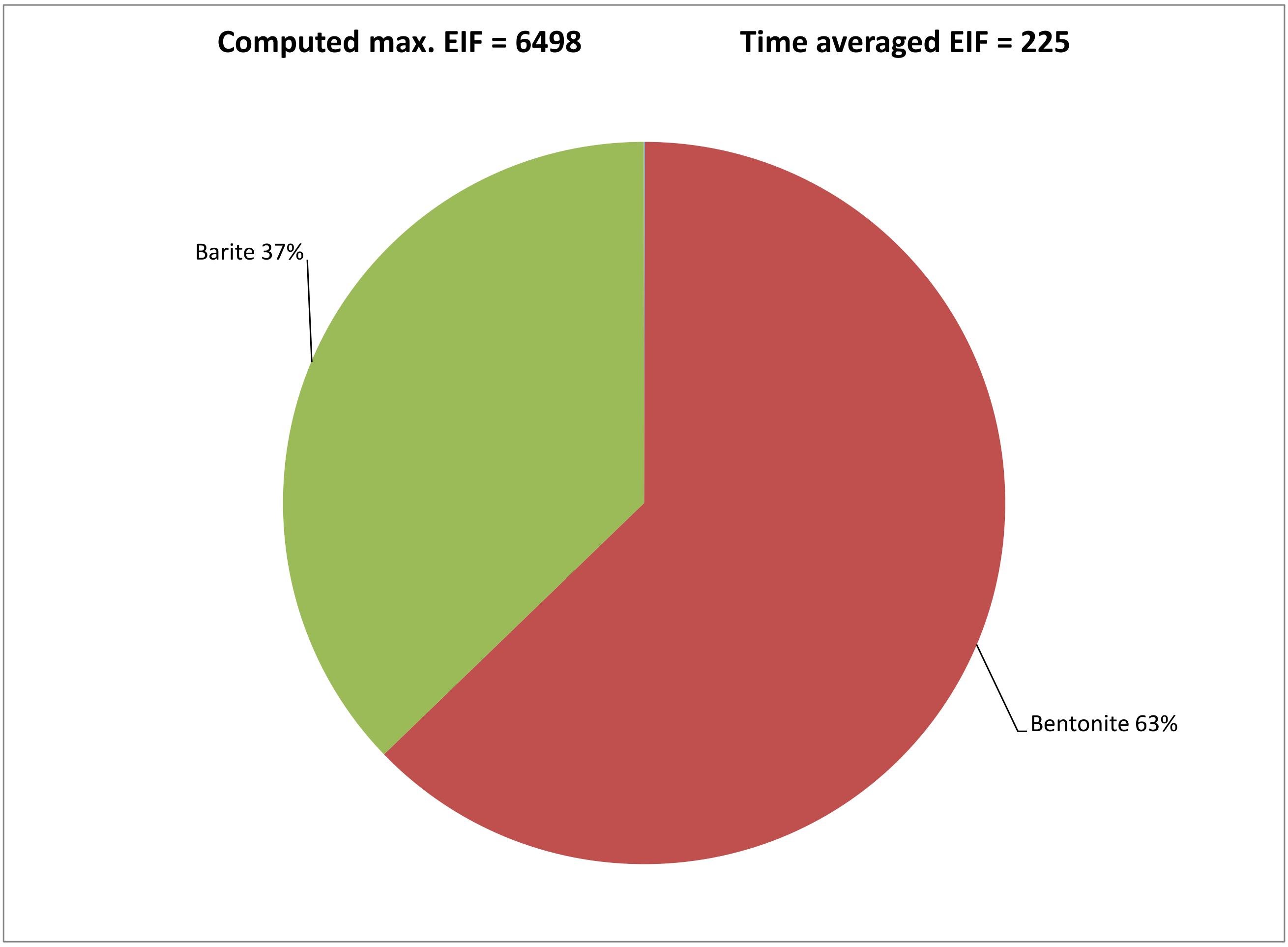


Figure 5-30 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, Simulation 7, discharge from 6 wells at Kvitsøy.

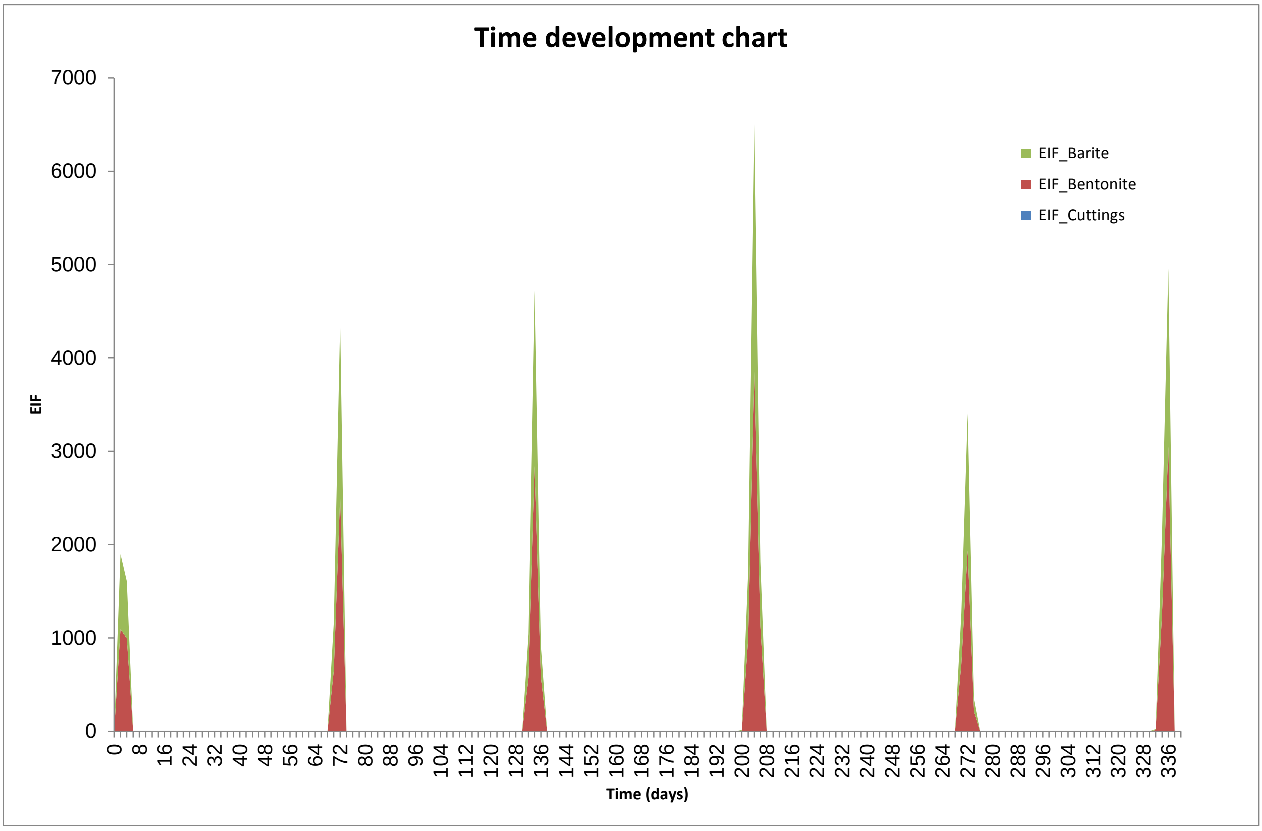


Figure 5-31 Time development of the EIF for the water column for Simulation 7, discharge from 6 wells at Kvitsøy.

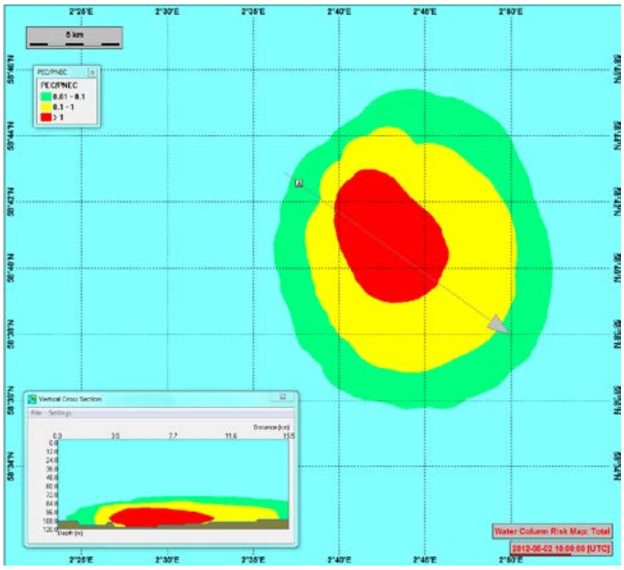


Figure 5-32 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 7, discharge from 6 wells at Kvitsøy.

5.3.8 Simulation 8

Simulation 8 includes drilling of 9 wells at Geitungen.

Table 5-11 and Figure 5-33 shows the contribution of each substance to the EIF in the water column. Computed max EIF is 6497 and time averaged EIF is 210. Max EIF of 6497 corresponds to a water volume of 649 700 000 m^3 and an averaged EIF of 210 corresponds to water volume of 21 000 000 m^3.

The EIF is dominated by bentonite and barite which contribute 64% and 36% to the total potential risk respectively.

Max EIF of 6497 is related to drilling of well 9 in December (see for Appendix B for details regarding time periods for drilling of different wells).

As illustrated in Figure 5-34 the potential risk varies from just below 1200 (well 1- drilled in January) to 6497 (well 9 - December) and is only related to a relatively short period when the different wells are drilled, and to the lower part of the water column (Figure 5-35).

Table 5-11 EIF results for the water column from drilling – Simulation 8, discharges 9 wells at Geitungen.

Computed max. EIF:	**6497**						
Time averaged EIF:	210						
Components	Product	PNEC ppb	Contribution to risk	Contribution EIF	Weight	Weighted contributions	Weighted EIF
Total							6496
Cuttings		100000	0.02	1.2993888	1	1.2993888	
Bentonite		88	64.04	4160.642938	1	4160.642938	
Barite		200	35.93	2334.351979	1	2334.351979	

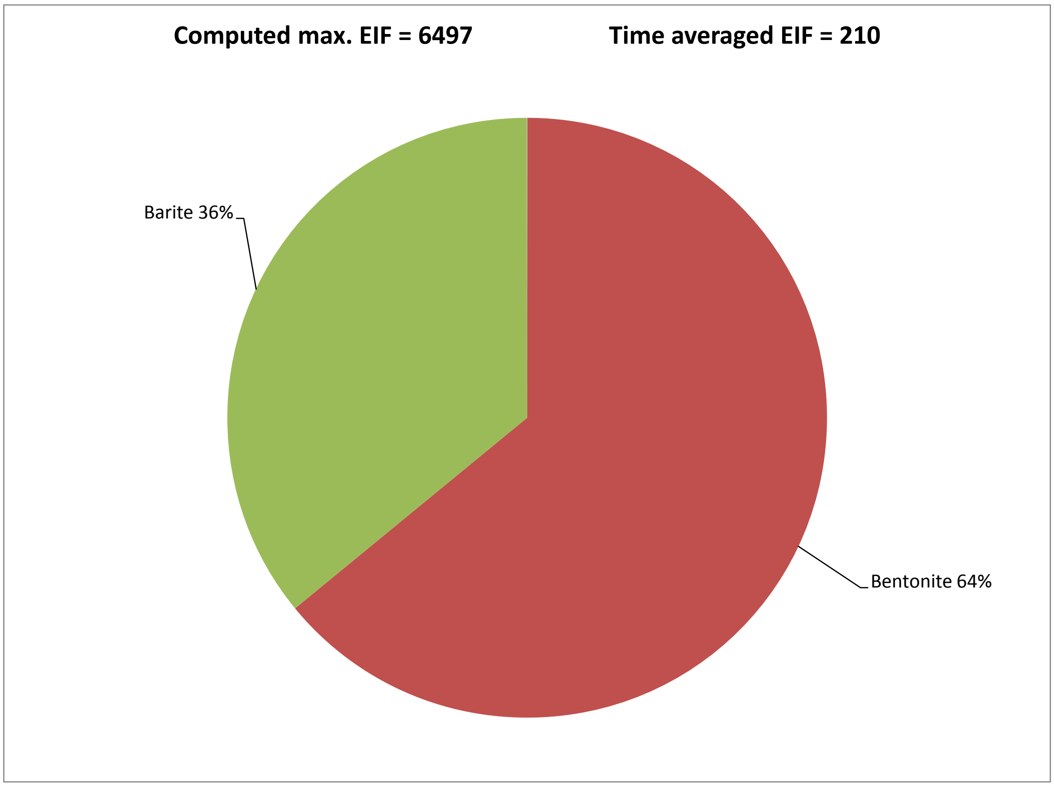


Figure 5-33 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column, Simulation 8, discharge from 9 wells at Geitungen.

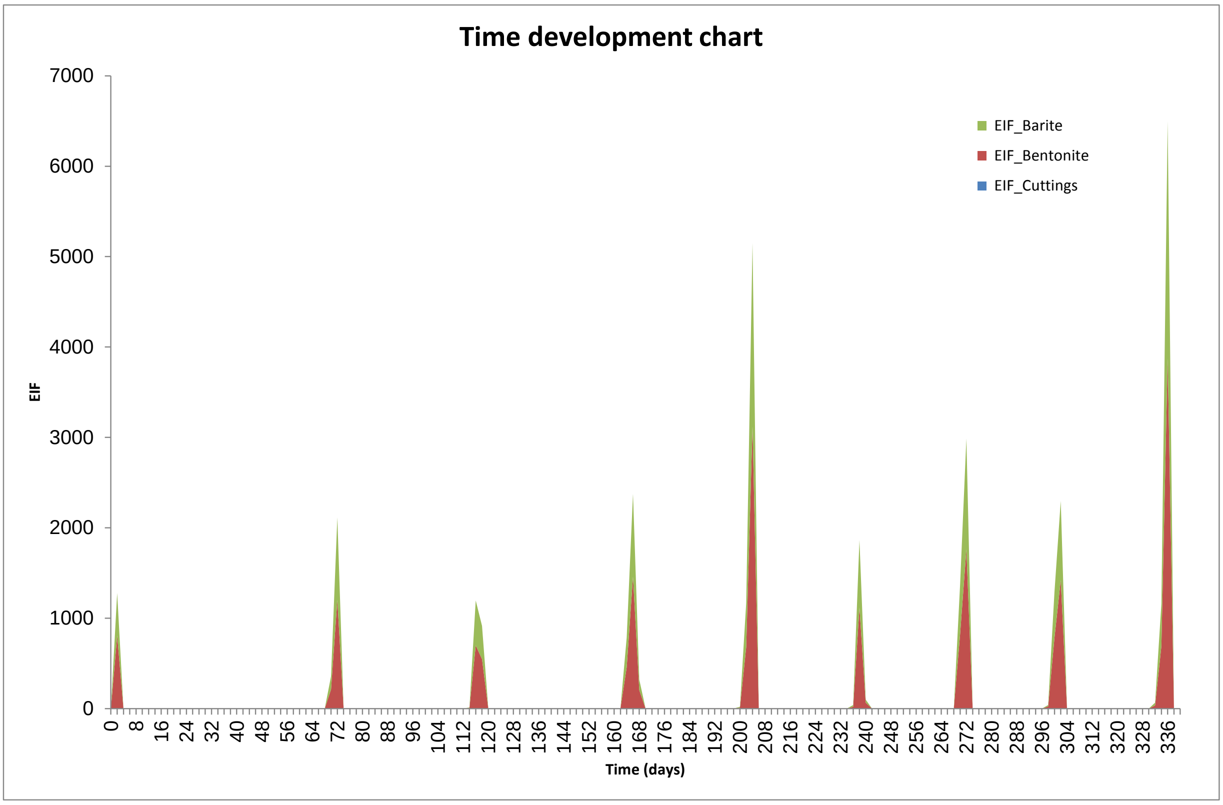


Figure 5-34 Time development of the EIF for the water column for Simulation 8, discharge from 9 wells at Geitungen.

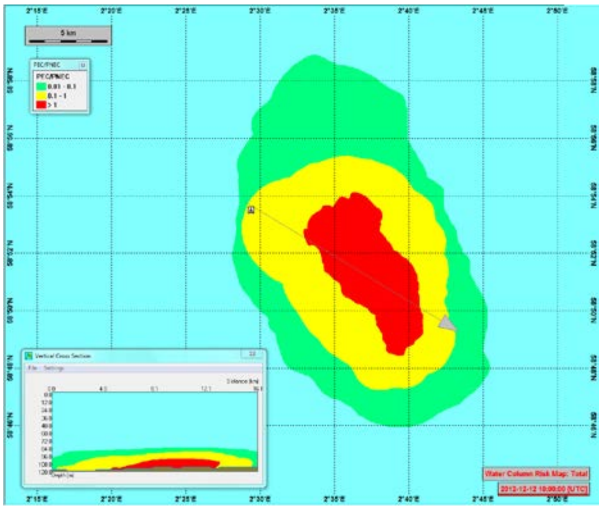


Figure 5-35 Snapshot showing the time instant with maximum potential risk for the water column for Simulation 8, discharge from 9 wells at Geitungen.

5.3.9 Simulation 9

Simulation 9 includes drilling of 27 wells at the Field center. Simulation 9 is the same as Simulation 2 except that cuttings from deeper sections drilled with oil based mud will be shipped to shore in simulation 9. In simulation 2 the cuttings from the deeper sections is cleaned off shore, with the same technology as used on shore, before discharging the cuttings to the sea. This simulation is part of the Alternative Case.

Due to technical limitations, Simulation 9 (water column) was performed for one well in four different seasons, February, May, August and November respectively. For sediments drilling of all 27 wells were simulated.

Table 5-12 shows the contribution of each substance to the EIF in the water column. Computed max EIF vary from 6703 in May to 9578 in February.

The EIF is dominated by barite and bentonite, see Figure 5-36.

As illustrated in Figure 5-37 potential risk is only related to a relatively short period when the drilling is carried out. The footprint of the plume and areas with potential risk are exemplified in Figure 5-38 (August), and as can be seen there is a potential risk in more or less the whole water column, because of discharges both from surface and sub-surface, in a short period of time.

Table 5-12 EIF results for the water column from drilling – Simulation 9, discharges from a well at the Field center in four different seasons.

		May	August	November	February
Computed max EIF		6703	9320	8648	9578
Time averaged EIF		1940	2379	2552	2181
Components	**PNEC ppb**	**Contribution EIF**			
Cuttings	100.000	3.35	7.46	4.34	6.70
Bentonite	88	4100.46	5513.74	5290.39	5753.75
Barite	200	2599.57	3797.92	3389.43	3817.96

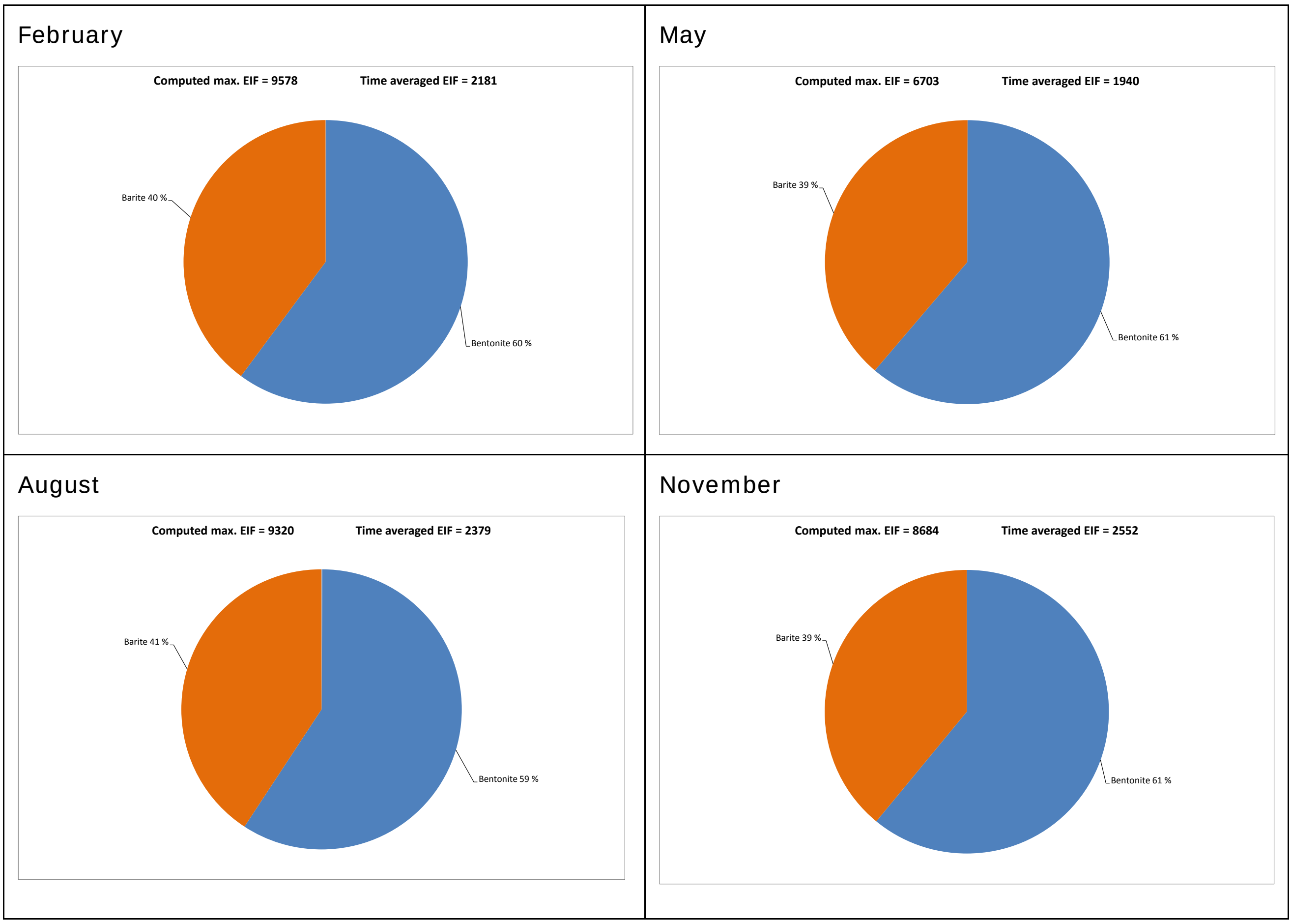


Figure 5-36 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column in 4 different seasons, simulation 9.

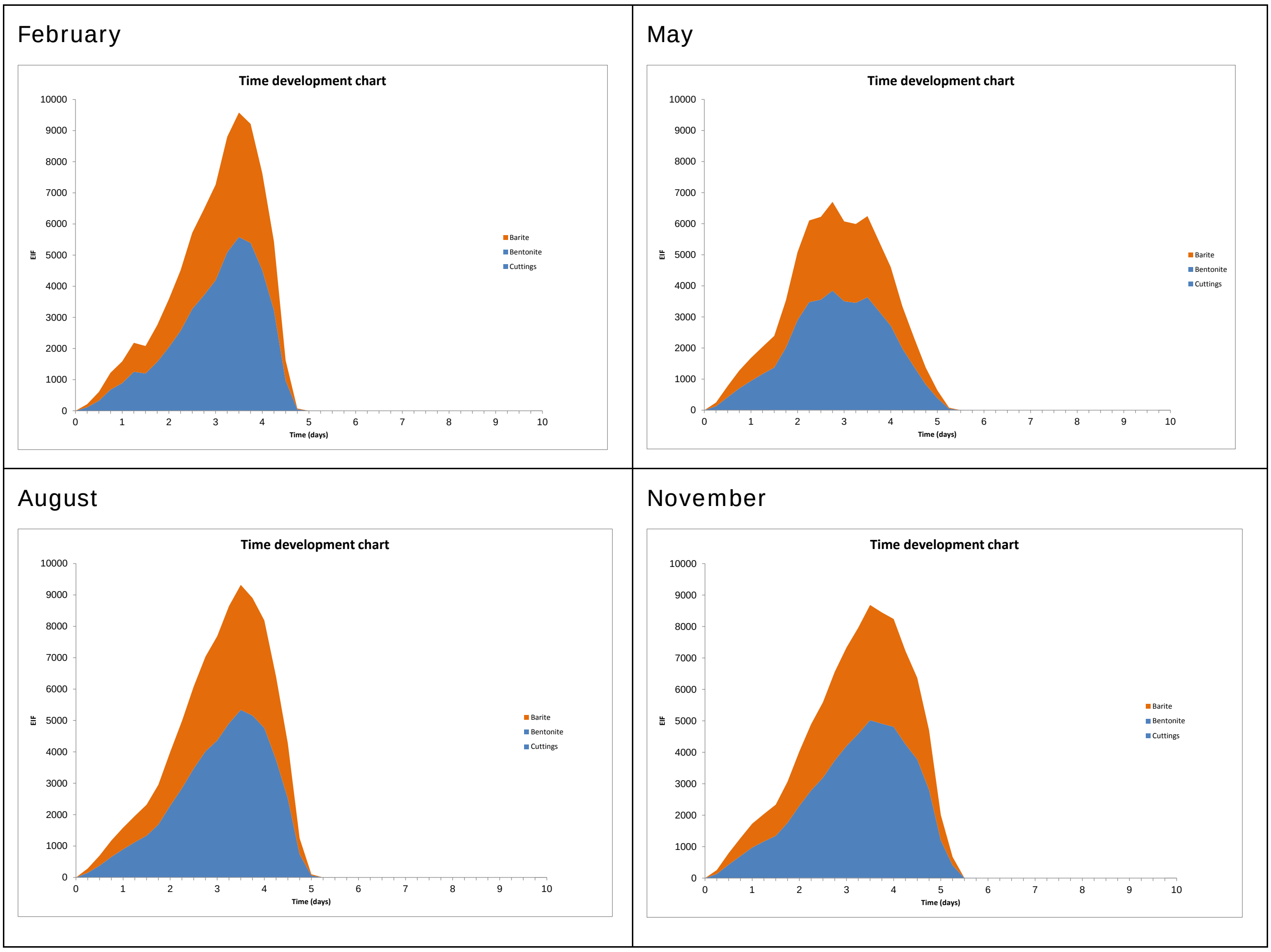


Figure 5-37 Time development of the EIF for the water column for Simulation 9, discharge from a well at Field-center in four different seasons.

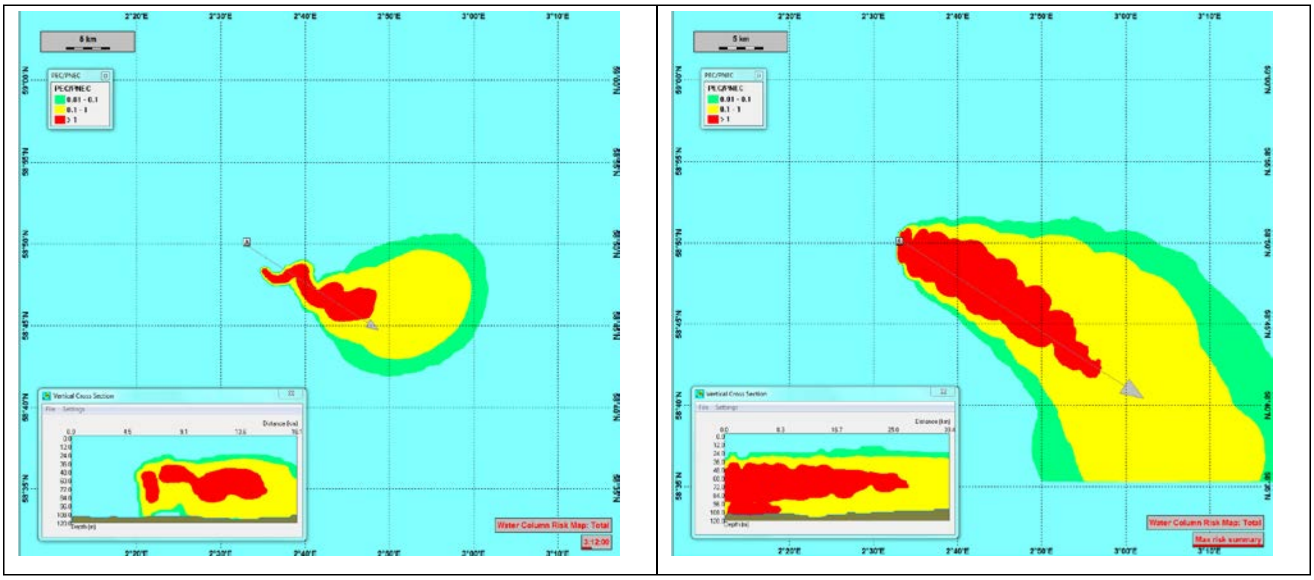


Figure 5-38 Snapshot showing Left: the time instant with maximum potential risk, Right: accumulated maximum potential risk for the whole simulation period (footprint) for the water column for Simulation 9. Discharge from 1 well at Field-center (CTS + rig), wind and current data for August.

5.3.10 Simulation 10

Simulation 10 includes drilling of 24 wells at the Avaldsnes. Simulation 10 is the same as Simulation 3 except that oil based cuttings from the deeper section are planned to be shipped to shore instead of discharged to sea. This simulation is part of the Alternative Case.

Due to technical limits Simulation 10 – water column was performed for one well in four different seasons, May, August, November and February respectively. For sediments drilling of all 24 wells were simulated.

Table 5-13 shows the contribution of each substance to the EIF in the water column. Computed max EIF vary from 6957 in May to 9585 in February.

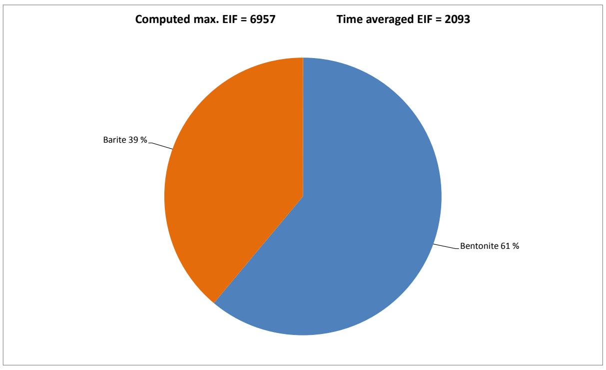
The EIF is dominated by barite and bentonite, see Figure 5-39.

As illustrated in Figure 5-40, potential risk is only related to a relatively short period when the drilling is carried out. The footprint of the plume and areas with potential risk are exemplified in Figure 5-41 (August), and as can be seen there is a potential risk in more or less the whole water column, because of discharges both from surface and sub-surface, in a short period of time.

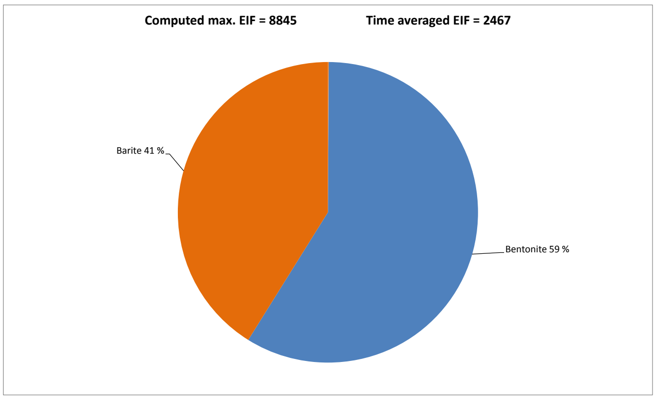
Table 5-13 EIF results for the water column from drilling – Simulation 10, discharges from a well at the Avaldsnes in four different seasons.

		May	August	November	February
Computed max EIF		6957	8845	8022	9585
Time averaged EIF		2093	2467	2668	2164
Components	**PNEC ppb**	**Contribution EIF**			
Cuttings	100.000	3.47	7.07	4.81	6.70
Bentonite	88	4245.57	5202.68	4881.98	5734.87
Barite	200	2707.48	3635.33	3135.67	3843.69

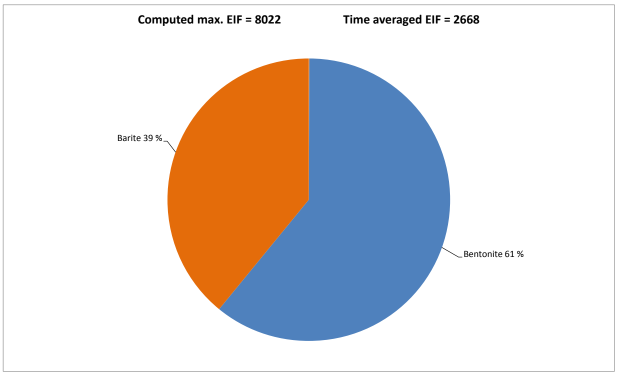
May



August



November



February

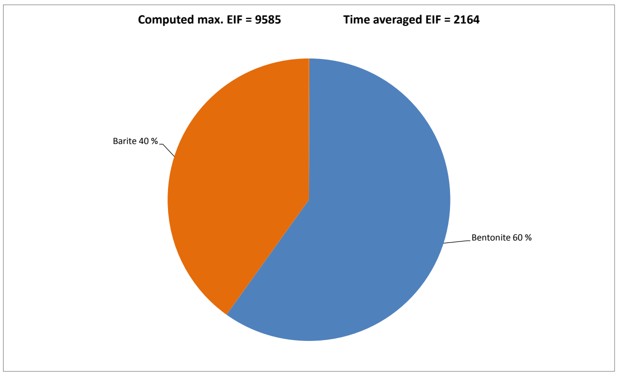


Figure 5-39 Pie chart of contribution of each substance in the drilling discharges to the overall EIF in the water column in 4 different seasons, Simulation 10.

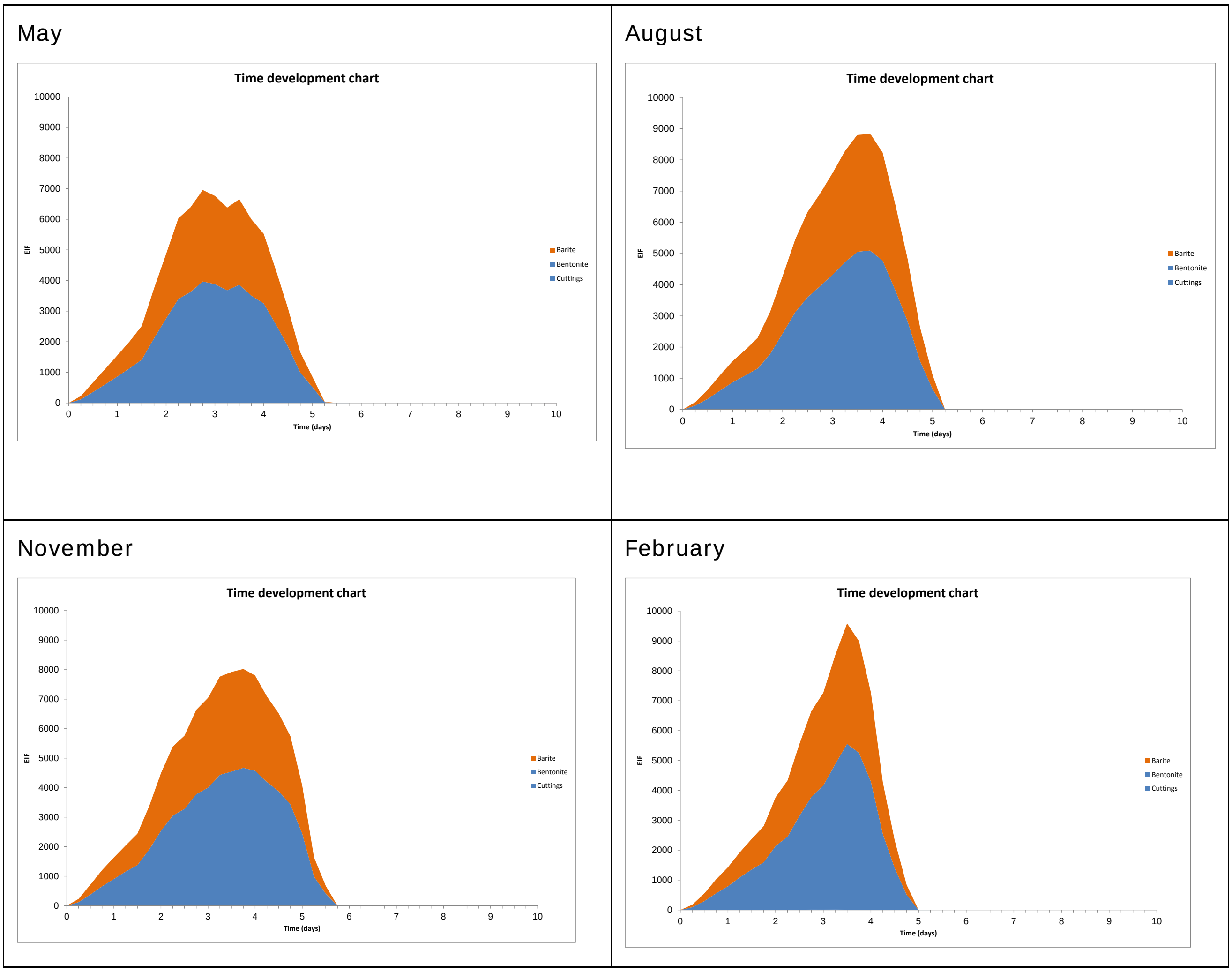


Figure 5-40 Time development of the EIF for the water column for Simulation 10, discharge from a well at Avaldsnes in four different seasons.

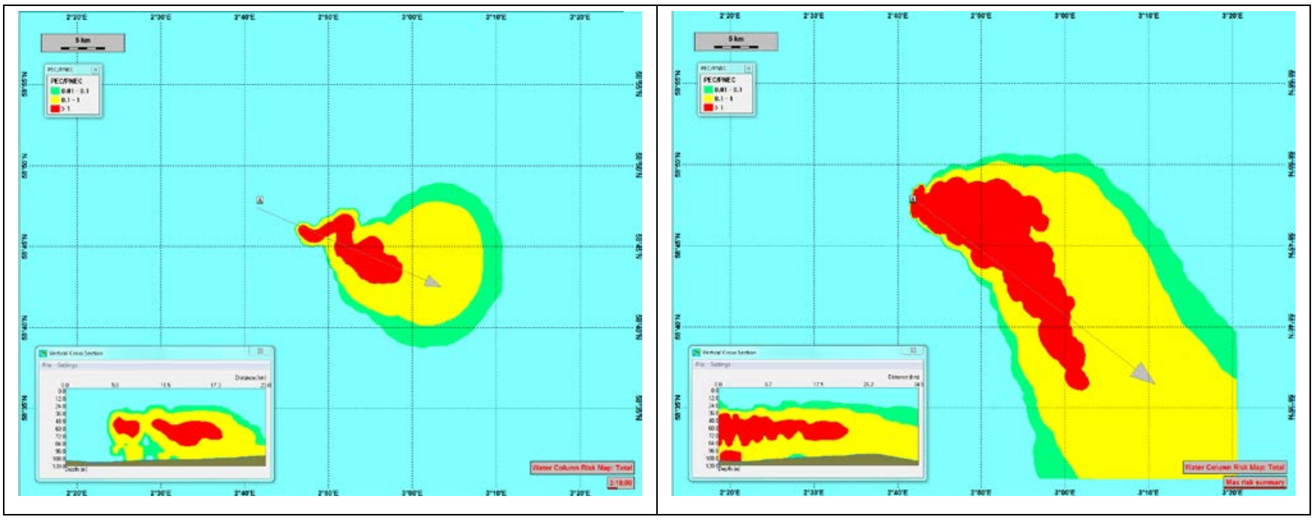


Figure 5-41 Snapshot showing Left: the time instant with maximum potential risk. Right: accumulated maximum potential risk for the whole simulation period (foot-print) for the water column for Simulation 10: Discharge from 1 well at Avaldsnes (CTS + rig), wind and current data for August.

5.3.11 Summary risk results – water column

A summary of the potential risk is presented in Table 5-14, expressed as EIF, and the contribution of the modelled substances to the overall potential risk in the water column.

Overall the model results indicate potential risk within the order of some kilometres from the discharge point. It is important to underline that potential risk in the water column is time variable and related to a short period of time when the actual discharges are taking place. After the discharges stop, the potential risk declines quickly due to dispersion and dilution of the particles in the water column. The vertical distribution varies, but as expected those simulations where discharges are at the sea bottom (CTS) the potential risk is associated with the lower part of the water column. In the simulations where surface discharges are included the potential risk is more distributed throughout the whole water column.

There are no obvious differences between the Base Case (simulation 1-8) and Alternative Case (simulation 1 and 4-10) with respect to overall potential risk. This is illustrated in Figure 5-42 which shows a snapshot of the period with maximum potential risk for all simulations included in the two cases. Looking more at the details, the potential risk from TCC powder is relatively dominant in simulation 2 and 3, and the potential risk contribution from bentonite and barite smaller compared to in simulation 9 and 10 (where TCC is not relevant and masses from the lower sections are shipped to shore). For all simulations the potential risk is associated with barite and bentonite particles in the water column, except for simulation 2 and 3 where the potential risk from TCC powder is more dominant.

Table 5-14. Comparison of the EIF results and contribution of each modelled stressor to the overall potential risk for the water column from the planned drilling operations at the Johan Sverdrup field.

Simulation nr.	EIF Water Max/time averaged	Contribution (%)						
		TCC Aliphatic HC	TCC aromatic HC	TCC powder	TCC PAH	Barite	Bento -nite	Cuttings
1. Floater. CTS. Field center	4632/267	n.r	n.r	n.r	n.r	39	61	0
2. Integrated rig. 24" from rig. TCC. Field center	9492[1)]/1680	0.22	0.08	58.81	0.82	16	23.55	0.03
3. Integrated rig.24" from rig. TCC. Avaldsnes	9377[1)]/1654	0.22	0.09	60.33	0.022	15.73	22.75	0.03
4. Floater 42". CTS. E-template	3502/102	n.r	n.r	n.r	n.r	37.49	62.48	0.03
5. Floater 42". CTS. F-template	4267/107	n.r	n.r	n.r	n.r	36.72	63.25	0.04
6. Floater 42". CTS. G-template	4833/104	n.r	n.r	n.r	n.r	37.36	62.6	0.04
7. Floater 42". CTS. Kvitsøy	6498/225	n.r	n.r	n.r	n.r	37.23	62.73	0.03
8. Floater 42". CTS. Geitungen	6497/210	n.r	n.r	n.r	n.r	35.93	64.04	0.02
9. Integrated rig. 24" from rig. Field center	9578[1)]/2181	n.r	n.r	n.r	n.r	39.86	60.07	0.07
10. Integrated rig.24" from rig. Avaldsnes	9585[1)]/2164	n.r	n.r	n.r	n.r	40.1	59.83	0.07

1) Max EIF from one of the four months simulated

n.r: Not relevant

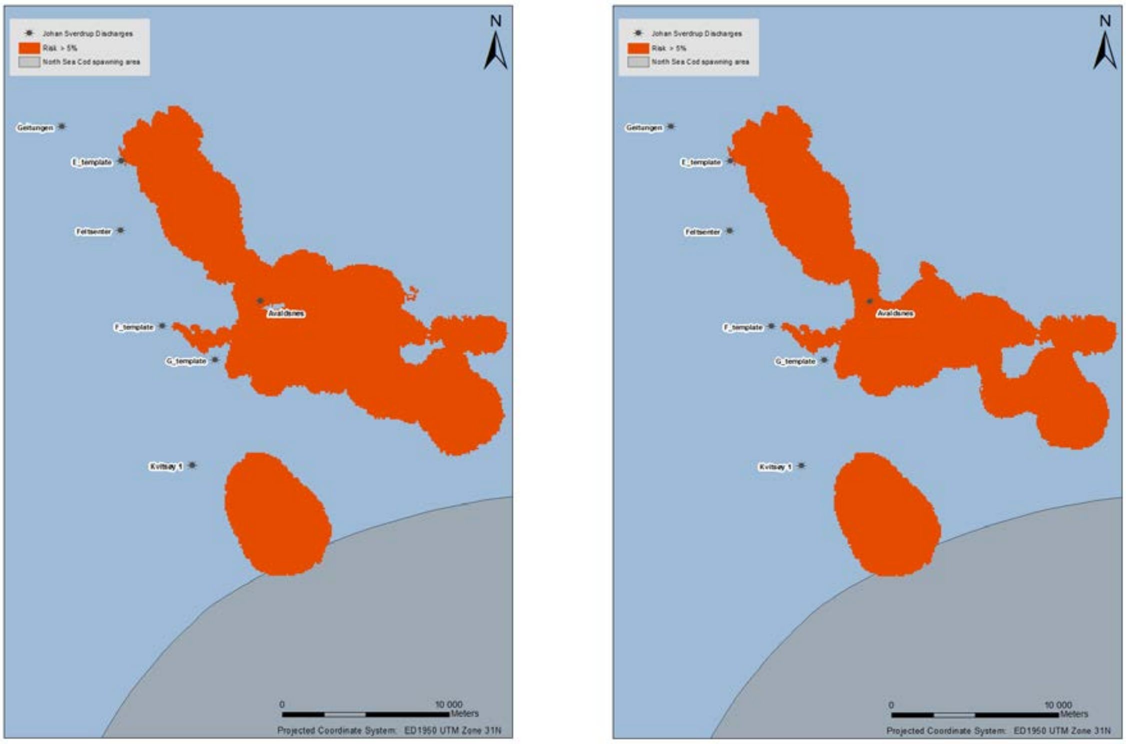


Figure 5-42 Areas with more than 5 % potential risk in the water column (corresponding to PEC/PNEC>1) for Base Case (left) and the Alternative Case (right). The figures represent a snapshot of a time step with the highest potential risk in the simulations period for all simulations.

5.3.12 Valuable resources in the area in relation to discharges

In Figure 5-43 and Figure 5-44 the time step with maximum potential risk in the water column together with identified valuable resources and areas for Base Case and Alternative Case are presented. The figures show an overlap between the cod spawning area and the “plume” representing a potential risk larger than 5%. For the other identified valuable resources there is no overlap; indicating that these identified resources and areas should not be directly affected by the planned drilling operations, when considering suspended particles in the water column. As mentioned for produced water discharges (Chapter 5.2) it cannot be ruled out that during periods of spawning eggs and larvae may drift from the spawning areas to the areas defined by the Johan Sverdrup field. Considering that increased water concentration of suspended particles in the water column is limited to a relatively short period of time and that spawning periods will cover a much larger time span it is considered unlikely that the produced water discharges have an effect at the population level. More likely is that individual larvae and eggs may be affected if the discharges overlap periods of spawning.

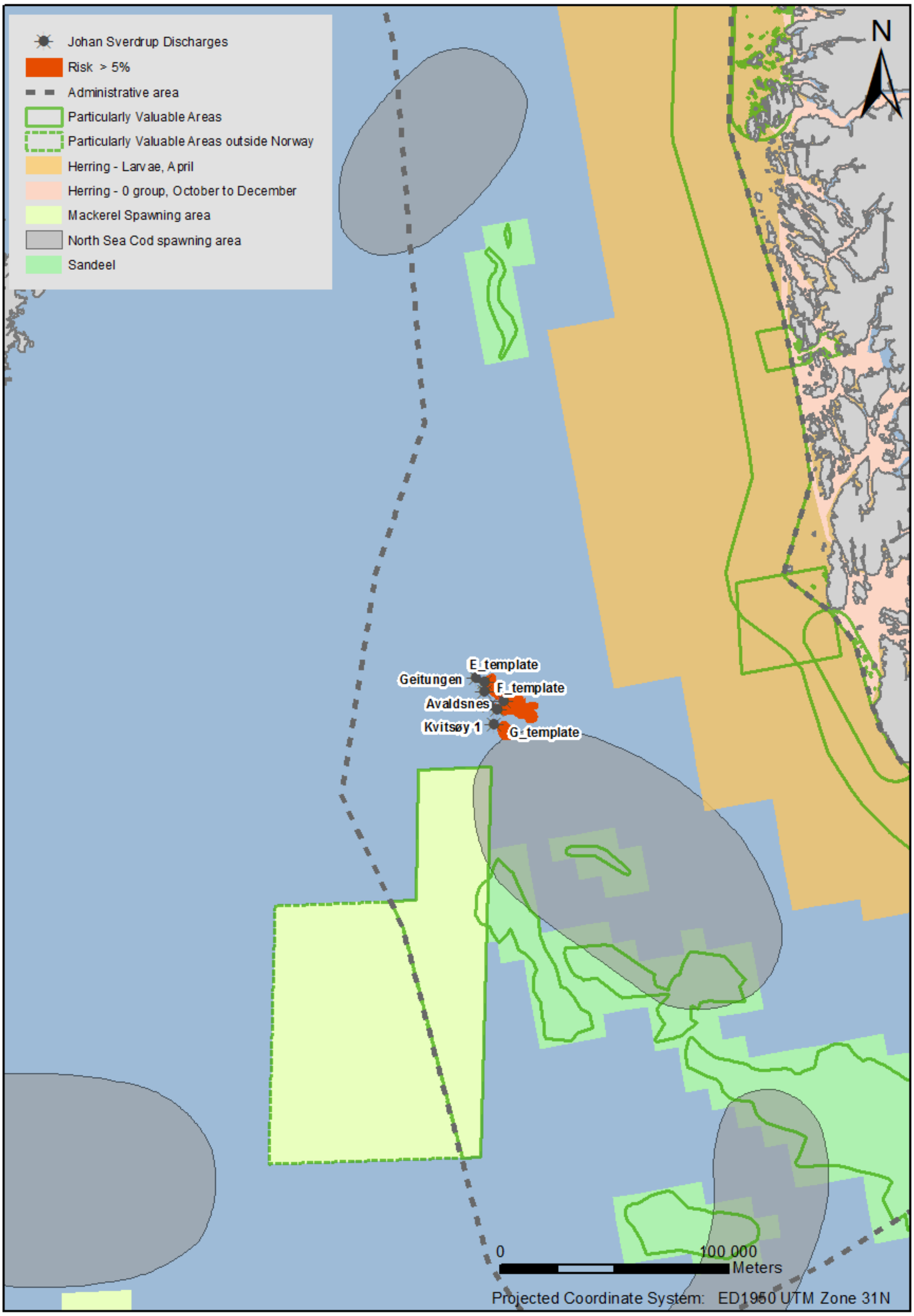


Figure 5-43 Identified valued resources and areas in the area of the Johan Sverdrup field overlaid by the areas where water column potential risk is >5% (corresponding to PEC/PNEC>1), <u>Base Case.</u>

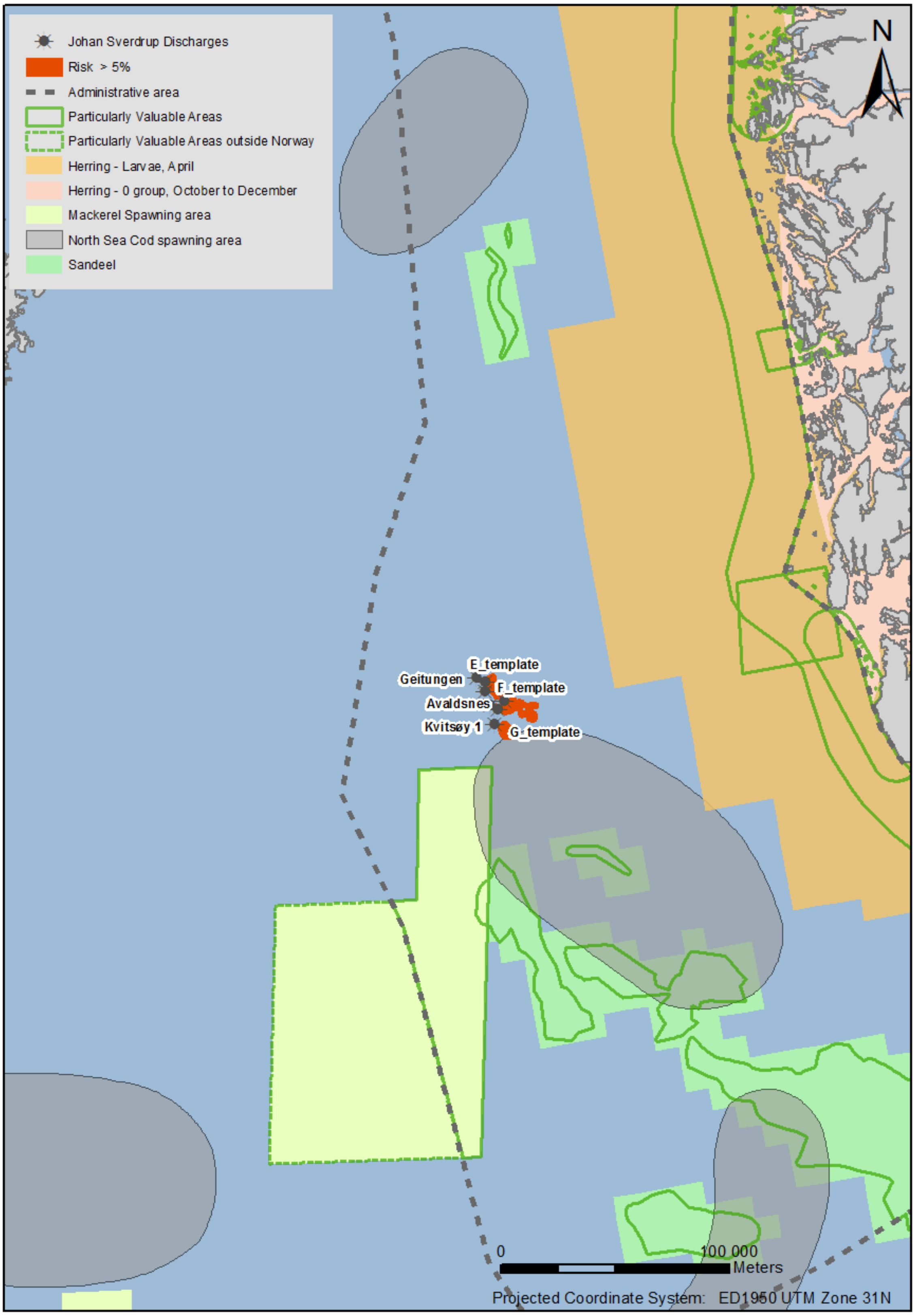


Figure 5-44 Identified valued resources and areas in the area of the Johan Sverdrup field overlaid by the areas where water column potential risk is >5% (corresponding to PEC/PNEC>1), <u>Alternative Case.</u>

5.3.13 Literature review

For impact related to increased particles in the water column, DREAM operates with PNEC values of 0.088 mg/l for bentonite, 0.2 mg/l for barite, and 10 mg/l for cuttings. These effect limits are "global" and have been derived from species sensitivity distributions (SSDs; Smit *et al.*, 2006). As such the effect limits include all sorts of water-living organisms including microalgae, filtering organisms and copepods.

The fact that the model indicates a potential risk in order of kilometres from the discharge point is debateable. For example during a monitoring project at the Mjøsa field in the Norwegian sea no elevated turbidity values was observed at a station located 1350 m away from the discharge point (DNV, 2013). Similarly during monitoring of a drilling operation at the Ronaldo field turbidity values at locations 800 and 2000 m away from the discharge point corresponded to more or less background values (DNV, 2011).

Barite ($BaSO_4$) and bentonite (a clay consisting of mainly aluminium phyllosilicate) are considered non-. hazardous and basically inert mineral particles. Differences in toxicity between the two weighting compounds (as well as other mineral particles) are likely a result from differences in size and shape of the particles: small particles are generally less hazardous than larger ones (Servizi & Martens, 1987), and rounded particles are less hazardous than angular ones (Lake & Hinch, 1999). As such, and partly due to the limited data availability for studies using barite and bentonite, both weighing agents have been considered representing general mineral particles with unspecific effects related to assimilation of an excess of particles.

Experiments with juvenile, Atlantic cod (24.7 ± 1.6 cm) using natural, muddy sediments collected from a shrimp-trawling site outside Bergen (Norway) showed no lethal effects during a 10 days exposure period to approximately 550 mg/l suspended sediments (Humborstad *et al.*, 2006). The same treatment induced pathological changes of the gills within 24 hours.

Static bioassays conducted with attapulgite suspensions on white perch (*Morone americana*), spot croaker (*Leiostomus xanthurus*), silversides (*Atheriniformes*), bay anchovies (*Anchoa mitchilli*), mummichog (*Fundulus heteroclitus*), striped killifish (*Fundulus majalis*) and Gulf menhaden (*Brevoortia patronus*) showed significant mortality in five of the seven species at concentrations of natural suspended solids typically found in estuarine systems during flooding, dredging and spoil disposal. Lethal concentrations ranged from 580 mg/l attapulgite (24 hr LC10) for silversides to 2450 mg/l (24 hr LC10) for mummichogs (Sherk *et al.*, 1975).

In a meta-analysis using data from several scientific studies on different salmon species, Newcombe (2003) produced a model describing the relationship between biological effect, concentration of particles and duration of exposure. The model established the following effect limits for lethal effects in adult and juvenile salmon:

- Exposure time 1-7 hours: lethal effects predicted at 3000 mg/l (7 h) to 22 000 mg/l (1 h).
- Exposure time 1-6 days: lethal effects predicted at 400 mg/l (6 d) to 3000 mg/l (1 d).
- Exposure time 2-7 weeks: lethal effects predicted at 55 mg/l (7 w) to 400 mg/l (2 w).

A well described, indirect sub-lethal effect of exposure to increased particle levels is reduced growth, although most studies have focused on farmed salmon species. Reduced growth is related to reduced feeding (success) and/or increased metabolic costs (McLeay *et al.*, 1987). In Coho salmon (*Oncorhynchus kisutch*), reduced growth has been reported at a particle concentration of 84 mg/l (Sigler *et al.* 1984), and 50 mg/l (Herbert & Richards, 1963; Sykora *et al.*, 1972). Atlantic salmon (*Salmo salar*) appear more tolerant to increased particle levels with increased feeding intensity reported up to a concentration of 180 mg/l, followed by a decrease at higher concentrations (Robertson *et al.*, 2007).

Gill pathologies have been reported at concentrations down to 50 mg/l (Au *et al.*, 2004; Weltens *et al.*, 2000). High concentrations of suspended solids (2-3 g/l) have been reported to stress various salmon species and measured as increased blood cortisol levels (Redding *et al.*, 1987).

Regarding behavioural effects, a breakdown in population hierarchy including reduction in territorial defence is reported in Atlantic salmon at concentrations exceeding 60 mg/l (Robertson *et al.*, 2007). Similar effects have been described in Coho salmon, however at a higher concentration (130 mg/l; Berg & Northcote, 1985). Avoidance of increased particle concentrations has also been reported in Atlantic salmon in the range 60-180 mg/l (Robertson *et al.*, 2007).

The meta analysis by Newcombe (2003) also suggested effect levels of sub lethal and behavioural effects in adult and juvenile salmon species, including the effects described above. Depending on exposure time, suggested effect limits are:

- Exposure time 1-7 hours: effects predicted at 55 mg/l (7 h) to 403 mg/l (1 h).
- Exposure time 1-6 days: effects predicted at 7 mg/l (6 d) to 55 mg/l (1 d).
- Exposure time 2-7 weeks: effects predicted at 3 mg/l (7 w) to 7 mg/l (2 w).

The literature review did not identify studies using Atlantic mackerel or related species in the *Scombridae* family (tunas and bonitos).

In relation to bottom-dwelling and demersal fish species it is known that they are more tolerant to higher levels of suspended particles than pelagic species (Sherk *et al.*, 1975; Wilber & Clark, 2001). The sandeels (*Ammodytidae* spp) represent a special group in that they spend a major part of their life buried in sediments, with occasional migrations to the water column related to feeding and spawning. There are no studies describing impact on sandeels as a result of increased particles in the water column, however as a burying species living within the sediments during long periods, it is reasonable to anticipate that this group will be less, or at least not more, sensitive to increased levels of suspended particles than exclusively pelagic species such as salmon.

Larvae and eggs of fish are more sensitive to an increased concentration of suspended sediment than adult life stages. Concentrations above 100 mg/l can already result in an increased mortality (Van Dalfsen, 1999). Herring (*Clupea harengus*) larvae fed at 20 mg dry sediment/l did consume significantly fewer *Artemia* nauplii than did the controls. Smaller larvae were found to be more affected by increased levels of suspended sediment than larger larvae (Johnston & Wildish, 1982). Late-stage haddock (*Melanogrammus aeglefinus*) embryos (8-12 days old) and yolk sac larvae (3-7 days post-hatch) showed significant mortality at 100 mg/l after acute exposure (96 h) to a suspension of WBM, whereas early-stage embryos (1-4 days old) and feeding-stage larvae (13-17 days post hatch) survived the same treatment (Kiørboe *et al.*, 1981). The same study also exposed eggs of herring to silt concentrations up to 500 mg/l without affecting embryonic development.

Based on the studies cited above, the following effect levels of lethal and sublethal effects (including behavioural effects) have been identified in adult/juvenile fish, and fish eggs/larvae:

- Lethal effects adults/juveniles: **400 mg/l** (Newcombe, 2003)
- Lethal effects eggs/juveniles: **100 mg/l** (Van Dalfsen, 1999)
- Sublethal effects adults/juveniles: **7 mg/l** (Newcombe, 2003)

- Sublethal effects eggs/juveniles: **3.5 mg/l** (estimated 50% of adult threshold)

Regarding the modelled drilling discharges at Johan Sverdrup, potentially toxic particle concentrations are expected to remain in the water column for some days to weeks based on conservative PNEC values of 0.088 mg/l for bentonite, and 0.2 mg/l for barite. The effect levels in fish suggested above are therefore conservatively related to exposure of mineral particles for up to two weeks (Newcombe, 2003).

Although these effect levels are mainly related to experiments performed on salmon species, there are no indications that other pelagic species including cod are more sensitive to suspended mineral particles. Based on the literature cited above concerning particles concentration having effect on fish it may be argued that particle concentrations up to 3.5 mg/l will not have an impact on fish eggs and larvae, whereas concentrations up to 7 mg/l will not affect spawning behaviour and success of the spawning stock.

In Figure 5-45 to Figure 5-54 a snapshot of the particle concentrations around the period of maximum potential risk for each simulation is presented. The concentrations are shown as intervals representing the suggested threshold values for particles suggested above for fish (adults, juveniles and eggs). A summary of the findings for each simulation is presented in Table 5-15. In Table 5-15, distance is an approximate value (km) of the longest distance the different concentrations interval is modelled and the volume of water (mill m^3) of those concentrations intervals.

An overall conclusion is that no concentrations above 100 mg/l are modelled in these time steps, meaning no concentrations above the suggested threshold values for lethal effects on adult fish, juveniles nor eggs. There are only modelled concentrations in the range corresponding to sub lethal effects, but it is important to underline that this is for a limited period of time and within a limited water volume. With regards to identified valued resources in the area (see Chapter 5.1) there are no overlap between the particle concentrations in the sub lethal range (3.5 – 100 mg/l).

Table 5-15 Summary of particle concentration with distance (Dist. => km) from the discharge point, volume of water (Vol. => mil m^3) with different concentrations and max concentration

(Max). Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l).

	Particle concentration interval (mg/l)								**Max (mg/l)**
Simulation nr.	3.5-7		7-100		100-400		>400		
	Dist.	Vol.	Dist.	Vol.	Dist.	Vol.	Dist.	Vol.	
1	2.7	3.4	1.4	1.3	n.r.	n.r.	n.r.	n.r.	32
2	3	6	2.7	4.7	n.r.	n.r.	n.r.	n.r.	34
3	5	9.5	2.5	3	n.r.	n.r.	n.r.	n.r.	26
4	1.4	8.6	0.9	2.5	n.r.	n.r.	n.r.	n.r.	39
5	2.1	2.6	1.4	1	n.r.	n.r.	n.r.	n.r.	16
6	2.5	2.7	2.2	0.9	n.r.	n.r.	n.r.	n.r.	15
7	2.3	10	2	4	n.r.	n.r.	n.r.	n.r.	46
8	3.5	9.1	2.8	1.5	n.r.	n.r.	n.r.	n.r.	57
9	5.5	6.6	2.2	2.3	n.r.	n.r.	n.r.	n.r.	21
10	5	3.8	2.1	2.6	n.r.	n.r.	n.r.	n.r.	25

n.r. Not relevant

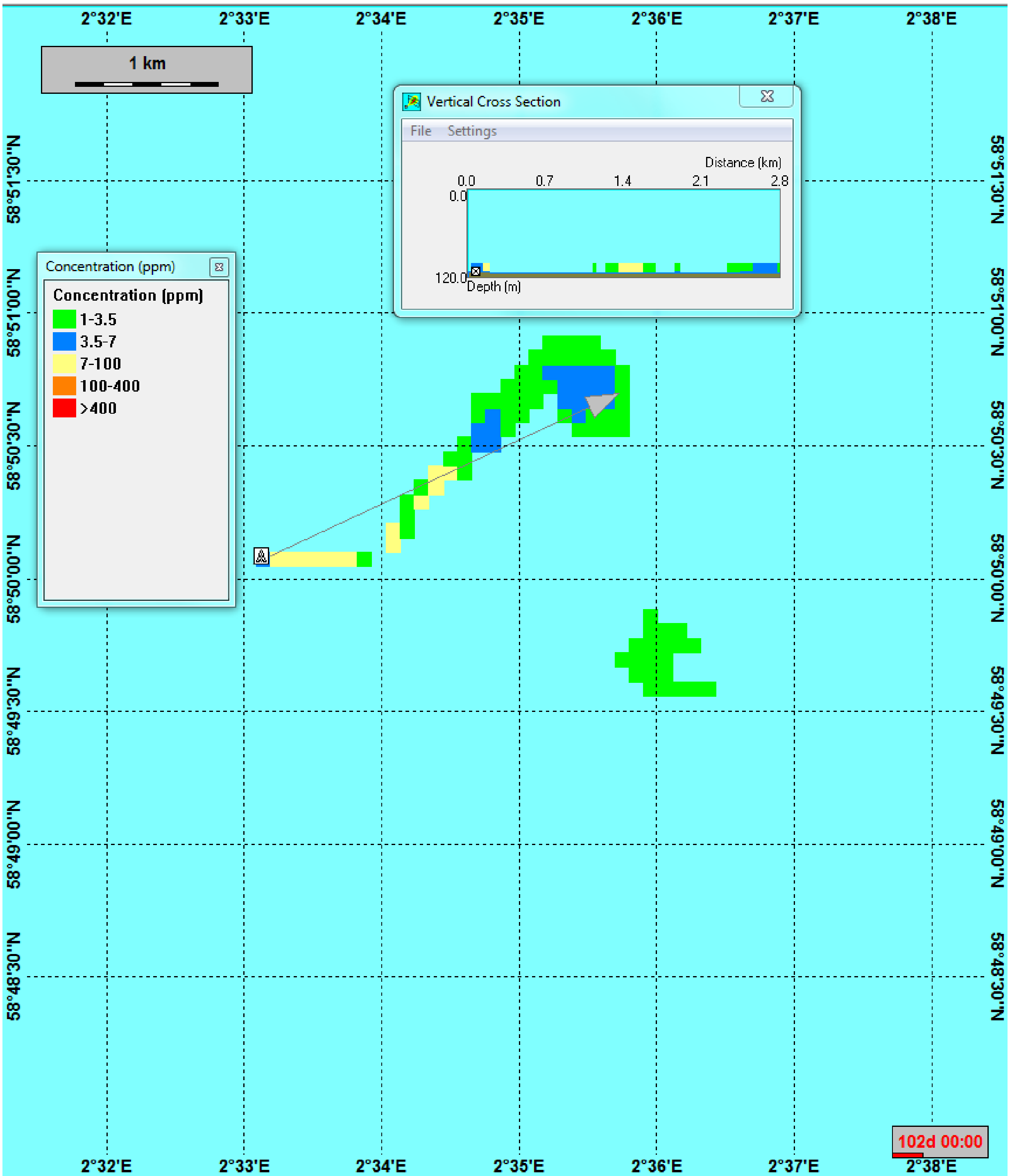


Figure 5-45 Particle concentrations around the time step with overall maximum potential risk, simulation 1. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field center.

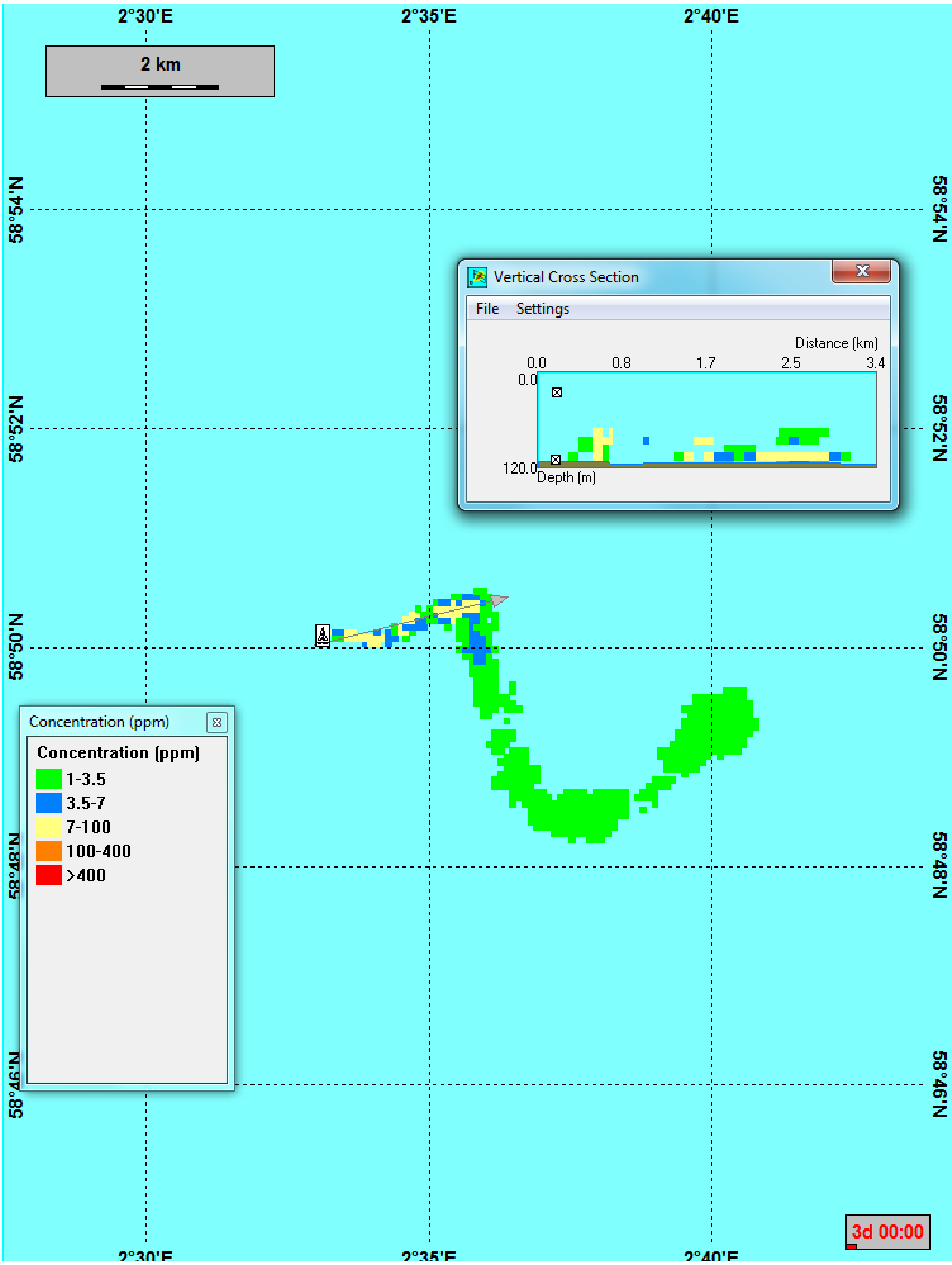


Figure 5-46 Particle concentrations around the time step with overall maximum potential risk (February), simulation 2. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field center.

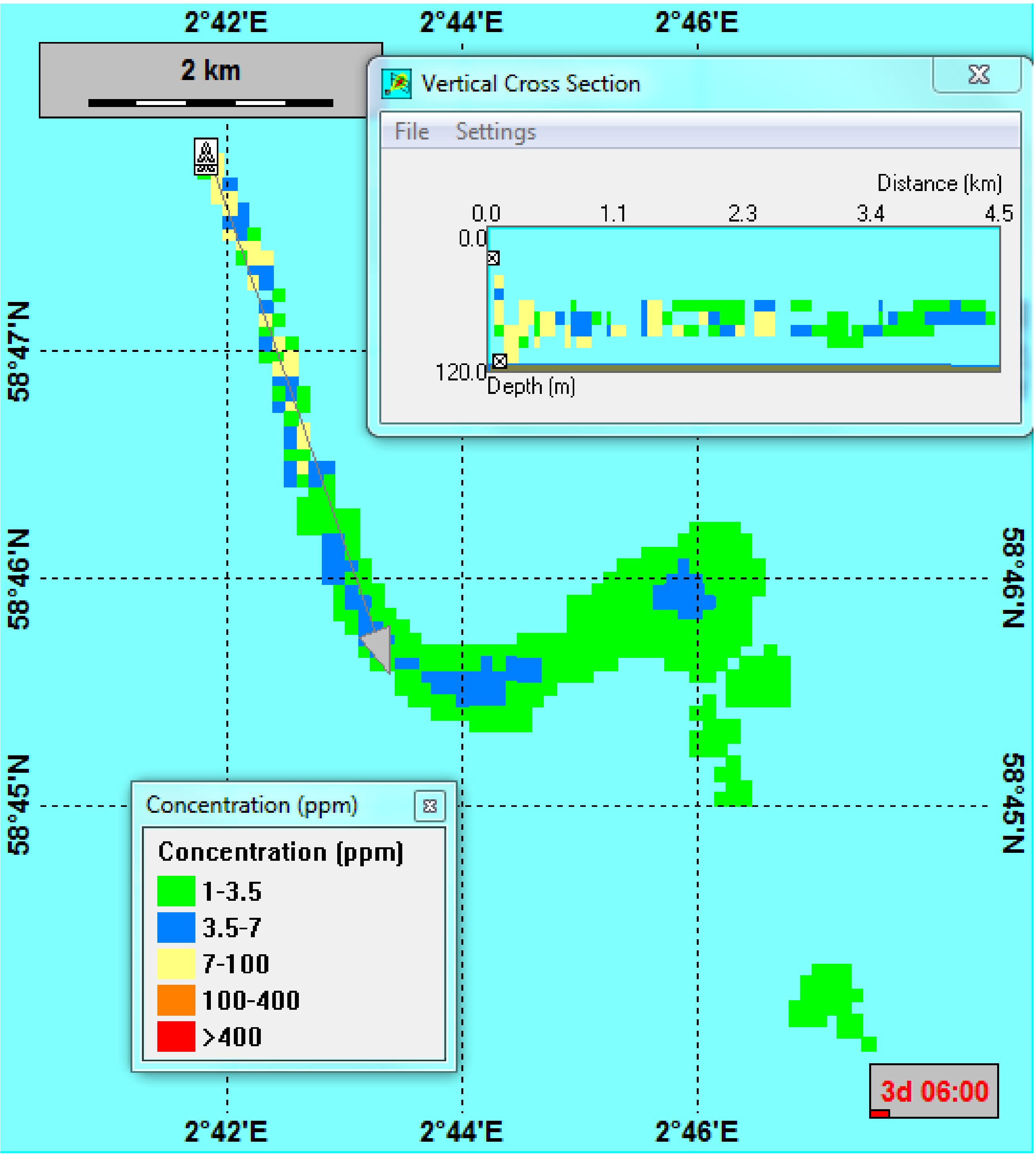


Figure 5-47 Particle concentrations around the time step with overall maximum potential risk (February), simulation 3. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is Avaldsnes.

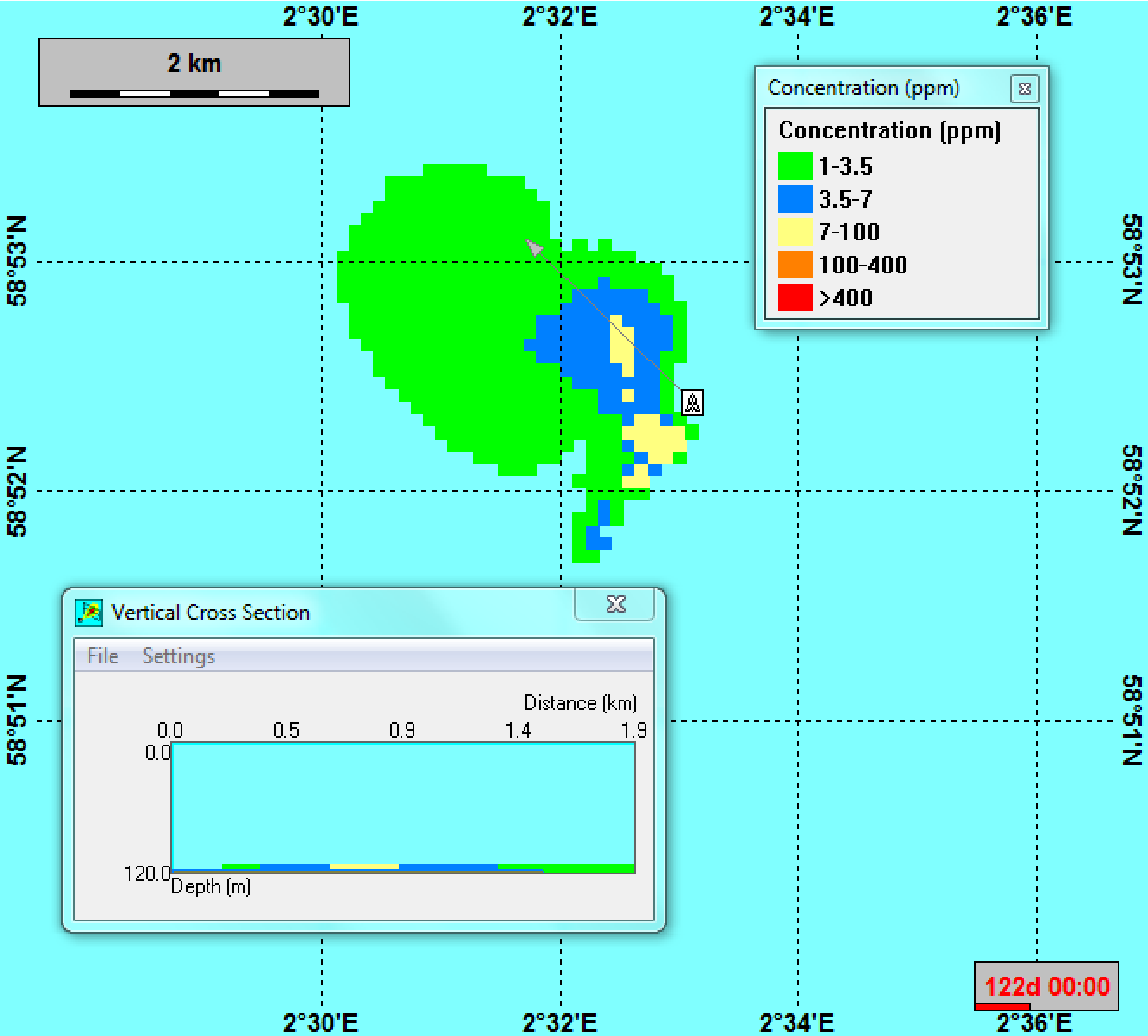


Figure 5-48 Particle concentrations around the time step with overall maximum potential risk, simulation 4. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the E-template.

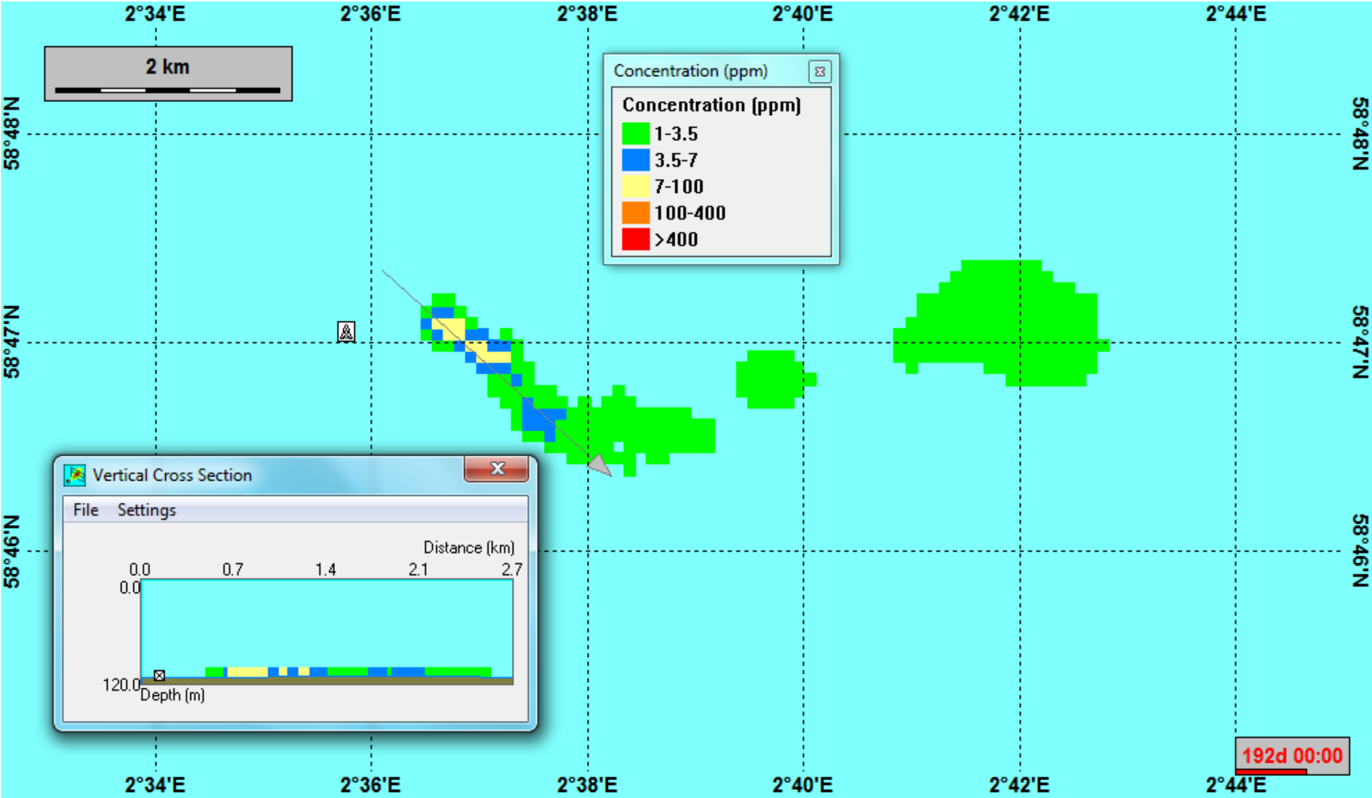


Figure 5-49 Particle concentrations around the time step with overall maximum potential risk, simulation 5. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the F-template.

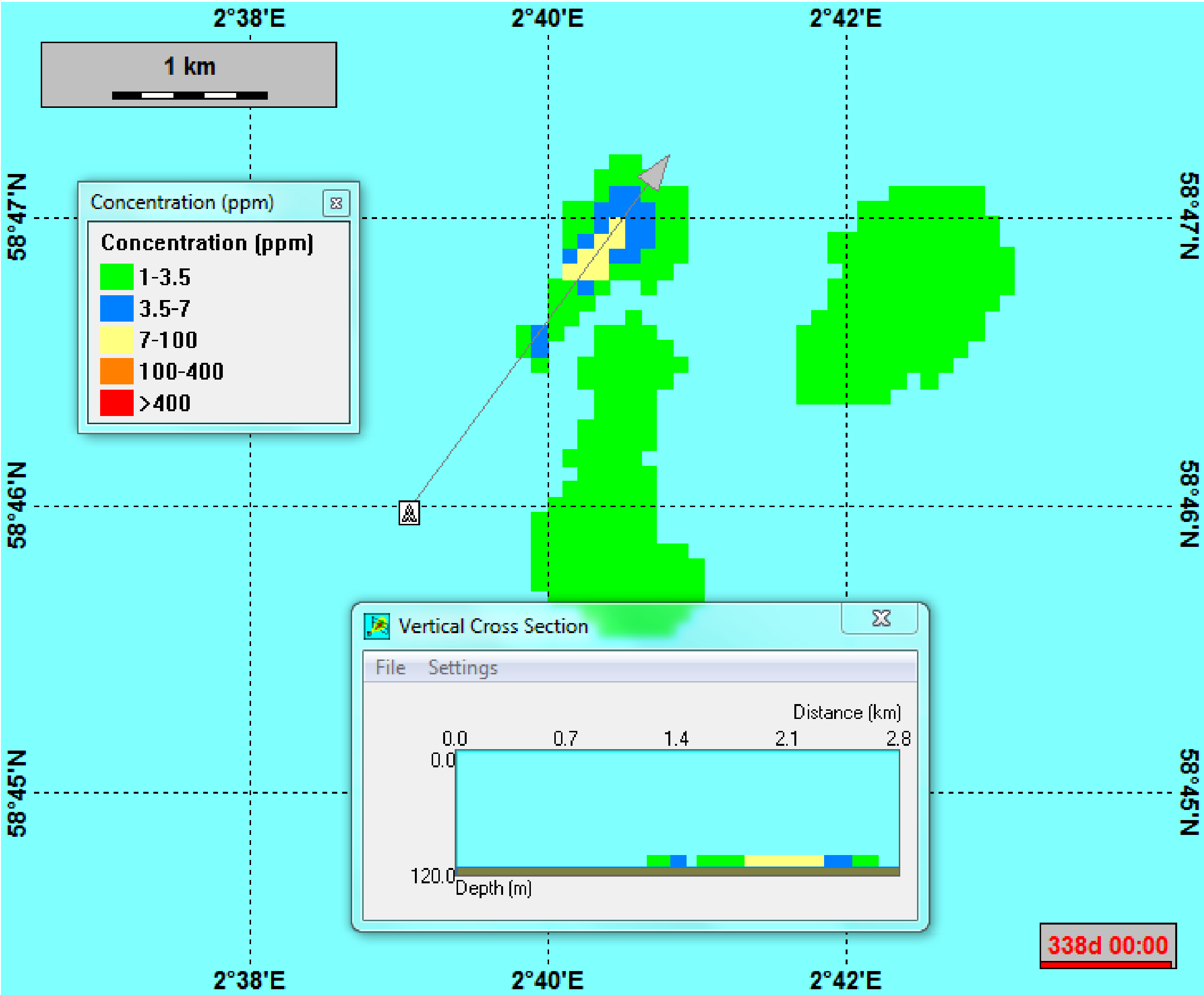


Figure 5-50 Particle concentrations around the time step with overall maximum potential risk, simulation 6. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the G-template.

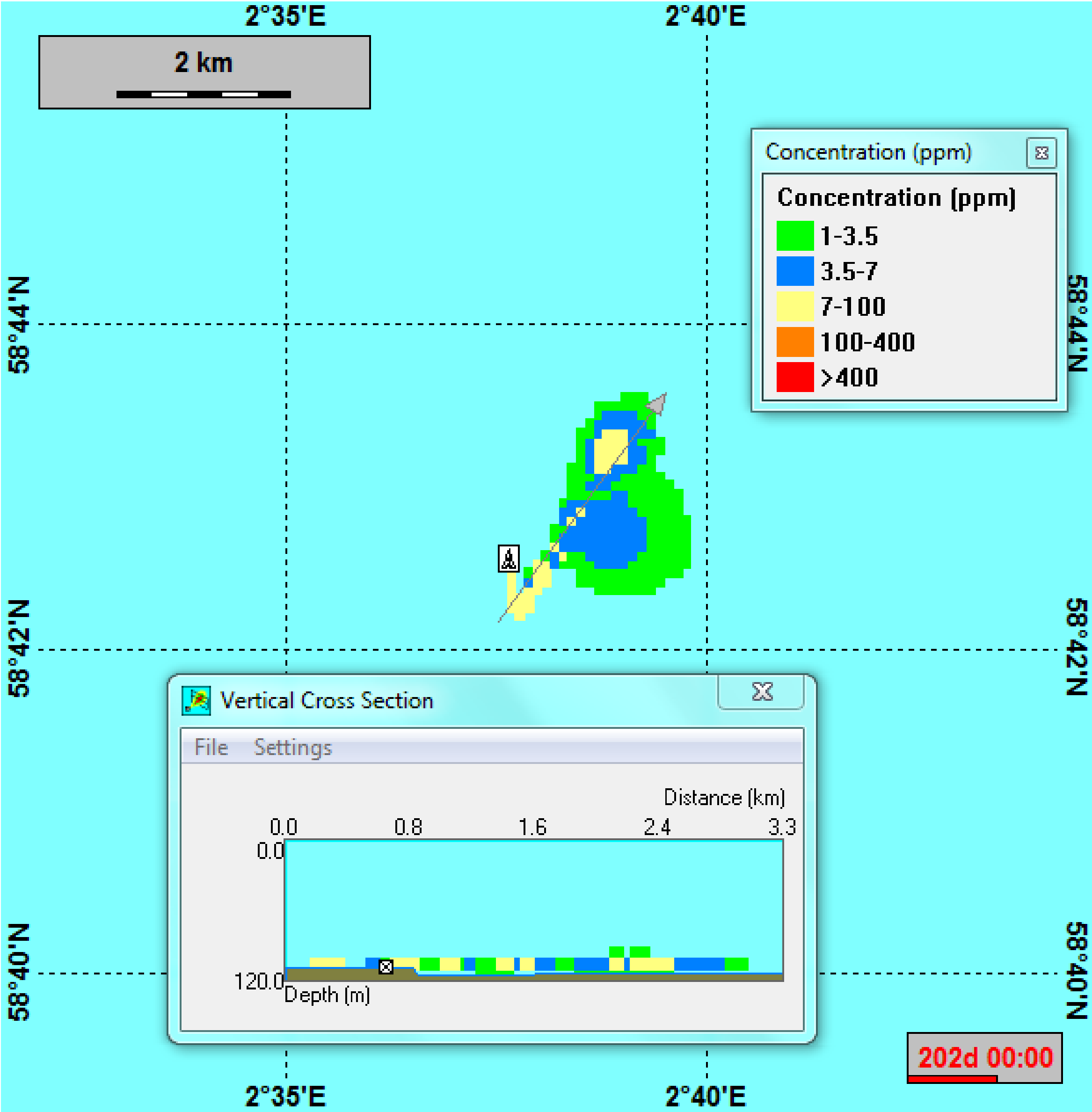


Figure 5-51 Particle concentrations around the time step with overall maximum potential risk, simulation 7. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Kvitsøy.

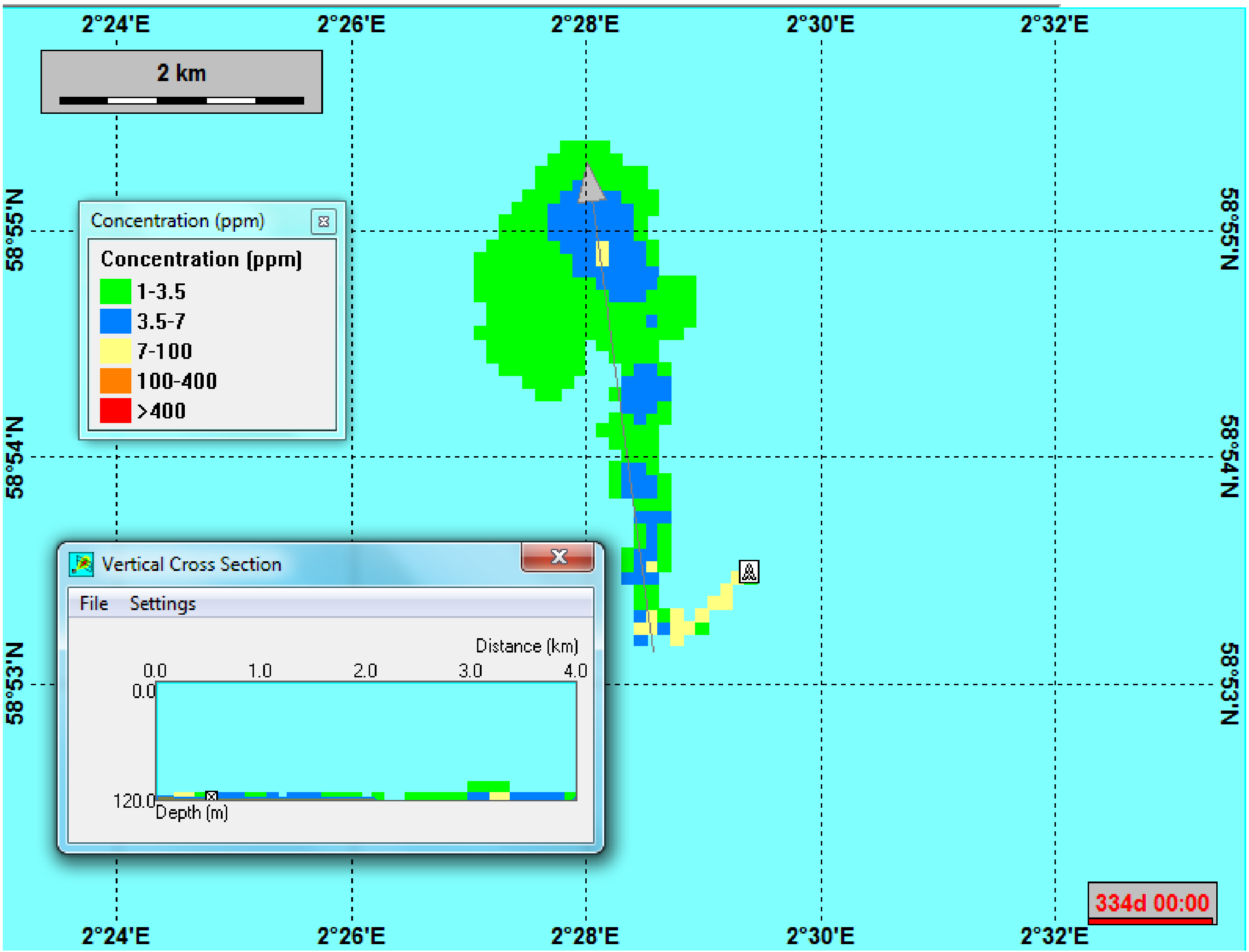


Figure 5-52 Particle concentrations around the time step with overall maximum potential risk, simulation 8. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Geitungen.

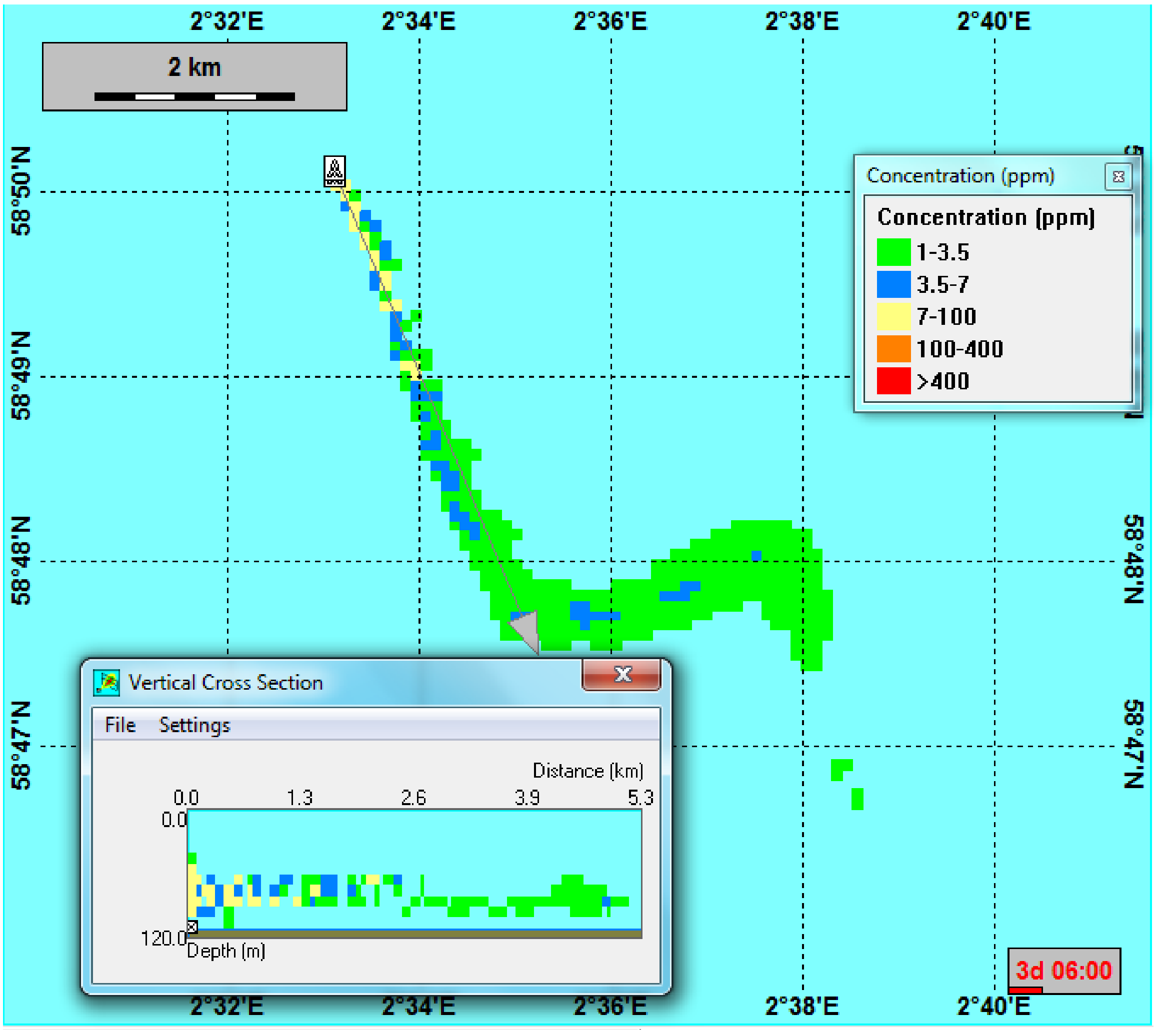


Figure 5-53 Particle concentrations around the time step with overall maximum potential risk (February), simulation 9. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Field center.

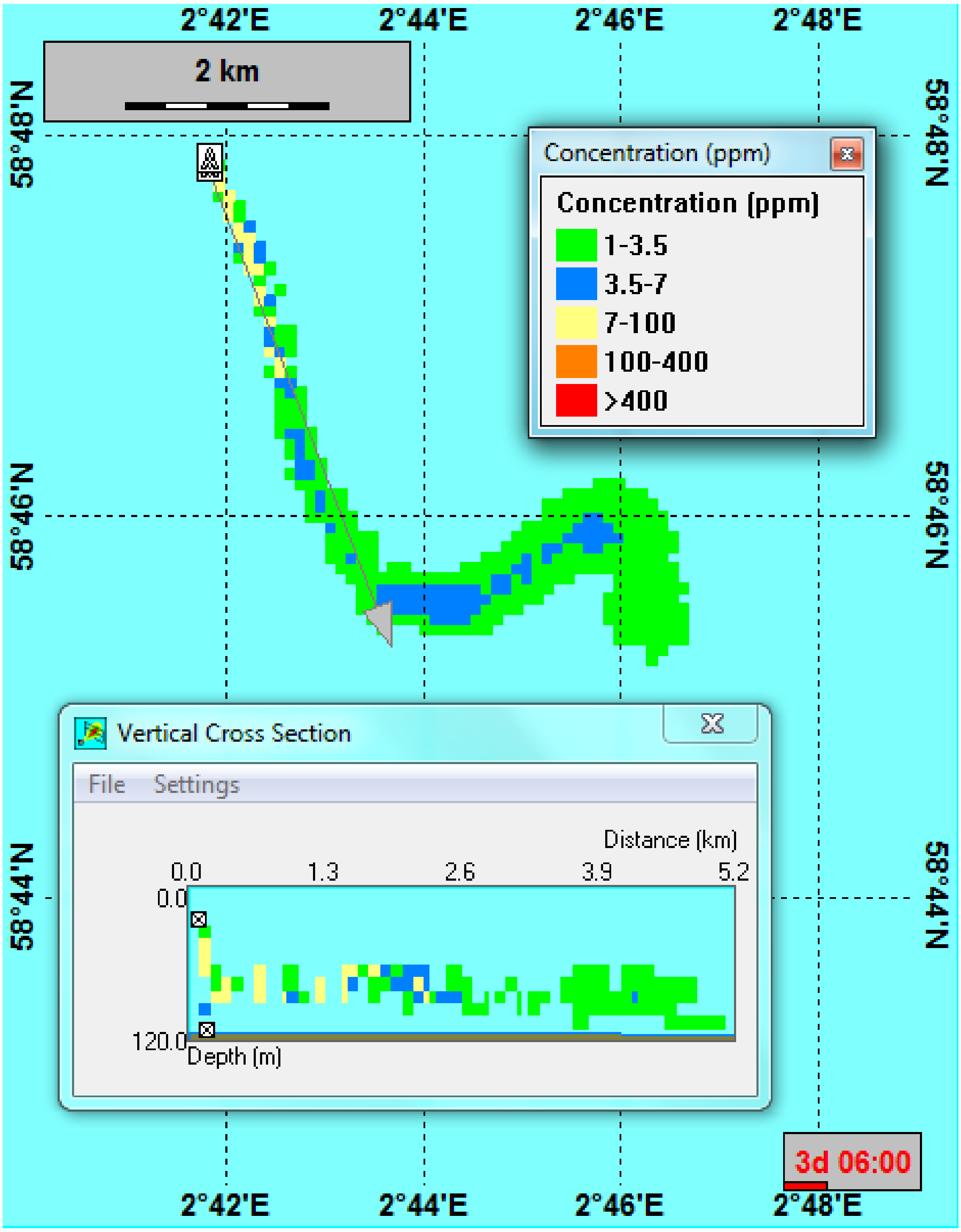


Figure 5-54 Particle concentrations around the time step with overall maximum potential risk (February), simulation 10. Concentrations are divided into intervals according to the suggested threshold values for sub lethal effects on fish eggs and juveniles (3.5 mg/l), sub lethal effects on adult/juveniles (7 mg/l), lethal effects on eggs and juveniles (100 mg/l) and lethal effects on adult fish/juveniles (400 mg/l). Included is a vertical cross section figure representing vertical concentrations along the arrow shown in the main figure. The square in the main figure is the Avaldsnes.

For studies performed on other organisms than fish: Bechmann *et al* (2006) found that suspension of barite-based WBM caused oxidative stress, DNA damage and reduced filtration rate in blue mussels and scallops (*Pecten maximus*). The lowest dose causing effects was 0.5 mg/l of OBM for 3 weeks. Cranford *et al* (1999) showed that exposure for 6-70 days to concentrations between 0.5 and 10 mg/l of used WBM in suspension caused negative effects in scallops. The same was observed when exposed to barite and OBM suspensions less than 5 mg/l. The effects were linked to physical stress rather than chemical toxicity. Bechmann *et al.* (2006) proposed a chronic PNEC for suspended cutting of 0.8 mg/l, and Smit *et al.* (2008) estimated PNEC values of 7.6 and 17.9 mg/l for suspended bentonite and barite, respectively, based on SSD tests on 12-15 marine species. Bakke *et al.* (2013) concludes that the levels of suspended WBM and WBM cuttings causing effects have been above 0.5 mg/l and that such levels are typically restricted to a radius of less than 1-2 km in the water masses. As mentioned, PNEC values of 0.088 mg/l and 0.2 mg/l are used for risk (EIF) calculations in DREAM for bentonite and barite respectively. These numbers are in general less than those levels causing effects reported from the literature cited above. This is important with regards to total water volume at potential risk because a higher PNEC means a smaller water volume at risk (smaller EIF) and vice versa.

5.4 Drilling – sediment

Bakke *et al.* (2013) state that there is strong evidences to conclude that sedimentation of WBM cuttings onto the seafloor has only local and short term effects on the sediment fauna. This conclusion is supported by experiments and by the extensive monitoring performed on the NCS. This is partly due to the fact that sedimentation levels in the order of a few millimetres are usually the case in the vicinity of the discharge point, for example at distances less than 250 m. Regional monitoring has generally not revealed any effects on the macro faunal community structure closer than 20-250 m from discharge point, indicating that if there are any effects, they will be confined to the seafloor and limited to the innermost stations in these studies, i.e. nearer than 25-250 m from the discharge point. DNV GL has performed a large number of monitoring projects of drilling operations in sensitive areas. Sensitive areas in this context have been restricted to areas with cold water corals, sponges and sandeel. The general experience from these projects is that sedimentation of a few millimetres is restricted to an area within 100-150 m from the discharge point. Even if the latter is experiences from drilling of one well, and at Johan Sverdrup 84 well are planned, these experiences together with more than 15 years of regional monitoring at the Norwegian sector presents strong evidence to conclude that sedimentation of WBM cuttings onto the seafloor has only local effects.

For sediment the parameter assessed is siltation. Currently a PNEC of 6.5 mm is used in the DREAM model. The results are presented in figures showing accumulated sedimentation after the end of the drilling period for each simulation. In the end a total picture for the two modelled cases (Base case and Alternative case) is presented, where accumulated sedimentation from all wells are included. All figures are shown with the area covered by 1-6.5 mm (below PNEC) and the area with 6.5 mm or more (above PNEC).

5.4.1 Simulation 1

Figure 5-55 shows the modelled sedimentation after drilling 6 wells at the Field center. The area covered by >6.5 mm corresponds to 67 500 m^2. Maximum spread of the area >6.5 mm is about 300 m south.

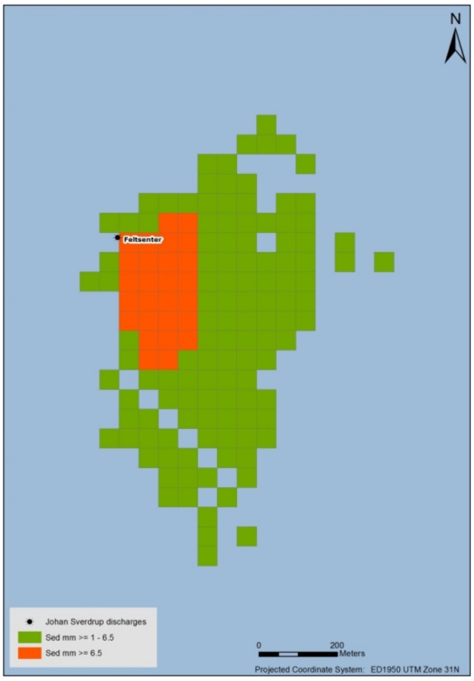


Figure 5-55 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm, simulation 1 discharge from 6 wells at Field-center.

5.4.2 Simulation 2

Figure 5-56 shows the modelled sedimentation after drilling 27 wells at the Field center. The area covered by >6.5 mm corresponds to 277 500 m^2. Maximum spread of the area >6.5 mm is about 500 m south.

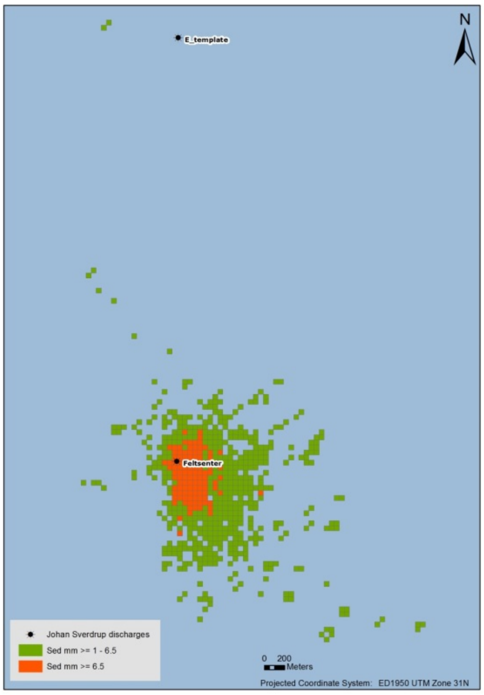


Figure 5-56 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm, simulation 2, discharge from 27 wells at Field-center.

5.4.3 Simulation 3

Figure 5-57 shows the modelled sedimentation after drilling 24 wells at the Avaldsnes. The area covered by >6.5 mm corresponds to 237 500 m^2. Maximum spread of the area >6.5 mm is 500 m south but with some modelled patches further away.

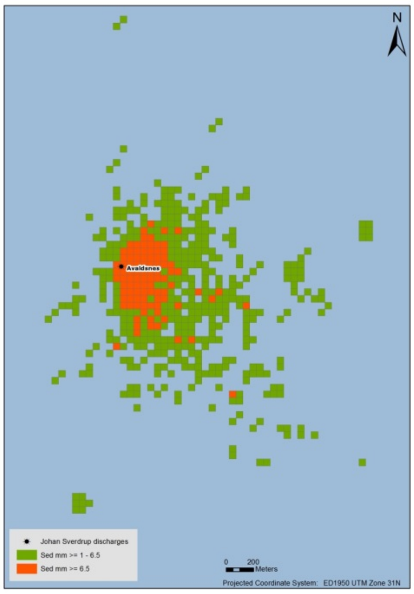


Figure 5-57 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 3, discharge from 24 wells at Avaldsnes.

5.4.4 Simulation 4

Figure 5-58 shows the modelled sedimentation after drilling 4 wells at the E-template. The area covered by >6.5 mm corresponds to 40 000 m^2. Maximum spread of the area >6.5 mm is about 180 m south east.

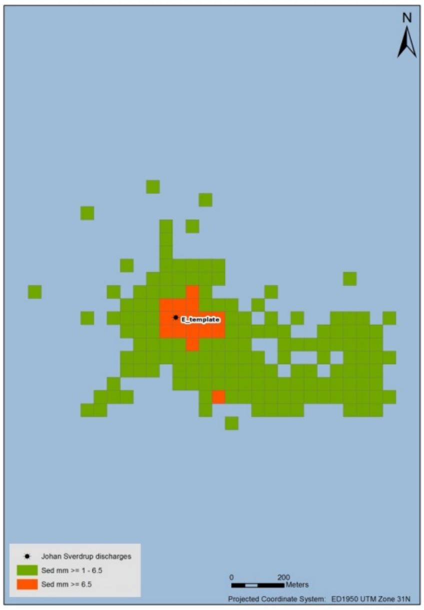


Figure 5-58 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 4, discharge from 4 wells at E-template.

5.4.5 Simulation 5

Figure 5-59 shows the modelled sedimentation after drilling 4 wells at the F-template. The area covered by >6.5 mm corresponds to 30 000 m^2. Maximum spread of the area >6.5 mm is about 150 m south east.

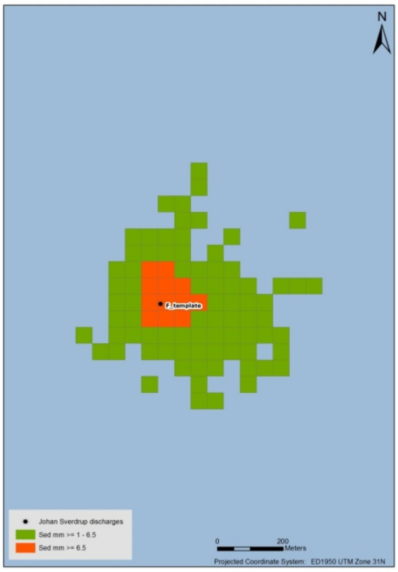


Figure 5-59 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 5, discharge from 4 wells at F-template.

5.4.6 Simulation 6

Figure 5-60 shows the modelled sedimentation after drilling 4 wells at the G-template. The area covered by >6.5 mm corresponds to 30 000 m^2. Maximum spread of the area >6.5 mm is about 180 m south.

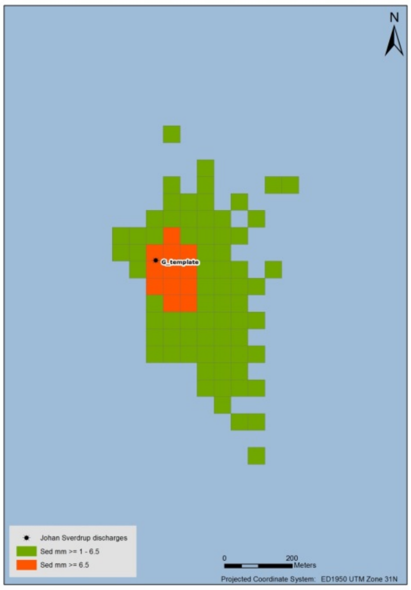


Figure 5-60 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 6, discharge from 4 wells at the G-template.

5.4.7 Simulation 7

Figure 5-61 shows the modelled sedimentation after drilling 6 wells at the Kvitsøy. The area covered by >6.5 mm corresponds to 47 500 m^2. Maximum spread of the area >6.5 mm is about 250 m south to south east.

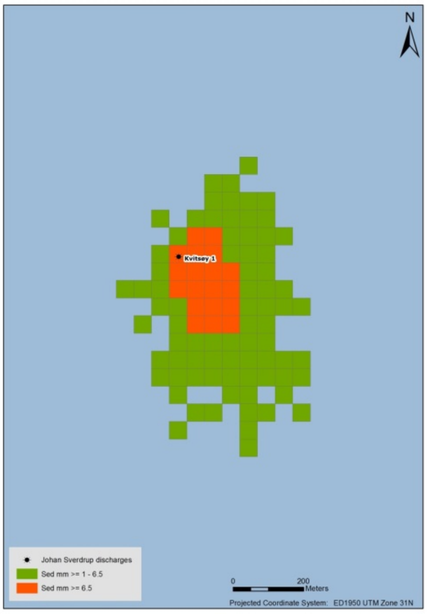


Figure 5-61 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 7, discharge from 6 wells at Kvitsøy.

5.4.8 Simulation 8

Figure 5-62 shows the modelled sedimentation after drilling 9 wells at the Geitungen. The area covered by >6.5 mm corresponds to 95 000 m^2. Maximum spread of the area >6.5 mm is about 350 m south.

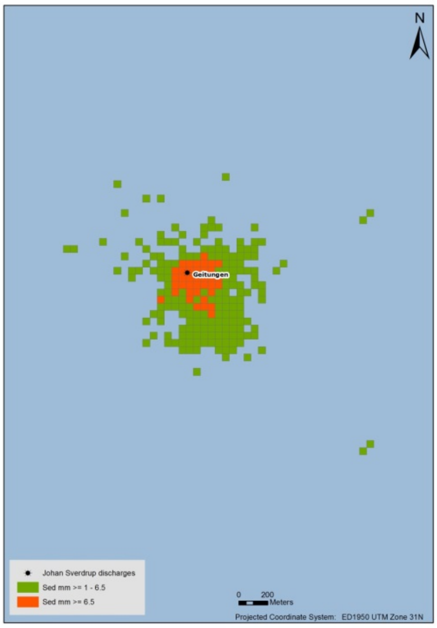


Figure 5-62 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 8, discharge from 9 wells at Geitungen.

5.4.9 Simulation 9

Figure 5-63 shows the modelled sedimentation after drilling 27 wells at the Field center. The area covered by >6.5 mm corresponds to 177 500 m^2. Maximum spread of the area >6.5 mm is about 500 m south.

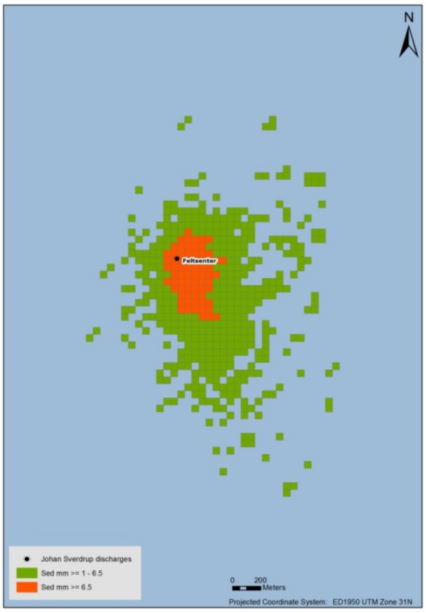


Figure 5-63 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 9, discharge from 27 wells at Field-center.

5.4.10 Simulation 10

Figure 5-64 shows the modelled sedimentation after drilling 24 wells at the Avaldsnes. The area covered by >6.5 mm corresponds to 150 000 m^2. Maximum spread of the area >6.5 mm is about 400 m south.

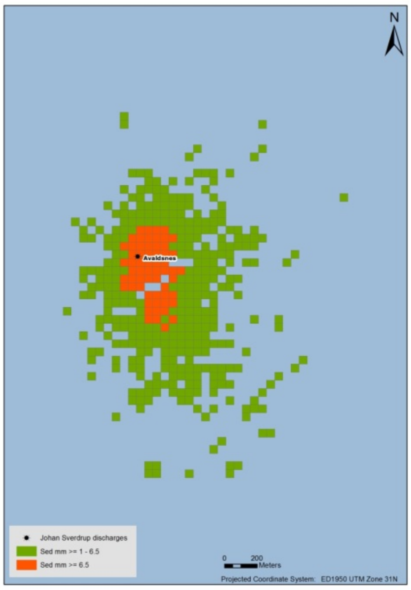


Figure 5-64 Areas where modelled sedimentation rates is 1-6.5 mm and >6.5 mm. Simulation 10, discharge from 24 wells at Avaldsnes.

5.4.11 Summary results - sediment

A summary of the modelled area covered by >6.5 mm due to the planned drilling operations at Johan Sverdrup is presented in **Table 5-16**. In general areas above a PNEC of 6.5 mm are local within 150 – 500 m from the discharge point. Overall there is modelled that Base case will affect a sediment area of 180 000 m^2 more than Alternative case.

Table 5-16 Summary of modelled area covered by >6.5 mm due to the planned drilling operations at the Johan Sverdrup field.

Simulation nr.	Area (m^2) >6.5 mm	Approximate largest distance (m) from discharge point covered by >6.5 mm/Direction
1	67 500	300/south
2	277 500	500/south
3	237 500	500/south
4	40 000	180/south east
5	30 000	150/south east
6	30 000	180/south
7	47 500	250/south to south east
8	95 000	350 south
9	177 500	500/south
10	150 000	400/south
Base case[1)]	790 000	
Alternative case[2)]	610 000	

1) Simulation 1-8

2) Simulation 1 and 4-10

5.4.12 Valuable resources in the area in relation to the discharges

In Figure 5-65 are the overall footprint of the sedimentation area for the two cases presented together with identified valuable resources in the area. Because the areas affected by >6.5 mm of sedimentation are very local there are in general no overlap between the areas with sedimentation rates >6.5 mm and the identified valuable fishery resources. The cod spawning area located approximately 8 km south of Kvitsøy is too long distance to be affected by the sedimentation due to the drilling operations. Regarding the two benthic species, the mussels *Arctica islandica* and *Tellimya tenella,* it cannot be ruled out that individuals of these species may be affected by the drilling operations. The abundance of these species at the Johan Sverdrup field are however uncertain. *Tellimya tenella* is mentioned because it is listed in the Norwegian Red List as DD – data deficient. There are no data on presence of this species within Johan Sverdrup, but data from the regional survey carried out in 2012 revealed some scattered densities in the region with the highest density far west. The category data deficient does not necessarily mean that this is a rare or vulnerable species but the simply that there are lack of data to assess it properly.

Arctica islandica is not mentioned in the Norwegian Red list but has been defined by OSPAR to by a species under threat and/or in decline within the greater North Sea (Ospar region II). There are no data on this species from Johan Sverdup, but data from 2012 revealed highest densities north west of Geitungen. Presence of this species within Johan Sverdrup can therefore not be ruled out.

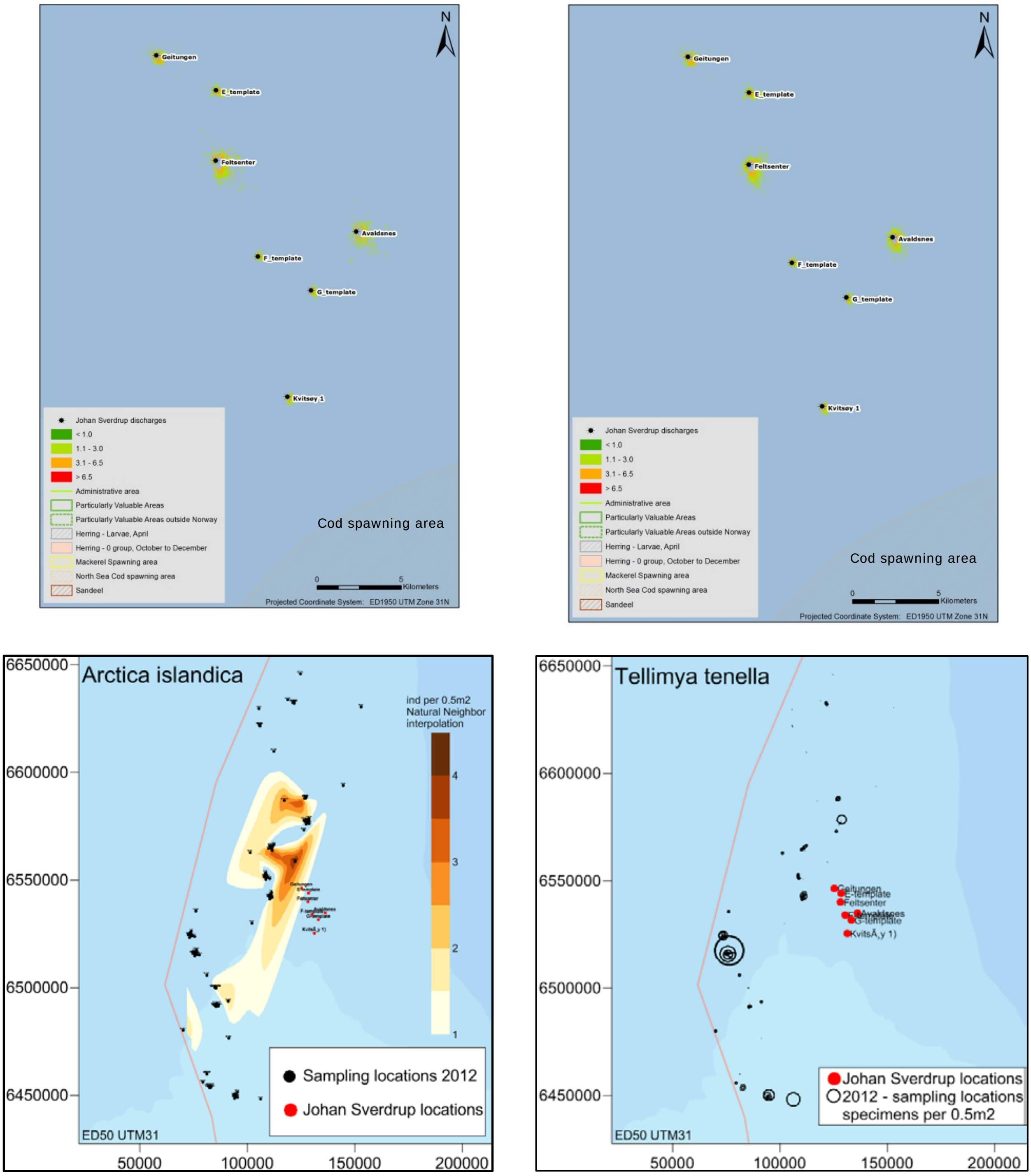


Figure 5-65 Overall footprint of the sedimentation areas together with identified valuable resources for Base case (upper left) and Alternative case (upper right). Interploated distribution of the OSPAR species *Arctica Islandica* (down left), data from Regional monitoring 2012. Distribution of registrations of *Tellimya tenella (down right)* listed in the Norwegian Red List, data from Regional monitoring 2012.

5.4.13 Literature review

The results from the modelling, which is supported by experiences from regional monitoring on the NCS and monitoring of drilling operations, suggests that effects of sedimentation due to drilling operations are local. No measurable effects are expected on identified valuable resources in the region such as sand eel areas, cod spawning areas or herring areas. The basis for the review below is therefore focused on two benthic mussels, *Arctica islandica and Tellimya tenella,* which may be found within the Johan Sverdrup area.

Arctica islandica lives buried in superficial, silty/muddy sediments with their relatively short siphons extended above the sediment surface. Although not fixed to the substrate like e.g. blue mussels on hard substrates, this species has a low ability of vertical movement through the sediments (Abele et al., 2009). It is estimated that *Arctica islandica* would react on burial by closing their shells, starting up anoxic metabolism and waiting for better environmental conditions. This would enable *Arctica islandica* to survive for extended periods (several weeks), however burial due to sedimentation may last for an extended period of time although in a relatively limited influence area. While *Arctica islandica* grow rather large (shell width may exceed 120 mm), it is estimated that acute burial of 6.5 mm of sediments (representing the LC5 effect limit of this parameter) would represent a critical limit also for this species. Consequently, the impact on *Arctica islandica* regarding burial is estimated to extend over the same influence area as modelled for this parameter.

Tellimya tenella is a small and thin-shelled species. Although often associated with the burying sea urchin *Brissopsis* sp., with a relatively high level of motility, it is estimated that acute burial of 6.5 mm of sediments would be lethal also for this species. Analogous with what was concluded for *Arctica islandica* above, the impact on *Tellimya tenella* related to burial is therefore estimated to extend over the same influence area as modelled for this parameter.

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APPENDIX A

Produced water modeling - details

Modeling produced water:

- 30 000 m^3/d i 8 days
- Discharge depth: 20 m below sea surface
- Diameter of caisson: 1200 mm
- Heading: 90° (perpendicular)
- Co ordinates Riser Plattform (ED50 UTM 31): 474 417 E, 6 522 134 N
- Constituents in the discharges: (ref fil: EIF input data Johan Sverdrup 2038 JS 6a rev01.xls, sheet: EIF 2012 input data provided by Statoil):

Concentrations and PNEC for components in the produced water for Johan Sverdrup.

	Johan Sverdrup	
Components	Concentrations	PNEC
	mg/l	µg/l
BTEX	3.8619	17
Naphthalenes	0.9786	2.1
PAH 2-3	0.1421	0.15
PAH 4+	0.0036	0.05
Phenols C0-C3	1.7827	10
Phenols C4-C5	0.0882	0.36
Phenols C6-C9	0.0040	0.04
Dispersed oil	10	40.4
Zinc (Zn)	0.00026	0.028
Copper (Cu)	0.0063	0.02
Nickel (Ni)	0.0029	0.008
Cadmium (Cd)	0.00011	0.182
Lead (Pb)	0.00063	1.22
Mercury (Hg)	0.00004	0.46

Chemical code	Component level 2	Concentration (mg/l)	Bioaccumulatio n LogPow	Biodegradatio n % 28 dg	K-factor	PNEC ppb, norm EC50 / 1000	Weighin g
Dem 6 KI	Ethylene glycol monobutyl ether	0.053	2.47	76.8	0.0522	21.8	1
Dem 6 KII	Butyldiglycol	0.57	3.16	90	0.0822	1000	1
Dem 6 KIII	Polyamine	1.13	0.0002	52.8	0.0268	55.6	2
Dem 6 KIV	PO/EO block polymer	0.42	0.0002	20	0.0080	50	2
Dem 6 KV	Di-epoxide	1.13	0.0002	47	0.0227	39.5	2
Floc 1 KI	Acrylic copolymer in aqueous emulsion	0.10	1.63	20.9	0.0084	1334	2
	Monoethylenglycol	2.09			0.0000		
DF 5 KI	Dearomated solvent containing aliphatic and alicyclic hydrocarbons	0.0087	5	69	0.0418	69	1
DF 5 KII	PDMS (Polydimethyl siloxane)	0.000082	0	0	0.0000	1000	2
SI 14 KI	Sodium polyasparate	1.00	0	35	0.0154	430	1
	Monoethylenglycol	2.25			0.0000		
AI 3 KI	Ethylene/vinyl acetae copolymer	0.000013	0	0	0.0000	1000	2
AI 3 KII	Surfactant	0.013	2	40	0.0182	25	2
AI 3 KIII	Fractionated hydrocarbon exract	0.00034	6	64	0.0365	51	1
HS 2 KI		30	0	87	0.0729	51	1
HS 2 KII		30	0	87	0.0729	27	1

APPENDIX B
Drilling discharges modeling - details

Coordinates for discharges (ED50 UTM31).

Locality	Surface discharges		CTS Discharges[1)]	
	East	North	East	North
Field Center	474 237	6 522 025	474 237	6 521 950
Avaldsnes	482 600	6 517 800	482 600	6 517 725
Kvitsøy 1)	478 518	6 507 955	478 518	6 507 880
Geitungen	470 700	6 528 300	470 700	6 528 225
E-template	474 253	6 526 215	474 253	6 526 140
F-template	476 749	6 516 308	476 749	6 516 233
G-template	479 919	6 514 290	479 919	6 514 215

1) CTS discharges were agreed to be 75 m south of surface discharges.

Identified discharge regimes for different drilling strategies.

Drilling strategy	42”	36”	24”	17,5”	12,25”	9,5”
1	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Discharges of cuttings and WBM from rig	Discharges of cuttings with hydrocarbons from TCC from rig.	Discharges of cuttings with hydrocarbons from TCC from rig.	Discharges of cuttings with hydrocarbons from TCC from rig.
2	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Discharges of cuttings and WBM from rig	No discharges	No discharges	No discharges
3	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	No discharges	No discharges	No discharges
4	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor.	n.a	Use of CTS to discharge cuttings, sea water and viscous pills at sea floor	No discharges	No discharges	No discharges

n.a: Not Applicable

TCC: Thermo mechanical Cuttings Cleaner Technology

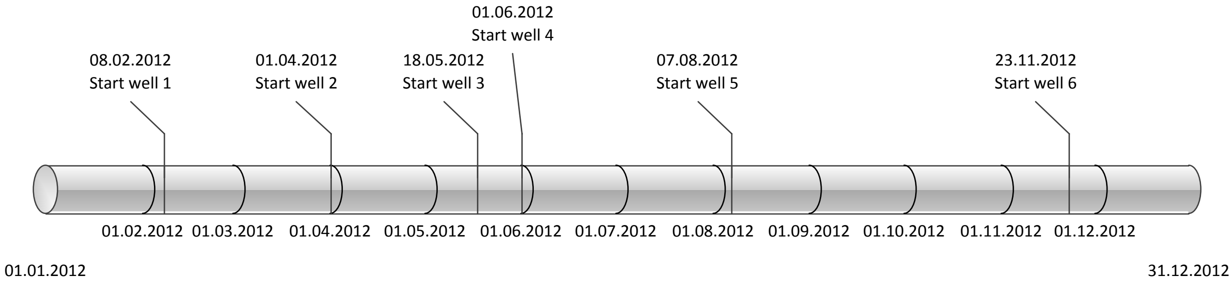
Identified modelling scenarios

Simulation nr./type	Drilling strategy	Number of wells	Locality	Discharge points
1/Floater with well head on platform (dry)	3	6	Field center	1: (CTS)
2/Integrated rig with well-head on platform. Discharges of oil atached after cleaning from sea surface	1	27	Field center	2: (CTS) + discharges from rig
3/ Integrated rig with well head on platform. Discharges of OBM after cleaning from sea surface	1	24	Avaldsnes	2: (CTS) + discharges from rig
4/ Floater with well head sub-sea (wet)	4	4	E-template	1: (CTS)
5/ Floater with well head sub-sea (wet	4	4	F-template	1: (CTS)
6/ Floater with well head sub-sea (wet	4	4	G-template	1: (CTS)
7/ Floater with well head sub-sea (wet	4	6	Kvitsøy	1: (CTS)
8/ Floater with well head sub-sea (wet	4	9	Geitungen	1: (CTS)
9/ Integrated rig with well head on platform. (dry) OBM shipped to shore	2	27	Feltsenter	2 (CTS)+ discharges from rig
10/ Integrated rig with well head on platform. (dry) OBM shipped to shore	2	24	Avaldsnes	2 (CTS)+ discharges from rig

<u>Simulations periods</u>

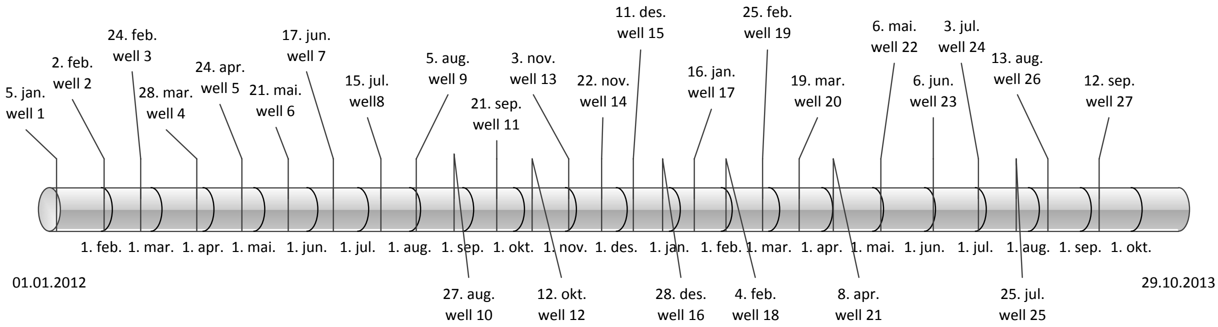
Simulation 1.

All of the discharges have duration of 54 hours => discharges from two sections => 24 hours between each section => total duration 78 hours.
Proposed commencement of each well is indicated in the figure below.



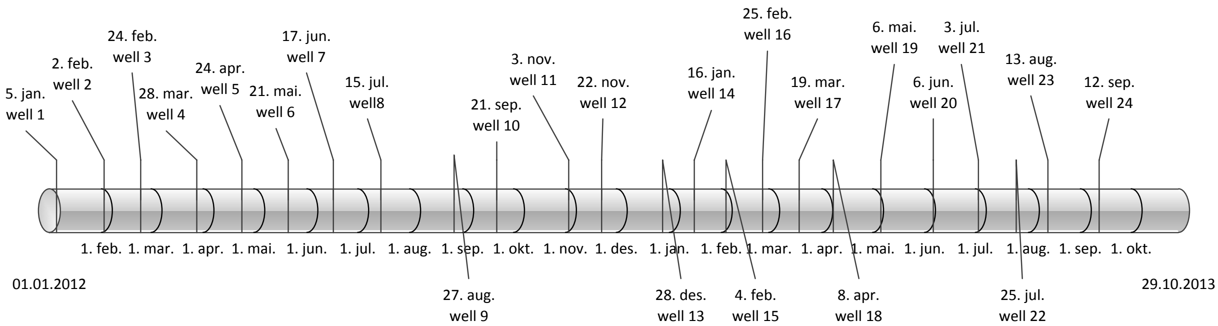
Simulation 2

All discharges have duration of 231 hours => discharges from 5 sections => 24 hours between each section => total duration 327 hours.



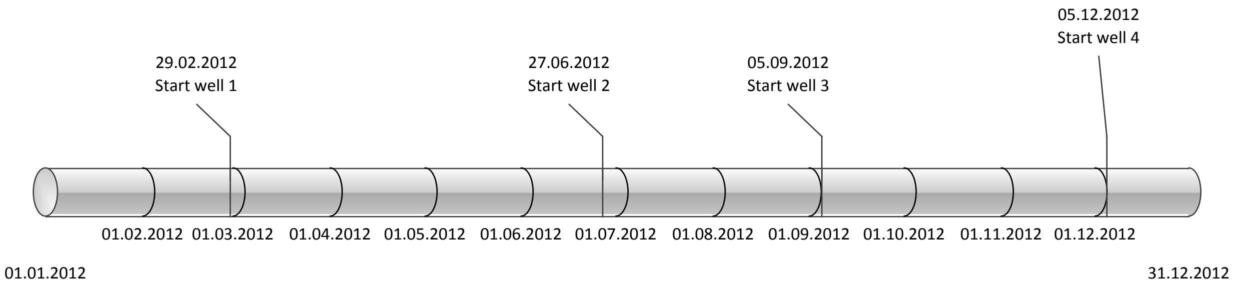
Simulation 3

All discharges have duration of 231 hours => discharges from 5 sections => 24 hours between each section => total duration 327 hours.



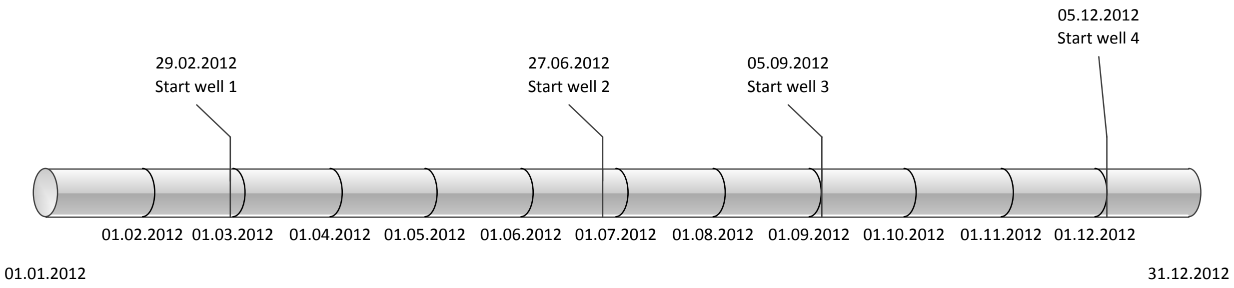
Simulation 4

All discharges have duration of 47 hours => discharges from two sections => 24 hours between each section => total duration 71 hours.



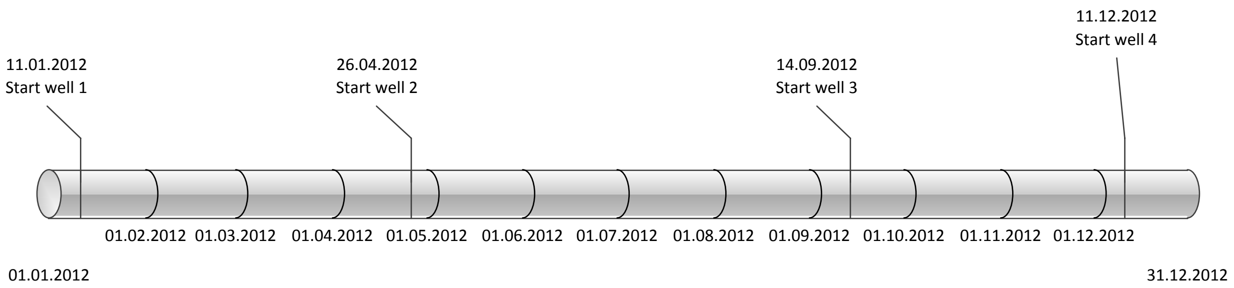
Simulation 5

All discharges have duration of 47 hours => discharges from two sections => 24 hours between each section => total duration 71 hours.



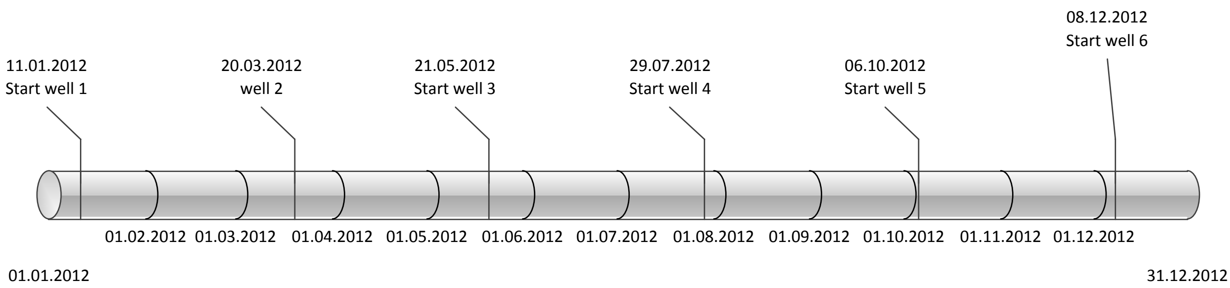
Simulation 6

All discharges have duration of 47 hours => discharges from two sections => 24 hours between each section => total duration 71 hours.



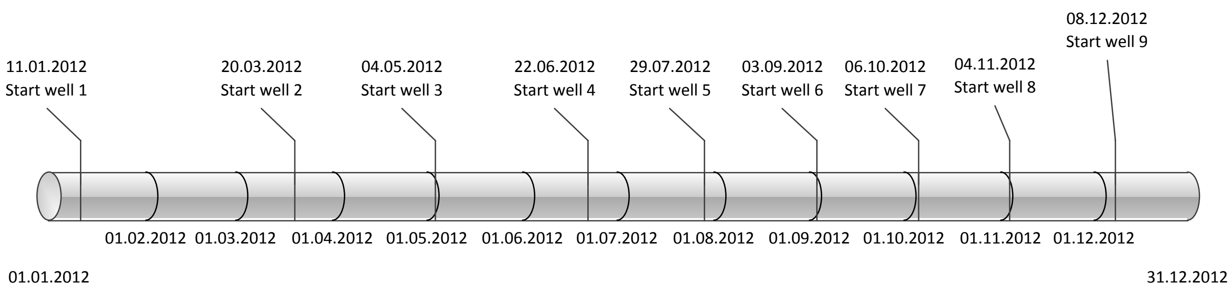
Simulation 7

All discharges have duration of 47 hours => discharges from two sections => 24 hours between each section => total duration 71 hours.



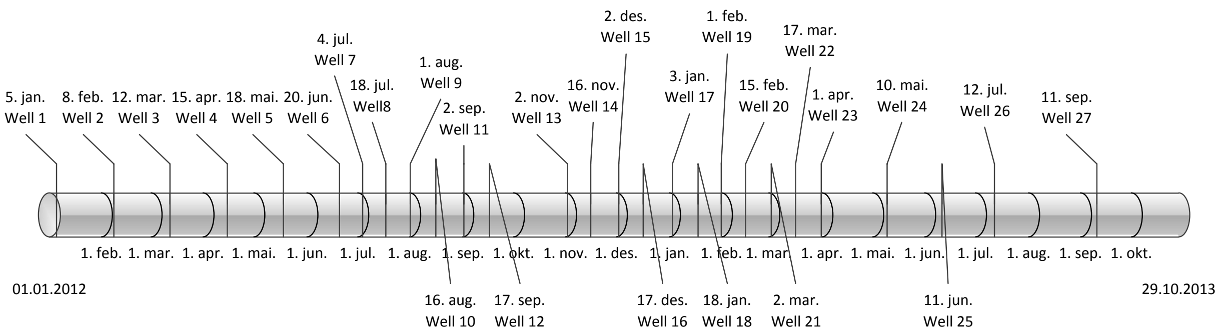
Simulation 8

All discharges have duration of 47 hours => discharges from two sections => 24 hours between each section => total duration 71 hours.



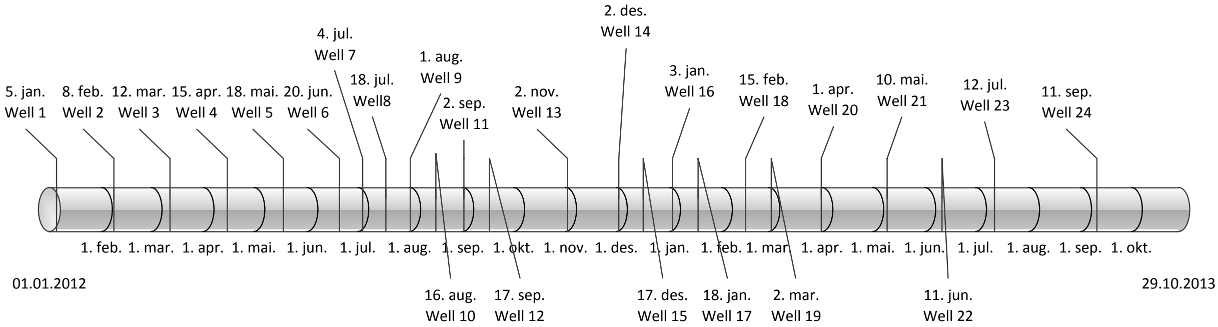
Simulation 9

All releases have duration of 54 hours => emissions from two sections => 24 hours between each section => total duration 78 hours.



Simulation 10

All releases have duration of 54 hours => emissions from two sections => 24 hours between each section => total duration 78 hours.



Discharge details for the different simulations

Simulation 1 – Floater with well head on platform => applies to 6 wells at Field center.

Drilling section:		36/42"	24"	17,5"	12,25"	9,5"
Start of discharge, month 1)		na	na	na	na	na
Section volume, m3 dry wells		105	269	208	84	23
Section length, m		160	920	1341	1102	500
Drilling (penetration rate, m/h 5)		20	20	23	22	18
Duration of discharge, hours		8	46	na	na	na
Discharge depth, m 2)		116 (Sea bed)	116 (Sea bed)	na	na	na
Diameter of outlet opening, m		0,25	0,25	na	na	na
Orientation of outlet opening (N, E, S, W)		towards south	down	down	down	down
Components	**Compound In discharge**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**
Particles,	Cuttings 3)	328	839	0	0	0
Particles,	Bentonite 6)	53,5	129,1	0	0	0
Particles,	GlyDril MC	na	na	na	na	na
Particles	Barite 6)	93,2	225,8	0	0	0
Particles,	KCL-Brine	na	na	na	na	na
Particles,	TCC powder 4)	0	0	0	0	0
Attach Chemical 1	TCC aliphatic HC 5)	na	na	na	na	na
Attach Chemical 2	TCC aromatic HC 5)	na	na	na	na	na
Attach Chemical 3	TCC PAH 5)	na	na	na	na	na
Chemicals		na	na	na	na	na
	Water	15923,7 8)	30554,6 8)	0	0	0
	Sum MUD					

1) Described above.
2) Below sea level
3) Used same washout factors as for Gina Krog, i.e. 20, 20, 10, 10, 3%. Formation density from JS exp well 16/5-3: 2,6 ton/m3
4) TCC powder equal to cuttings generated
5) Same as for Gina Krog simulations
6) Based on input to Gina Krog simulations
7) 2 m3 sea water is added for each m3 TCC powder discharged (as for Gina Krog)

8) Based on input to Morvin 2013 simulations

Simulation 2 = > applies to 27 wells at Field center and simulation 3 => applies to 24 wells at Avaldsnes

Drilling section:		**36/42"**	**24"**	**17,5"**	**12,25"**	**9,5"**
Start of discharge, month [1]		na	na	na	na	na
Section volume, m3 dry wells		105	269	208	84	23
Section length, m		160	920	1341	1102	500
Drilling (penetration rate, m/h [5]		20	20	23	22	18
Duration of discharge, hours		8	46	99	50	28
Discharge depth, m [2]		116 (Sea bed)	25	25	25	25
Diameter of outlet opening, m		0,25	1	1	1	1
Orientation of outlet opening (N, E, S, W)		towards south	down	down	down	down
Components	**Compound In discharge**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**
Particles,	Cuttings [3]	328	839	0	0	0
Particles,	Bentonite [6]	53,5	129,1	0	0	0
Particles,	GlyDril MC	na	na	na	na	na
Particles	Barite [6]	93,2	225,8	0	0	0
Particles,	KCL-Brine	na	na	na	na	na
Particles,	TCC powder [4]	0	0	595	240	62
Attach Chemical 1	TCC aliphatic HC [5]	na	na	5000 ppm	5000 ppm	5000 ppm
Attach Chemical 2	TCC aromatic HC [5]	na	na	178 ppm	178 ppm	178 ppm
Attach Chemical 3	TCC PAH [5]	na	na	5 ppm	5 ppm	5 ppm
Chemicals		na	na	na	na	na
	Water	15923,7 [8]	30554,6 [8]	457,6 [7]	184,8 [7]	47,38 [7]
	Sum MUD					

1) Described above
2) Below sea level
3) Used same washout factors as for Gina Krog, i.e. 20, 20, 10, 10, 3%. Formation density from JS exp well 16/5-3: 2,6 ton/m3
4) TCC powder equal to cuttings generated
5) Same as for Gina Krog simulations
6) Based on input to Gina Krog simulations
7) 2 m3 sea water is added for each m3 TCC powder discharged (as for Gina Krog)
8) Based on input to Morvin 2013 simulations

Simulation 4-8 => applies 4 wells at E-template, 4 wells at F-template, 3 wells at G-template, 6 wells at Kvitsøy and 10 wells at Geitungen.

Drilling section:		36/42"	24"	17,5"	12,25"	9,5"
Start of discharge, month 1)		na	na	na	na	na
Section volume, m3 dry wells		72	248	139	129	19
Section length, m		80	850	893	1701	506
Drilling (penetration rate, m/h 5)		20	20	23	22	18
Duration of discharge, hours		4	43	na	na	na
Discharge depth, m 2)		116 (Sea bed)	116 (Sea bed)	na	na	na
Diameter of outlet opening, m	|	0,25	0,25	na	na	na
Orientation of outlet opening (N, E, S, W)		towards south	down	down	down	down
Components	**Compound In discharge**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**
Particles,	Cuttings 3)	225	774	0	0	0
Particles,	Bentonite 6)	26,8	119,3	0	0	0
Particles,	GlyDril MC	na	na	na	na	na
Particles	Barite 6)	46,6	208,6	0	0	0
Particles,	KCL-Brine	na	na	na	na	na
Particles,	TCC powder 4)	0	0	0	0	0
Attach Chemical 1	TCC aliphatic HC 5)	na	na	na	na	na
Attach Chemical 2	TCC aromatic HC 5)	na	na	na	na	na
Attach Chemical 3	TCC PAH 5)	na	na	na	na	na
Chemicals		na	na	na	na	na
	Water	7961,9 8)	28229,8 8)	0	0	0
	Sum MUD					

1) Described above
2) Below sea level
3) Used same washout factors as for Gina Krog, i.e. 20, 20, 10, 10, 3%. Formation density from JS exp well 16/5-3: 2,6 ton/m3
4) TCC powder equal to cuttings generated
5) Same as for Gina Krog simulations
6) Based on input to Gina Krog simulations
7) 2m3 sea water is added for each m3 TCC powder discharged (as for Gina Krog)
8) Based on input to Morvin 2013 simulations

Simulation 9 => applies to 27 wells at Field center (Alternative Case) and Simulation 10=> applies to 24 wells at Avaldsnes (Alternative Case)

Drilling section:		36/42"	24"	17,5"	12,25"	9,5"
Start of discharge, month 1)		na	na	na	na	na
Section volume, m3 dry wells		105	269	208	84	23
Section length, m		160	920	1341	1102	500
Drilling (penetration rate, m/h 5)		20	20	23	22	18
Duration of discharge, hours		8	46	na	na	na
Discharge depth, m 2)		116 (Sea bed)	25	na	na	na
Diameter of outlet opening, m		0,25	1	na	na	na
Orientation of outlet opening (N, E, S, W)		towards south	down	down	down	down
Components	**Compound In discharge**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**	**Amounts, Ton**
Particles,	Cuttings 3)	328	839	0	0	0
Particles,	Bentonite 6)	53,5	129,1	0	0	0
Particles,	GlyDril MC	na	na	na	na	na
Particles	Barite 6)	93,2	225,8	0	0	0
Particles,	KCL-Brine	na	na	na	na	na
Particles,	TCC powder 4)	0	0	0	0	0
Attach Chemical 1	TCC aliphatic HC 5)	na	na	na	na	na
Attach Chemical 2	TCC aromatic HC 5)	na	na	na	na	na
Attach Chemical 3	TCC PAH 5)	na	na	na	na	na
Chemicals		na	na	na	na	na
	Water	15923,7 8)	30554,6 8)	0	0	0
	Sum MUD					

1) Described above
2) Below sea level
3) Used same washout factors as for Gina Krog, i.e. 20, 20, 10, 10, 3%. Formation density from JS exp well 16/5-3: 2,6 ton/m3
4) TCC powder equal to cuttings generated
5) Same as for Gina Krog simulations
6) Based on input to Gina Krog simulations
7) 2 m3 sea water is added for each m3 TCC powder discharged (as for Gina Krog)
8) Based on input to Morvin 2013 simulations

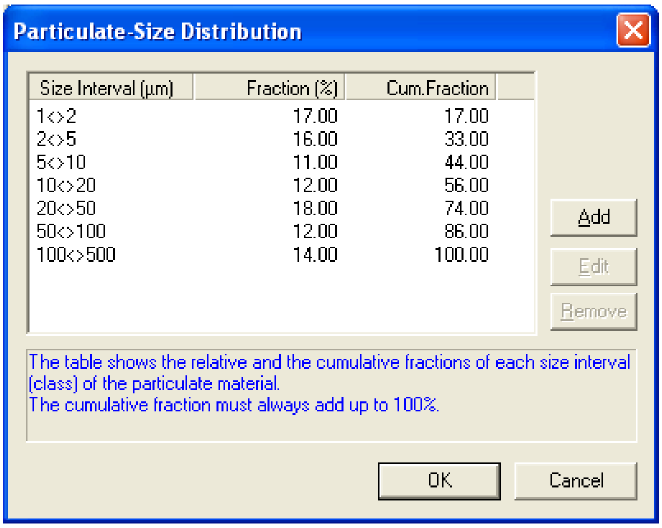
Particle size of the natural sediment

The model calculates the stresses caused by the deposition of grains that have sizes that are different from the natural grain sizes on the actual location. Therefore, the actual natural grain size on the location should be known. A median grain size equal to 0.15 mm is used in the calculations. The choice of this number may influence on the size of the environmental risk in the sediment due to grain size changes.

Grain size distributions in the discharge

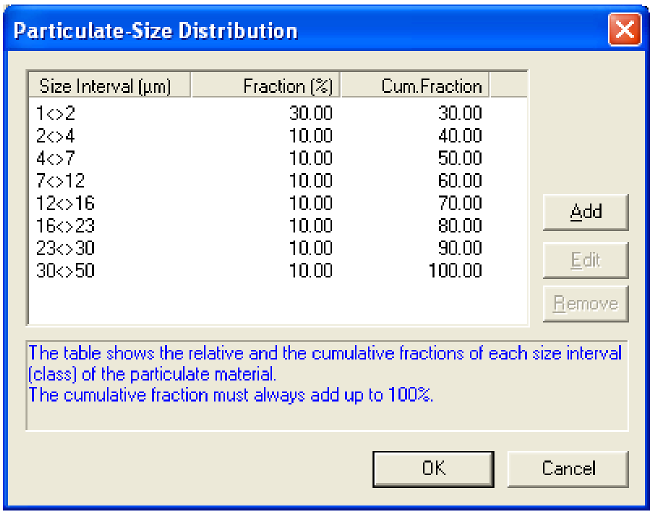
The particulate content in the discharge consist of particles (cuttings, bentonite and barite) for the top hole sections, for the deeper sections the cuttings will be released from the platform after treatment with the TCC Rotomill process (TCC powder). Particle size distribution used in the calculations is given in **Error! Reference source not found.**- **Error! Reference source not found.**.

Grain size distributions of TCC powder particles measured by Macaulay Scientific Consulting Ltd. Density 2500 kg/m^3. Distribution used for the TCC powder discharged from the drilling rig.



Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	17.00	17.00
2<>5	16.00	33.00
5<>10	11.00	44.00
10<>20	12.00	56.00
20<>50	18.00	74.00
50<>100	12.00	86.00
100<>500	14.00	100.00

Grain size distributions of barite particles measured during an exploration drilling in the Barents Sea (Saga 1994). The sampling of the barite is taken at the shaker, after the particles have been through the drill pit. Density of barite 4.2 tonnes/m^3.

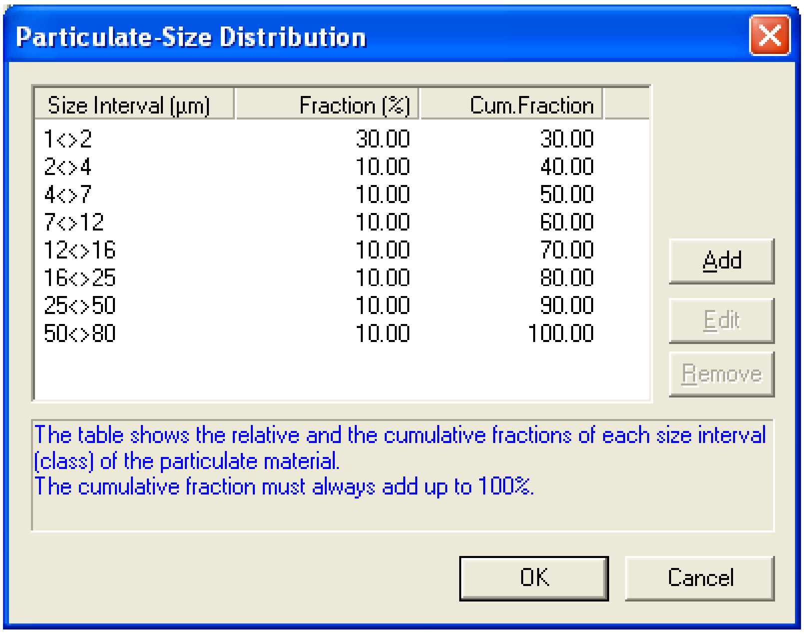


Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	30.00	30.00
2<>4	10.00	40.00
4<>7	10.00	50.00
7<>12	10.00	60.00
12<>16	10.00	70.00
16<>23	10.00	80.00
23<>30	10.00	90.00
30<>50	10.00	100.00

Bentonite is also planned to be used for the upper (top hole) drilling sections. The particle size distribution assumed for bentonite is shown in **Error! Reference source not found.**. Since the particle size distribution for the bentonite is not known, it is assumed to be similar to barite (**Error! Reference source not found.**).

Generally, bentonite is a clay-like material with individual particle sizes of order ≤ 1 – 2 µm. However, experience has shown that this material flocculates to a large extent when discharged to the sea. The flocculation process causes the formation of larger particles. This process therefore justifies the use of larger particles sizes for bentonite in the discharge calculations.

Grain size distribution of the bentonite particles. Density of bentonite is 2500 kg/m^3.



PNEC's for particles and components in the mud packages used

Error! Reference source not found. gives an overview of the partition coefficients and PNEC's used for the particles generated from the TCC process, and the attached hydrocarbon components.

Concentrations and toxicity data for TCC powder, barite and the attached oil content, ref to T.Frost *et al.* ERMS report no. 4, 2006 (table 5.12) and OSPAR 2012.

	Density, tonnes/m^3	KOC (Pow)	PNEC, ppb
TCC powder	2.5	-	150
TCC aliphatic hydrocarbons	1.2	790861	70.5
TCC aromatic hydrocarbons	0.865	9891.22	2
TCC PAH	1.202	790861	0.022

Ambient water column stratification

In the present simulations metrological data for 2012 and 2013 have been used. The temperature and salinity profiles used in the model are given in **Error! Reference source not found.**.

Temperature and salinity profile used for the Johan Sverdrup field.

Depth m	Spring/Summer conditions	
	Temperature (°C)	Salinity
0	14.51	34.10
10	14.22	34.30
20	13.09	34.70
30	10.78	35.00
40	9.52	35.00
50	8.25	35.10
60	7.97	35.10
70	7.68	35.10
80	7.46	35.20
90	7.32	35.20
100	7.18	35.20
110	7.17	35.20

Ambient wind and current conditions

The DREAM model uses simulated three-dimensional and time variable ocean currents for the actual area. This type of data secures that the behaviour (actual time and space variability) of the discharges in the ambient sea is included in the simulations. For the actual cases we have used modelled current data based on output from the SINMOD model operated by SINTEF Fisheries and Aquaculture.
The have used datasets for two years (from January 2012 to October 2013) of ocean currents and winds that covers the waters of Northern Europe. The spatial resolution is 4km and the temporal resolution is 2 hours

APPENDIX C

EBSA criteria - criteria to assess ecologically and biologically important areas

CBD COP 9 Decision IX/20)		
Criteria	**Definition**	
Uniqueness or rarity	(i)	unique ("the only one of its kind")
		rare (occurs only in few locations)
		endemic species
		endemic populations
		endemic communities
	(ii)	unique habitats
		rare habitats
		distinct habitats
		unique ecosystems
		rare ecosystems
		distinct ecosystems
	(iii)	unique geomorphological features
		unusual geomorphological features
		unique oceanographic features
		unusual oceanographic features
Special importance for lifehistory stages of species	Areas that are required for a population to survive and thrive.	
Importance for threatened, endangered or declining species and / or habitats	Area containing habitat for the survival and recovery of endangered species.	
	Area containing habitat for the survival and recovery of threatened species	
	Area containing habitat for the survival and recovery of declining species	
	Area with significant assemblages of endangered species.	
	Area with significant assemblages of threatened species.	
	Area with significant assemblages of declining species.	
Vulnerability, fragility,sensitivity, or slow recovery	relatively high proportion of sensitive habitats	
	relatively high proportion of sensitive biotopes	
	relatively high proportion of species that are functionally fragile	
	habitats with slow recovery	
	biotops with slow recovery	
	species with slow recovery	
Biological productivity	Area containing species with comparatively higher natural biological productivity	
	Area containing populations with comparatively higher natural biological productivity	
	Area containing communities with comparatively higher natural biological productivity	
Biological diversity	Area contains comparatively higher diversity of ecosystems	
	Area contains comparatively higher diversity of habitats	
	Area contains comparatively higher diversity of communities	
	Area contains comparatively higher diversity of species	
	Area contains comparatively higher genetic diversity.	

Naturalness	Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.

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