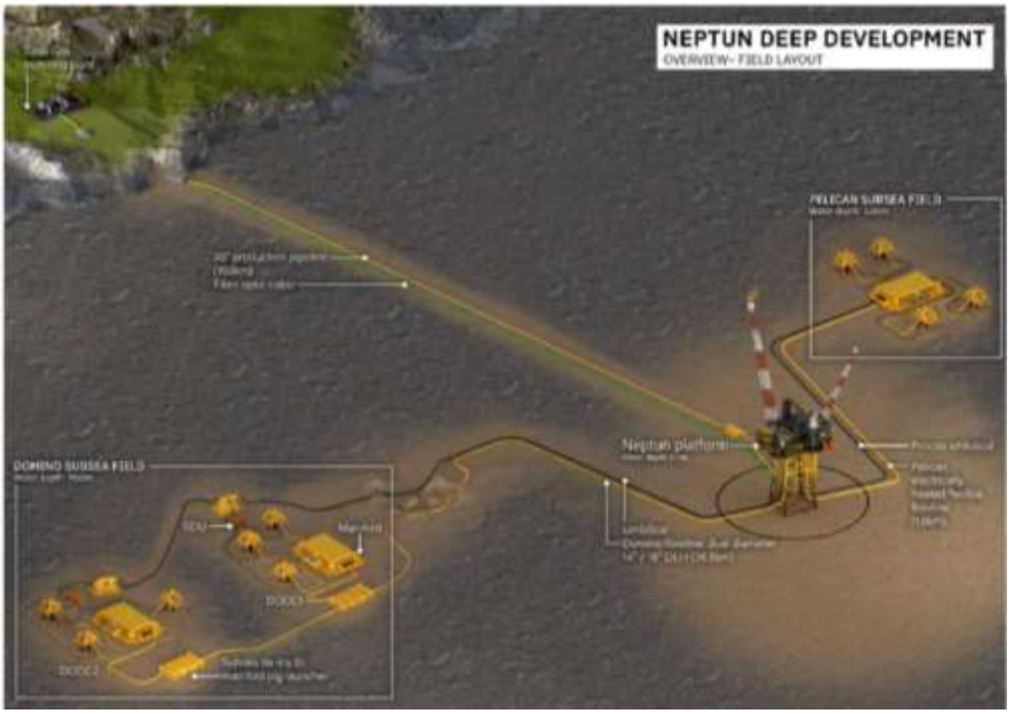

Report

Produced water simulations for the Neptun Deep Development, Black Sea

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Report No:

OC2023:00001

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Report

Produced water simulations for the Neptun Deep Development, Black Sea

DREAM modelling and EIF computations for selected scenarios

KEYWORDS
DREAM
RBA
Produced Water
Black Sea

VERSION
7.0

DATE
2023-05-12

AUTHOR(S)
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CLIENT(S)
io consulting

CLIENT'S REFERENCE
Safina Jivraj

PROJECT NO.
302007202

NO. OF PAGES/APPENDICES
167

SUMMARY
SINTEF Ocean has performed simulations of a variety of Produced Water (PW) discharge scenarios into the Black Sea at the location of the Neptun Deep development.
The objective was to support the BAT study for the field development as well as to assess the environmental risk from potential discharges and the applicability of the OSPAR risk-based approach to discharges into the marine environment.

In cooperation with oil and gas operators on the Norwegian Continental Shelf and internationally, SINTEF has developed DREAM, a numerical model that simulates transport and fates of chemicals in the marine environment, based on ambient conditions and chemical properties. The DREAM model computes the so-called EIF, a measure for environmental risk from these discharges, a method that is the accepted de-facto standard for PW discharges in the OSPAR region, e.g. Norway, the UK, and the Netherlands.

Results show low EIFs for the chosen chemical package and discharge conditions. Details and assumption are described in the report.

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REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
OC2023:00001	.	Confidential	Confidential

Document history

VERSION	DATE	VERSION DESCRIPTION
1.0	2022-11-10	Simulation results for discharges with varying parameters
2.0	2022-11-16	Abstract and executive summary
3.0	2022-11-23	Draft report with results and met ocean analysis
4.0	2022-12-04	Final Draft with all text
5.0	2023-01-02	Final Draft with changes after Bucharest meeting and QA
6.0	2023-01-15	Version after QA and feedback from io consulting
7.0	2023-05-11	New chapter F in Appendix with latest cases

Table of contents

List of abbreviations

DREAM	Dose-related Risk and Effects Assessment Model
EC50	The concentration where a specific effect is observed for 50% of the test specimen
EIF	Environmental Impact Factor
ERMS	Environment Risk Management System
HOCNF	Harmonized Offshore Chemical Notification Format
LC50	The concentration which causes lethality for 50% of the test specimen
LOEC	Lowest Observed Effect Concentration
MEMW	Marine Environmental Modelling Workbench
NCS	Norwegian Continental Shelf
NOEC	No Observed Effect Concentration
NOS	Naturally Observed Effect Concentration
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration
PLONOR	Pose Little Or NO Risk to the environment
PW	Produced water
REACH	Registration, Evaluation, Authorisation and restriction of CHemicals
SSD	Species Sensitivity Distribution
SHC	Sodium Hypochlorite
TGD	Technical Guideline Document (EC 1996)

Executive summary

SINTEF Ocean has performed simulations of a variety of Produced Water (PW) discharge scenarios into the Black Sea at the location of the Neptun Deep development using SINTEF DREAM (Dose-related Risk and Effects Assessment Model). The objectives included a) to support of the BAT study for the field development, b) to assess the environmental risk from potential discharges and c) to demonstrate the applicability of the OSPAR risk-based approach to discharges into the marine environment.

When assessing discharges to marine environment, the tasks are threefold:

A. Assessment of environmental conditions,
B. Assessment of transport to determine model area and resolution and possible advice to discharge arrangements,
C. Assessment of chemicals for toxicity and biodegradation (with respect to available oxygen demand and availability).

A Assessment of the environmental conditions at the site and in the surrounding waters

Summary

SINTEF assessed the environmental conditions through available data downloaded from the Copernicus Marine Service[1], a modelled data set from The Black Sea Physical Analysis and Forecast System[2]. Currents, temperature, and salinity as well as mixed layer information are available for download as hourly data for a period of ca. one year, a horizontal resolution of 1/40° x 1/40° and 121 vertical levels.

Analysis showed seasonal variations with generally **homogenous upper layer in the cold** and **stratified layer in the warmer months** which are well represented by the months of **April** and **September**, respectively. Data was compared to both, re-analysis (i.e. simulations with assimilation of observations) and a water quality study provided by io and showed good alignment.

The envisioned discharge depths with 90 and 130m are above the anoxic zone and pycnocline which is found below 150m and might extend to 200m in coastal areas. The biologically active zone is expected in the upper 50m [3].

To not pick extremes but still represent differences, April and September 2022 were chosen for the modelling study (see Figure 3-2).

Salinity and temperature are determining the stratification of the water column, i.e. existing layering that are relevant for the vertical transport in the water column. Profiles for the chosen months show stratification between the upper 15m and waters below in September vs. a homogeneous layer in April. Water density is here mainly driven by temperature. More details can be found in Chapter 3 and the Appendix (E.5).

The modelled data comes in a sufficient spatial and temporal resolution, is available for a long period and covers the discharge location and the surrounding waters. **It was therefore assessed as the best available data for this study.**

[1] https://marine.copernicus.eu/
[2] https://data.marine.copernicus.eu/product/BLKSEA_ANALYSISFORECAST_PHY_007_001/description
[3] Also see http://www.blacksea-commission.org/Inf.%20and%20Resources/Publications/SOE2009/#_Toc225838287

B Assessment of the transport of the discharged matter in the marine environment and possible implications of discharge design (such as depth, discharge diameter)

Summary

SINTEF performed simulations of a large matrix of possible discharge scenarios, of which the most significant ones are reported in detail in the report (Chapter 5) and additional results (from other variations of input) are summarized in the Appendix (E.3 and F).

A first assessment concentrated on the effects on discharge depth and diameter from short simulations. The results show that due to the salinity and hence density of the discharge, discharged matter will be trapped around 70-100m once discharged at 90m or below. Discharges at 60-70m might surface at low concentrations and result in transport within the upper water column, which is expected to host the marine life in the area due to light and oxygen conditions. Discharge from the pipeline at 130m will always stay in the lower water column, either at the sea floor (high saline discharge) or slightly further up (~100m) for the lower salinity.

A smaller caisson and thus discharge diameter does not change the overall EIF and transport result significantly, but results in slightly better mixing and lower chemical concentrations in the water column as the direct result. A reduction of discharge diameter from 750 mm to 500 mm produces similar results at 90 m discharge depth versus 100 m for the larger diameter.

After this assessment and in agreement with the BAT study, all caisson discharge simulations were run for 90 m discharge depth and 500 mm discharge diameter. Further variations included discharge depth, discharge diameter and discharge location (to study caisson vs. pipeline) with different discharge profiles (chemical compositions with or without chlorinated cooling water) at the caisson and the pipeline outlet, as well as high and low salinity.

See Chapter 4.1 for details.

C Biodegradation and toxicity of the chemicals and resulting environmental risk

Summary

The DREAM model features oxygen demand from biodegradation as one of the simulation results. As the Black Sea is known for anoxic conditions at greater depths, this feature was used to assess the biodegradability of the discharge chemicals, specifically for the cooling water treatment Sodium Hypochlorite (SHC), which exhibits high toxicity while it is highly biodegradable at oxidated seawater conditions. Results show that that available oxygen – while low in concentration - is sufficient to assume full biodegradation at the studied water depths.

The discharge of SHC is allowed for under NTPA 001 Legislation at 0.2ppm at the point of the discharge. SHC was therefore not accounted for in some of the scenarios.

Without SHC, environmental risk is dominated by two of the chemical components in the corrosion inhibitor. This applies to both chemical packages that are considered for the operations, with the chemical package from Schlumberger producing a significantly higher EIF (a reference water volume with environmental risk exceeding acceptable levels) than the chemical package from ChampionX.

Environmental risk is computed from transport and fate (e.g. biodegradation) and hence predicted environmental concentrations (PEC) and toxicity (predicted no-effect concentrations, PNEC) into a reference water volume where PEC exceeds PNEC. Produced water dilutes very quickly once discharged (Lee and Neff, 2011) and concentrations are very varying due to the environmental conditions that case mixing and transport.

1 EIF is the water volume of 100 x 100 x 10m = 100000m^3 with environmental risk, i.e. PEC > PNEC or PEC/PNEC > 1. Due to the varying water concentrations, also this water volume varies over time due to e.g. currents and other factors. **We report maximum EIF / water volume and time averaged EIF / water volume together with PEC at the time of maximum EIF.**

D Summary of all simulation results

- Schlumberger chemicals produce higher EIF than ChampionX chemicals,
- Sodium Hypochlorite produces higher EIF (factor 120 for ChampionX, 4.5 for Schlumberger),
- Warm September scenarios produce higher EIF than cold April scenarios, esp. for the caisson discharges, where ChampionX does not produce any EIF in April.
- Salinity of the PW is an important factor for the pipeline discharges and has less significant effect for the caisson discharges. The low salinity PW – when discharged through pipeline at 130 m - is transported into a different current layer and diluted faster. High-salinity PW sinks to the sea floor where it might impact possible sea floor habitats through chemical stress in the pore water. As there is very little oxygen at 130 m, biodegradation is slow. DREAM does not account for anaerobic biodegradation. High salinity PW – when discharged from caisson – results in higher EIF for the Schlumberger chemicals.

To put the study results into context we have plotted the EIF numbers from the scenarios in this study together with EIF numbers from a paper for fields on the Norwegian Continental Shelf in 2002 and 2008, see Figure A-6-1.

The unit for the environmental impact factor EIF computed by DREAM to assess environmental risk in the water column is a reference water volume where stress levels are above accepted levels. The affected water volume is very dependent on local current conditions, the chemicals in the discharge and the discharge arrangement. For the example simulations the maximum measure for environmental risk (water column EIF) is 945 for the Schlumberger case (Case 2b) vs. minimum 650 for the ChampionX case (Case 4a) when regarding Sodium Hypochlorite (i.e. a water volume of 0.0945 km^3 and 0.065 km^3, respectively). Without Sodium Hypochlorite there is no environmental risk reported for the ChampionX simulations for April.

With the exception to the cases that include Sodium Hypochlorite in the discharge from the treated cooling water, all cases compare relatively low, with the ChampionX cases producing significantly lower EIF values / water volumes with environmental risk.

Table 1 Results from all study scenarios

September (warm)		*ChampionX*			*Caisson*
Case #	Sodium Hypochloride considered	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
1a	YES	HIGH	724	549	Sodium hypochlorite 95%
1b	YES	LOW	697	557	Sodium hypochlorite 95%
*1c**	NO	HIGH	6	2	Corrosion inhib. B Comp.3 40% Corrosion inhib. B Comp.4 36%
*1d**	NO	LOW	4	1.3	Corrosion inhib. B Comp.3 40% Corrosion inhib. B Comp.4 36%

* Used in presentation in Romania

September (warm)		Schlumberger			Caisson
Case #	Sodium Hypochloride considered	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
2a	YES	HIGH	942	702	Sodium hypochlorite 55% Corrosion inhib. Comp.4 39%
2b	YES	LOW	954	708	Sodium hypochlorite 55% Corrosion inhib. Comp.4 38%
2c*	NO	HIGH	219	129	Corrosion inhib. Comp.4 85% Corrosion inhib. Comp.5 13%
2d*	NO	LOW	195	126	Corrosion inhib. Comp.4 85% Corrosion inhib. Comp.5 13%

September (warm)					Pipeline
Case #	Chemical	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
3a	ChampionX	HIGH	10	4	Corrosion inhib. Comp.3 50% Corrosion inhib. Comp.4 45%
3b	ChampionX	LOW	3	0.6	Corrosion inhib. Comp.3 50% Corrosion inhib. Comp.4 45%
3c	Schlumberger	HIGH	257	181	Corrosion inhib. Comp.4 87% Corrosion inhib. Comp.5 13%
3d	Schlumberger	LOW	254	156	Corrosion inhib. Comp.4 87% Corrosion inhib. Comp.5 13%

April (cold)		ChampionX			Caisson
Case #	Sodium Hypochloride considered	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
4a	YES	HIGH	650	546	Sodium hypochlorite 98%
4b	YES	LOW	665	580	Sodium hypochlorite 98%
4c*	NO	HIGH	0	0	EIF = 0
4d*	NO	LOW	0	0	EIF = 0

April (cold)		*Schlumberger*			*Caisson*
Case #	*Sodium Hypochloride considered*	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
5a	YES	HIGH	782	654	Sodium hypochlorite 73% Corrosioninhib_comp.4 23%
5b	YES	LOW	806	683	Sodium hypochlorite 75% Corrosioninhib_comp.4 21%
5c	NO	HIGH	86	54	Corrosioninhib_comp.4 85% Corrosioninhib_comp.5 14%
5d	NO	LOW	86	45	Corrosioninhib_comp.4 85% Corrosioninhib_comp.5 14%

April (cold)					*Pipeline*
Case #	Chemical	Produced Water Salinity	Max. EIF	Time averaged EIF	Main Contributor
6a	ChampionX	HIGH	11	3	Corrosion inhib. Comp.3 50% Corrosion inhib. Comp.4 45%

Scenario sets with running numbers 7, 8 and 9 were to study dilution of the Produced water (7 and 8 (different caisson diameter) and initial cases for intermittent methanol (MEOH) discharges due to well restart (9).

The final cases with corrected discharge concentrations based on maximum PW rates at Domino and Pelican of the Neptun Deep project are reported with numbers 10 (operational PW discharges) 11 (intermittent MEOH discharges in addition to operational PW) in Appendix F.

					Main Contributor to risk	
Case #	Chemical	Produced Water Salinity	Max. EIF	Time Averaged EIF	Corrosion inhibitor Comp-3	Corrosion inhibitor Comp-4
10A	ChampionX	HIGH	2	0.31	49.84	43.31
10B	ChampionX	LOW	1	0.16	49.85	43.31
10C	ChampionX	HIGH	0	0.00	0	0
10D	ChampionX	LOW	0	0.00	0	0
10E	ChampionX	-	21	7.84	50.59	44.33
10F	ChampionX	-	6	0.68	50.73	44.21

					Main Contributor to risk	
Case #	Chemical	Produced Water Salinity	Max. EIF	Time Averaged EIF	Corrosion inhibitor Comp-3	Corrosion inhibitor Comp-4
10G	ChampionX	HIGH	18	9.34	50.77	44.25
10H	ChampionX	LOW	21	7.52	50.56	44.46
10I	ChampionX	HIGH	10	1.82	50.8	44.25
10J	ChampionX	LOW	6	0.80	50.84	44.21
11A	ChampionX	HIGH	2	*	49.8	43.37
11B	ChampionX	LOW	2	*	49.78	43.4
11C	ChampionX	HIGH	0	*	0	0
11D	ChampionX	LOW	0	*	0	0
11E	ChampionX	HIGH	2	*	49.84	43.31
11F	ChampionX	LOW	1	*	49.85	43.31
11G	ChampionX	HIGH	0	*	0	0
11H	ChampionX	LOW	0	*	0	0

Produced water simulations for the Neptun Deep Development, Black Sea

1 Introduction to study

SINTEF has developed DREAM (Dose-related risk and effects assessment model) to simulate produced water discharges into sea water based on discharge chemicals and their properties and environmental conditions at the discharge location. When computed environmental concentrations (PEC) of the chemicals exceed their predicted no effect concentrations (PNEC), the model will report this as environmental risks associated with discharges of these chemicals to sea. For comparison reason, this risk is reported in the unit of a reference water volume of 100x100x10m=100000m^3, which is called Environmental Impact Factor, EIF.

In the present study, DREAM has been used to study different discharge arrangements and chemicals and to calculate the EIF for several discharge scenarios that represent possible discharges at the Neptun Deep development.

The following scenarios have been simulated for Neptun Deep:

1. Maximum flowrate at 10,000bwpd (input from OMV Petrom)
2. Caisson discharge with 500mm discharge diameter at 90m depth (find details and reasoning in Chapter 4.1 below)
3. Pipeline discharge with 300mm discharge diameter at 130m depth and different location than caisson (input from OMV Petrom)
4. With and without regarding Sodium hypochlorite from cooling water treatment in the caisson discharge
5. Seasonal variations
   EIF simulations are usually run for one month (in Norway this is May). When assessing conditions for fields not yet in production, one would look at seasonal differences that are important for the results. Met ocean data for the Black Sea area of interest for the months **September** (warm and wet season) and **April** (cold season) are used in the simulations (find reasoning for that in Chapter 3 below)
6. High- and low-salinity produced water (input from OMC Petrom)
7. Two chemical packages, Schlumberger (A) and ChampionX (B) (input from OMV Petrom on HOCNF data for the chemical packages from ChampionX and Schlumberger, see Chapter 4.4 for details).

The software version used in the present DREAM study was *14.0* dated 07.07.2022 (*Fates.exe (model engine) and MEMW.exe (user interface)*.

The module for presentation graphics (*MEMW.xls*) is dated 30 May 2011.

2 DREAM and the EIF, model and concepts

2.1 Background

In 1996 the Norwegian government issued a White Paper requiring the Norwegian oil industry to reach the goal of 'zero discharge' for the marine environment by 2005. To achieve this goal the Norwegian oil and gas industry initiated the Zero Discharge Programme for produced water discharges.

In order to quantify and document the potential risk to the marine environment from substances in produced water, SINTEF and the Norwegian oil and gas industry started the development of DREAM (Dose-related Risk and Effect Assessment Model) and the Environmental Impact Factor (EIF).

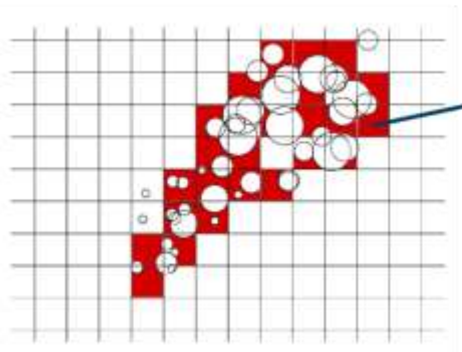
Since 2002, DREAM is used by all operators on the Norwegian Continental Shelf as a modelling platform for calculating the EIF and to report progress toward the goal of "zero discharge," interpreted as "zero harmful discharges," to the regulators. The EIF is a risk-based management tool and represents a volume of the receiving water where substances in the discharge exceed thresholds for environmental effects (Smit et. al, 2011).

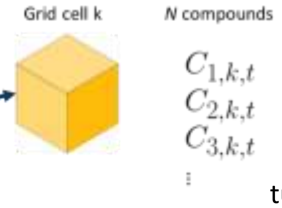
There is a global trend towards the application of a risk-based approach (RBA) to assessing and managing environmental risks and considering the potential impacts from discharges of produced water. One of the advantages of RBA is the absence of generic end-of-pipe limits for individual produced water components. Instead, a risk-based approach allows for flexibility to evaluate environmental risks and potential impacts of discharges site-specifically and on a case-by-case basis (Smit et. al, 2020).

2.2 The EIF concept in details

The EIF methodology follows the generic concept for environmental risk assessment as described by the United States' Environmental Protection Agency (USEPA, 1993) and the **European Commission** (EC, 2003). A standard set of chemicals has been defined to characterise the composition of produced water (natural occurring substances) that are assumed to represent a potential for harmful impact on the biota. In addition, information on production chemicals is used to complete the chemical profile of the discharge. The EIF method is based on a **PEC/PNEC approach**, in which the predicted environmental concentration (PEC) for each discharged compound is compared to a predicted no-effect concentration (PNEC) for that same compound. When the PEC exceeds the PNEC, adverse effects may occur as a result of exposure to that compound. In the following sections, the PEC and PNEC are briefly described as well as the risk principles behind the EIF calculation. More details can be found in Johnsen et al. (2000) and Smit et al. (2011).

The PEC. The PEC (*Predicted Environmental Concentration*) is expressed as concentration for individual substances or as dilution for the whole effluent. Computed with the DREAM model, PEC is the three-dimensional and time-variable concentration in the recipient of all compounds present in the discharge under the influence of ambient currents, vertical and horizontal transport and mixing, evaporation at the sea surface, biodegradation, and adsorption-desorption dynamics. Site-specific meteorology and hydrodynamics are used as input for the model simulations. The fates calculation for produced water substances is mainly based on **recommendations from the European Commissions' technical guidance document** on environmental risk assessment (EU-TGD) (EC, 2003).





DREAM is a numerical "particle", or Lagrangian model, i.e., the model generates numerical particles at the discharge point, which are transported with the currents and turbulence in the sea. Different properties, such as the mass of various compounds, densities and sinking velocities, are associated with each particle to represent the characteristics of a discharged compound. Model particles can also represent different states or phases, such as bubbles, droplets, dissolved matter and solid matter. Particles are computed into concentration by dividing the model area into a gridded representation, 'cells', and accounting for the particles and the properties of each chemical (or other) compound in each grid cell. Details are given in Reed and Hetland (2002). DREAM comes with a near-field ('plume') model that computes possible turbulence or jets at the discharge outlet. This module also accounts for temperature differences before the discharge is mixed with the ambient water.

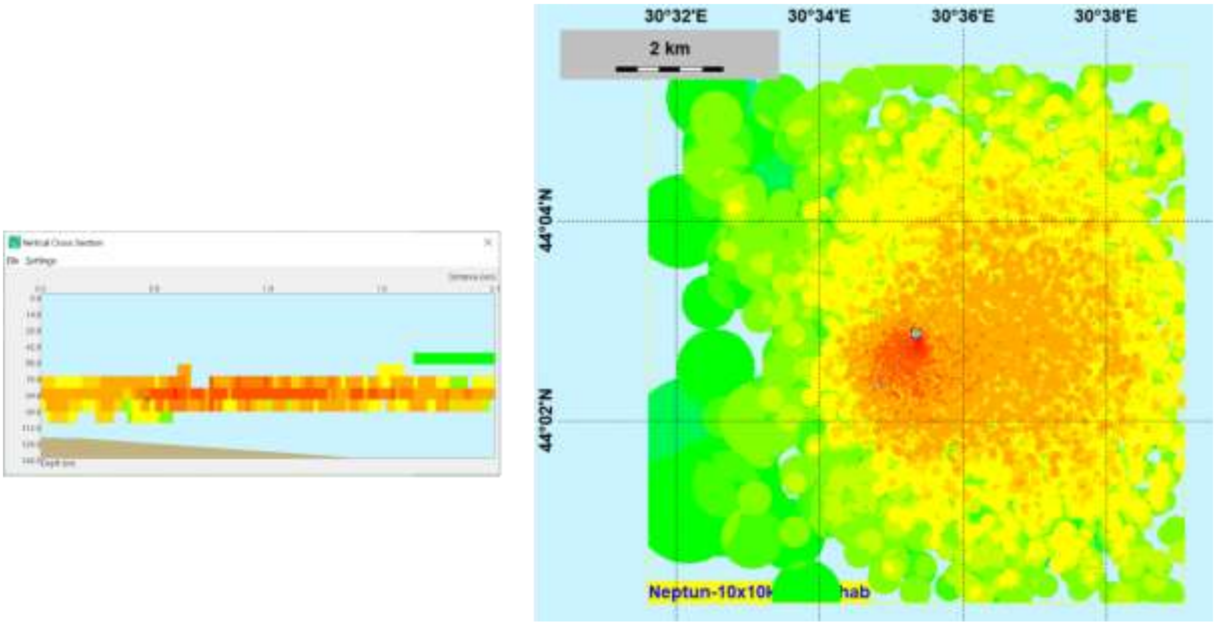


Figure 2-1 Close-up simulation[4] of near field with DREAM showing model area (yellow square) and cross-section along an arrow.

The ocean current-, water temperature- and salinity fields used in simulations with the DREAM model are usually generated by 3-dimensional and time-variable hydrodynamic models.

The PNEC. The PNEC (*Predicted No Effect Concentration*) for a compound is the concentration below which it is unlikely that adverse effects to the environment will occur. An effect probability or risk of 5% is often used as a cut-off criterion, assuming that risk is unacceptable if more than 5% of the **most sensitive** species are exposed above their chronic no-effect concentration (Smit et al., 2011)).

[4] The figures show a bird view 'through' the water column with the maximum concentration through the entire water column which is why we always include a cross section to show in which layer the maximum is located

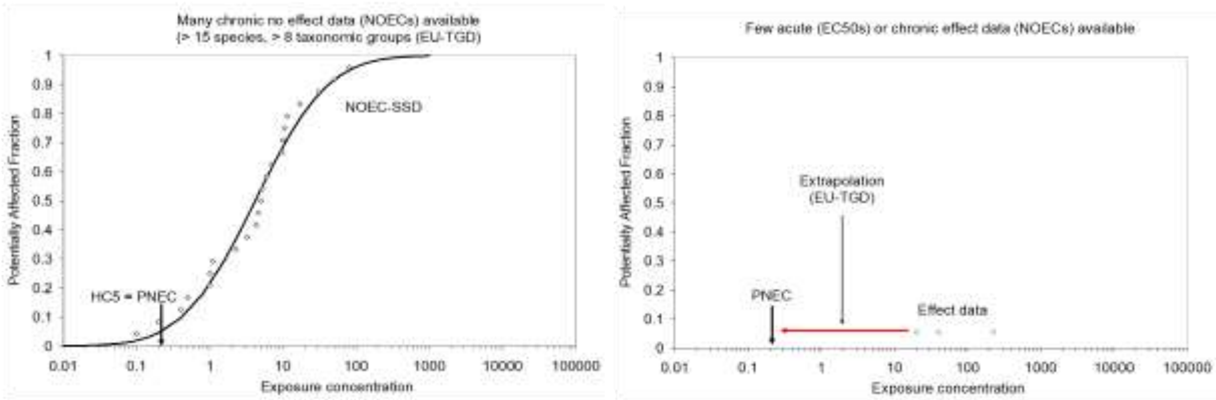


Figure 2-2 Derivation of PNEC, either from species sensitivity curve (left) or from few toxicity data and safety factor (right).

A PNEC is derived from results of laboratory toxicity tests and should be provided for each compound present in the discharge. Guidelines on how the PNEC value is derived from laboratory toxicity test results available from the EU (ECHA, 2008; EC, 2011). In 2012, OSPAR (www.ospar.org) published a preferred set of PNECs for naturally occurring components in produced water (OSPAR, 2012). The selected PNECs were mainly taken from European Risk Assessment Reports (EU-RAR) and studies that derived Environmental Quality Standards for the EU Water Framework Directive (EU-WFD). The PNEC values for added chemicals can be derived from HOCNF (*Harmonized Offshore Chemical Notification Format*) data. Details on how to derive PNECs for added chemicals are described in Johnsen et al., 2000.

Environmental risk, PNEC and the EIF. The results from the transport and fate calculations in DREAM are a dynamic representation of the produced water plume in the receiving environment. Based on this, PEC will be translated to an effect probability or risk via a defined risk curve.

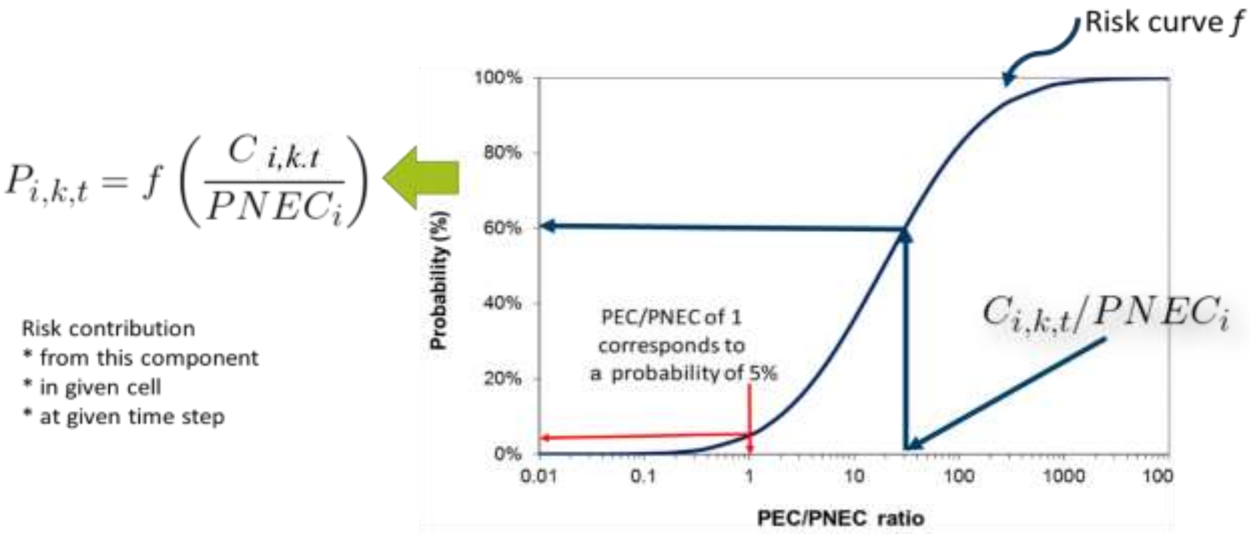


Figure 2-3 Calculation of risk from each compound from its concentration in a grid cell via defined risk curve for this compound. C

This risk can be explained as the probability that a **randomly** selected species in the environment is exposed to concentrations exceeding its chronic no-effect concentration (NOEC). Again, a PEC/PNEC ratio of 1 means a risk of 5%.

For each produced water compound the modeled concentration field is calculated into a risk probability field. For each model grid cell and time step risk probabilities for the different produced water compounds are then combined into one overall risk probability to address the contribution to risk from all individual compounds (Karman and Reerink, 1997). The overall risk probability from a sum of compounds, is calculated as the sum of independent probabilities using below formula:

$$P(A+B) = P(A) + P(B) - P(A) * P(B) \tag{1}$$

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

The overall risk probability resulting from all compounds in a produced water release is calculated by DREAM in space and time for all grid cells within the model domain. If the computed environmental risk in a grid cell k at time t is above 5%, add the volume of the cell to the overall water volume with risk over 5%:

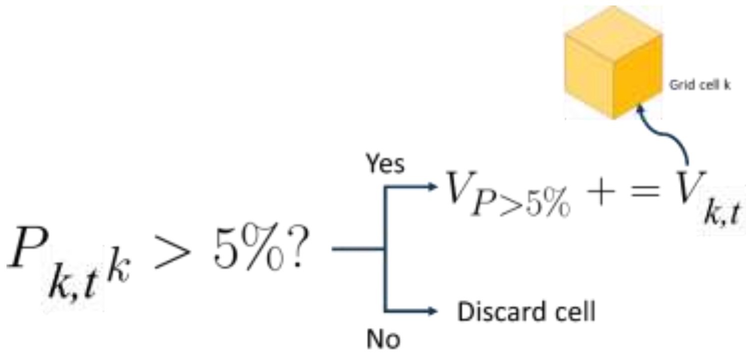


Figure 2-4 Computation of water volum from all grid cells in the model domain with environmental risk > 5%.

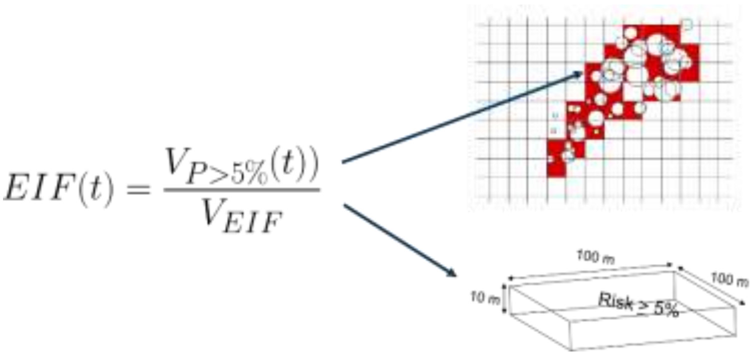


Figure 2-5 Computing water volume with risk > 5% to EIF via refernece water volume.

The selected unit for the EIF is the recipient water volume of

100m x 100m x 10m (100,000 m^3).

Therefore, an EIF of 10 represents a water volume in the recipient of 1,000,000 m^3. Due to time varying wind and current conditions the plume and corresponding water volume with an overall risk probability exceeding 5% varies over time. Both maximum EIF and the time averaged EIF are reported. At the time of maximum EIF, the contribution from each compound is investigated for risk mitigation.

2.3 Presentation of results and risk management

The results of the DREAM risk calculations can be presented as shown in Figure 2-6 (snapshot in time) that shows the PEC/PNEC ratio for the total produced water mixture. These results can also be presented as a total risk probability in percent.

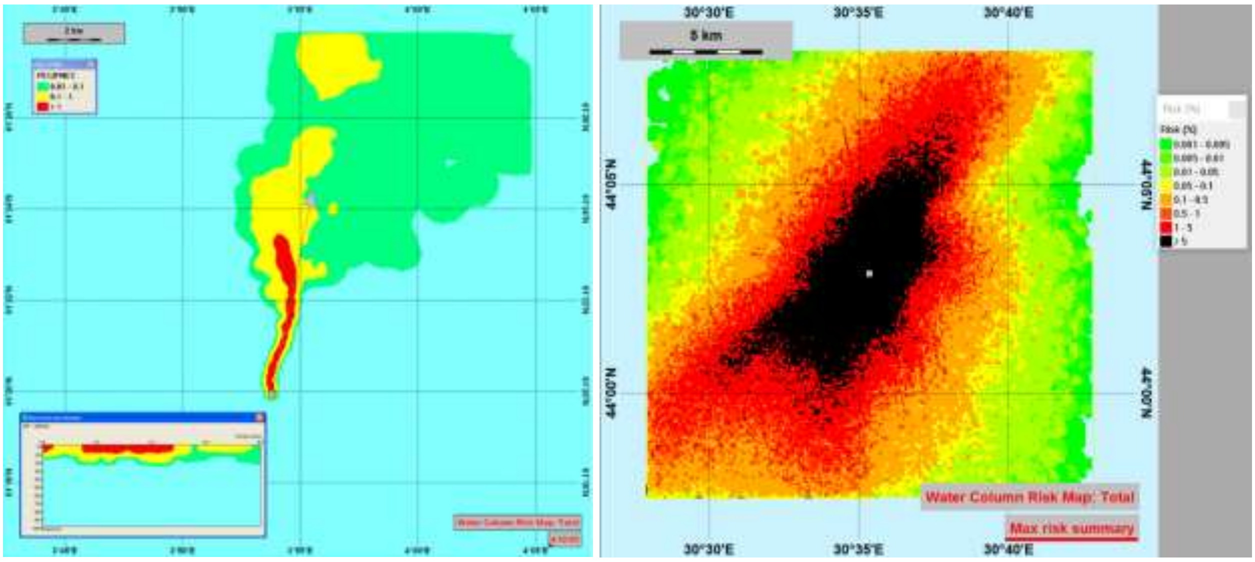


*Figure 2-6 Result of an **example** DREAM calculation showing the PEC/PNEC for the sum of various compounds in a discharge (**snapshot in time** of both the horizontal and vertical plume extent to the left, maximum risk **time-independent** on the right).*

The water volume indicated by the red color in the left figure indicates the water volume where the PEC/PNEC is larger than one (or where the total risk probability exceeds 5%) **at that time step**. This is shown in black on the right for the **maximum of all time steps.**

An attractive feature of the EIF approach is that the method enables the quantification of the contribution of the various compounds in the discharge to the overall environmental risk. This is done by showing the situation at the maximum EIF as a pie chart.

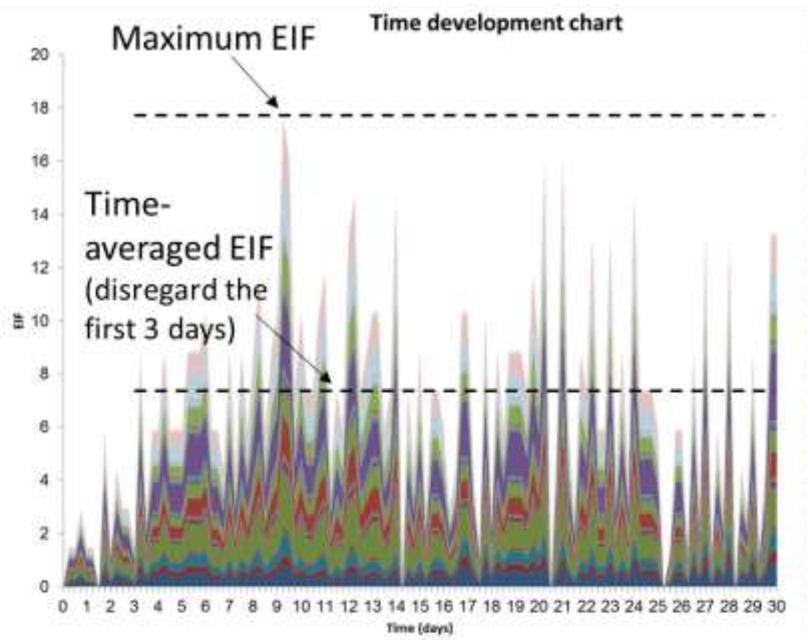


*Figure 2-7 EIF over time. Maximum EIF at peak and time-averaged EIF from **an example EIF** calculation as average over simulation duration without the first 3 days for numerical reasons.*

An example of the contribution to risk attributed to the different compounds in a release is shown in Figure 2-8. This enables the identification of the highest risk contributors in the discharge and facilitates the definition and selection of cost-effective risk mitigation measures. These can for instance be the selection of additional effluent treatment technologies or the substitution of harmful compounds from added production chemicals.

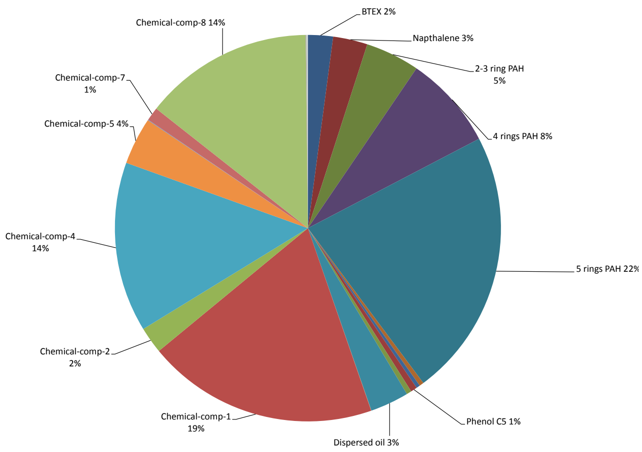


*Figure 2-8 Distribution of the contribution to risk from the different produced water constituents from **an example EIF** calculation.*

Chemicals are anonymised as usual for these simulations, the naturally occurring compound *5-rings PAH* is the main contributor to environmental risk with 22%, the *Chemical comp. 1* contributes with 19% to the overall environmental risk.

3 Environmental conditions at the Neptun Deep discharge locations

Every modelling task starts with finding suitable data for the simulations and assessing environmental conditions at the site. Current-, salinity- and temperature conditions will define transport and fate of any discharges to the marine environment.

Metocean data for the Black Sea are available at Copernicus Marine Service. 'The Copernicus Marine Service (or Copernicus Marine Environment Monitoring Service) is the marine component of the Copernicus Programme of the European Union. It provides free, regular and systematic authoritative information on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale. It is funded by the European Commission (EC) and implemented by Mercator Ocean International. It is designed to serve EU policies and International legal Commitments related to Ocean Governance'.[5] Data for transport and fate modelling should come with a **time resolution** of under 6 hours to account for tidal phenomena and a **resolution in depth** to assess behaviour in the water column. Produced water discharges do usually not spread over large areas du to biodegradation of the released substances, so that data at one point can be assessed as sufficient, however data that cover a larger region in higher **spatial resolution** is preferred (see also Nepstad et al. 2022).

3.1 Data used in the study

Data was downloaded from the Black Sea Physics Analysis and Forecast. These data are available for the (rolling) period of ca. 1 year and come with a spatial resolution of 1/40° x 1/40° and 121 vertical levels. Time resolutions are hourly, daily and monthly means and we used hourly data for this task.

[5] https://marine.copernicus.eu/about

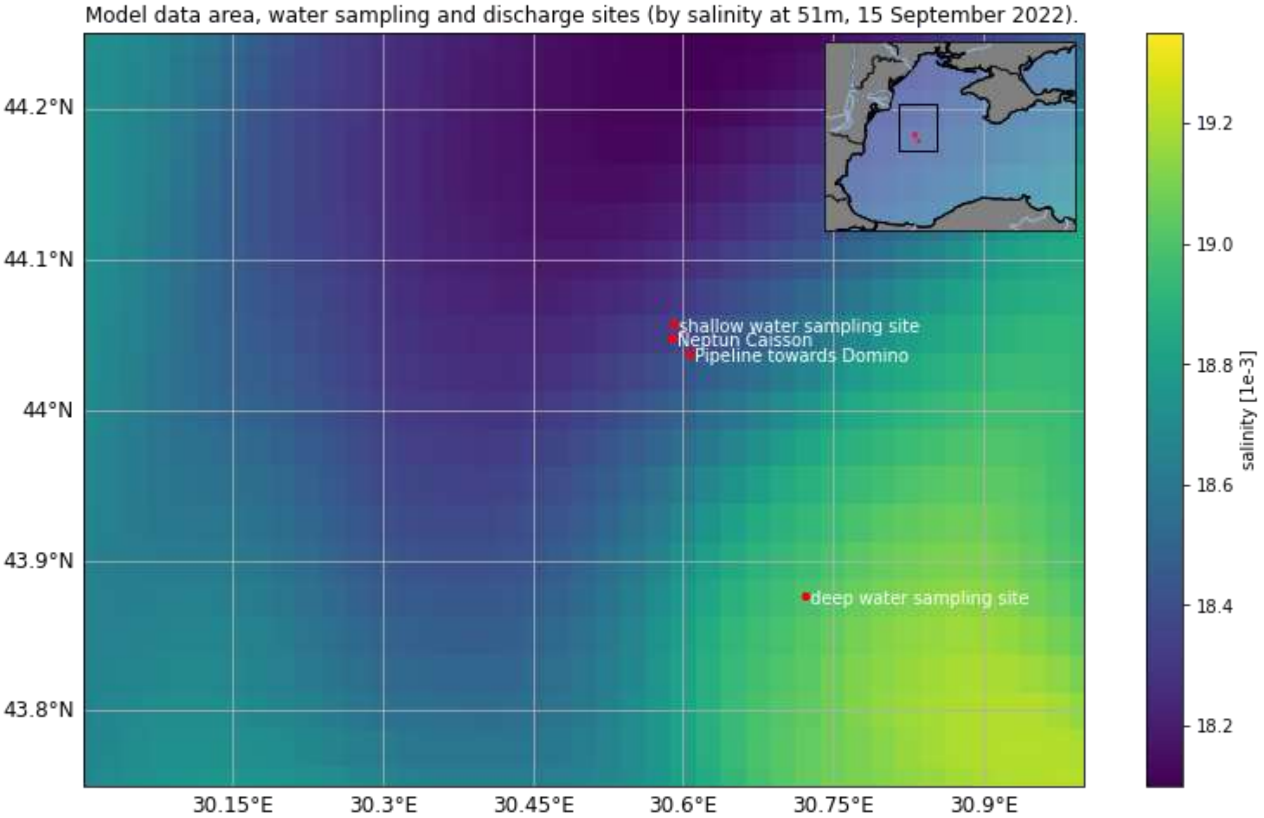
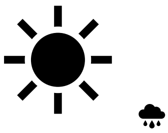


Figure 3-1 Spatial extend of the metocean data used in this study at the example of salinity at ca. depth for cooling water intake. September 15th, noon. The plot also shows the water sampling sites and discharge locations pipeline and caisson.

More information on this data set can be found at the Copernicus website for data access at https://data.marine.copernicus.eu/product/BLKSEA_ANALYSISFORECAST_PHY_007_001/description.

As Produced Water modelling is usually done for the duration of **one month** the first task was to assess **seasonal variations** in environmental conditions and determine representative modelling periods.

	 dry
warm (September)	cold (April)

The Black Sea exhibits seasonal variations with a **warm and cold season**. The warmer month have significantly higher water temperature at the surface while similar salinity, resulting in a different layering or mixing of sea water. This is important for the vertical transport of any discharge and potential surfacing. We wanted to find the two months that are typical for the differences though not exhibiting the extremes, either, to have a good representation for the environmental conditions for the all-year operations. Once a field is in operation, one will pick the month or period that will result in the most **conservative** results; in Norway this is the month of May (least mixing) according to the EIF guideline (NOROG 2003).

Assessment of the mixing depth data, which can be downloaded as a separate data file, resulted in the months **April** and **September** for the cold and warm season, respectively. These months show the environmental differences, though not the extremes. Surface water temperatures in September are significantly higher in September than in April with over 20 vs. 8.5, respectively, while there is a larger variation in mixing in April representing the homogenous upper layer in the cold and stratified layer in the warmer months. The figures below show the extension of mixing through the period of November 2021 to September 2022 and respective temperature and salinity variations.

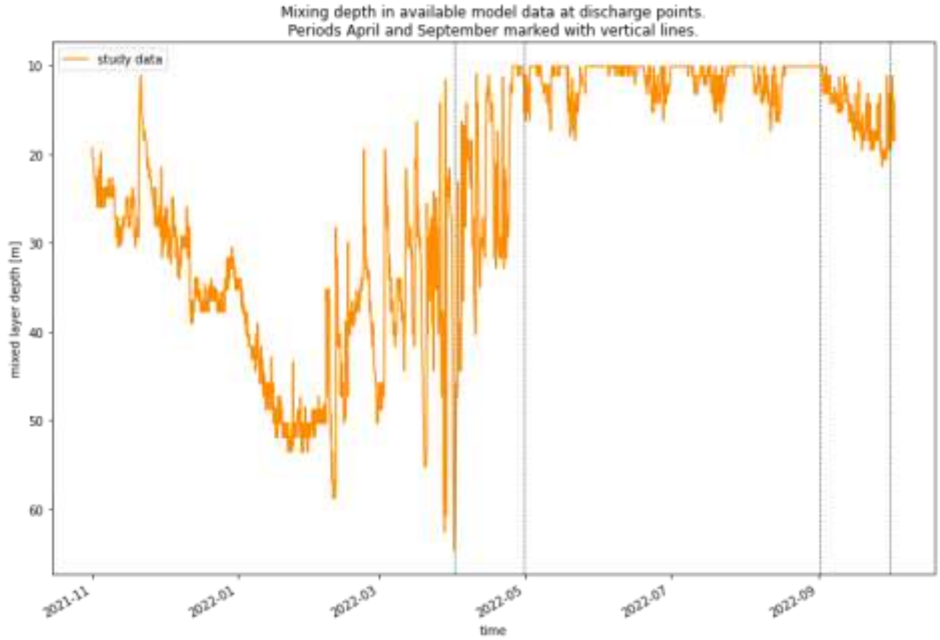


Figure 3-2 Plot of mixed layer depth between November 2021 and September 2022. April and September marked with vertical lines.

3.2 Salinity and temperature

Salinity and temperature are determining the stratification of the water column, i.e. existing layering that are relevant for the vertical transport in the water column. Profiles for the chosen months show stratification between the upper 15m and waters below in September vs. a homogeneous layer in April. Water density is mainly driven by temperature.

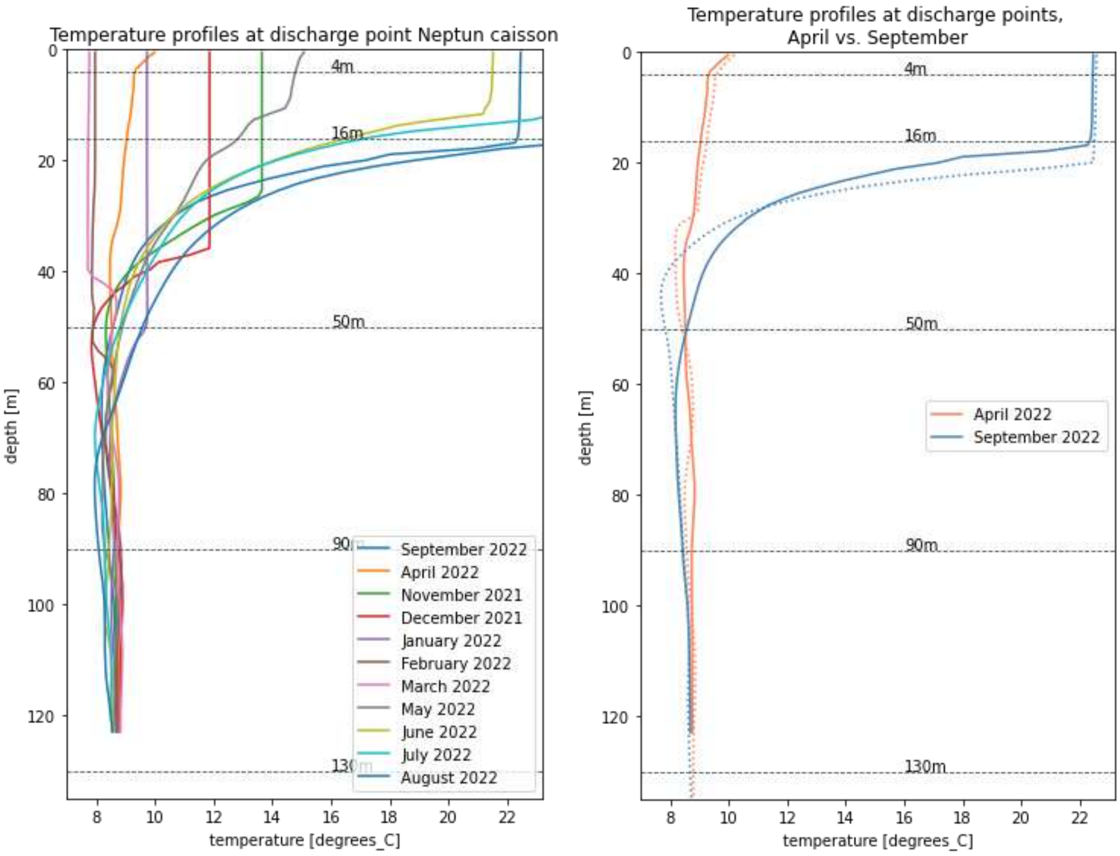


Figure 3-3 Temperature profiles at discharge location Neptun caisson and pipeline (in the right panel at the deep-water sampling point in addition) for different months, showing the reasoning for April and September as the chosen modelling periods for warm and temperate months or dry and wet, respectively. Vertical lines show surface layer (4 and 16m), seawater intake (50m), and discharge depths (90m, caisson and 130m, pipeline).

Salinity is rather stable, both through the year and through depth, especially up to 50m, ranging between 18 and 21 ppt (g/l). This means that the Black Sea has brackish waters, *normal* sea water salinities are around 30-35 ppt. This also means that buoyancy and mixing is mainly determined by temperature and currents.

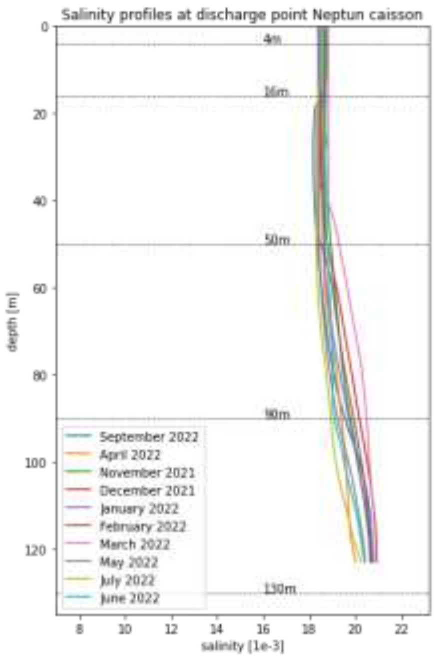


Figure 3-4 Salinity profiles at discharge location Neptun caisson and pipeline

Data were also compared to results from a water sampling report and to a dataset from reanalysis (assimilation of measured data into the ocean model) and showed good agreement.

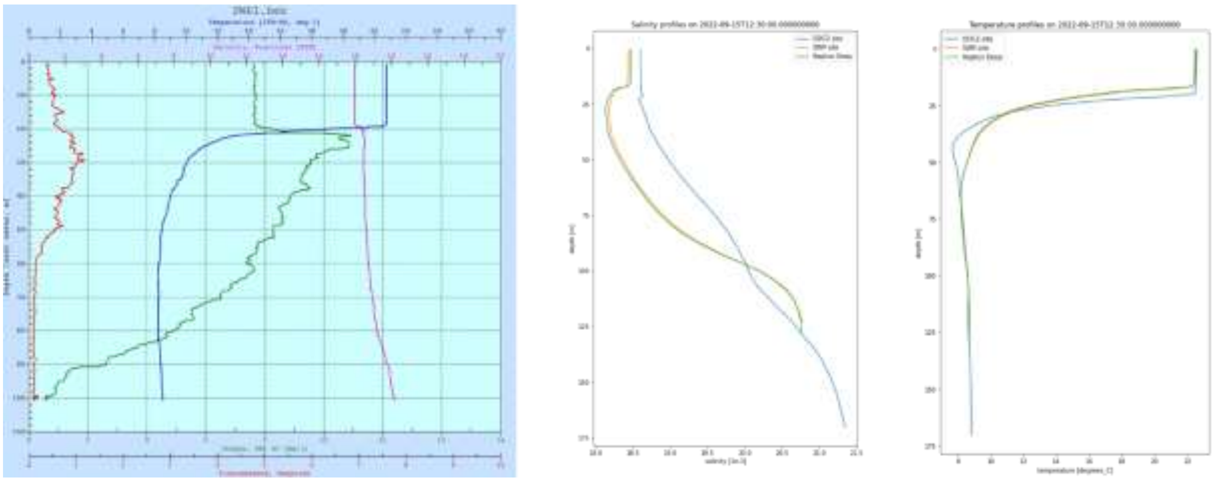


Figure 3-5 Data from water sampling (left) and model showing the same characteristics for temperature and salinity.

The Black Sea Physics Reanalysis[6] produces daily and monthly values with data assimilation from measurements of temperature and salinity available at SeaDataNet. Direct comparison is not possible due to different scale and period, but comparison showed reasonable agreement.

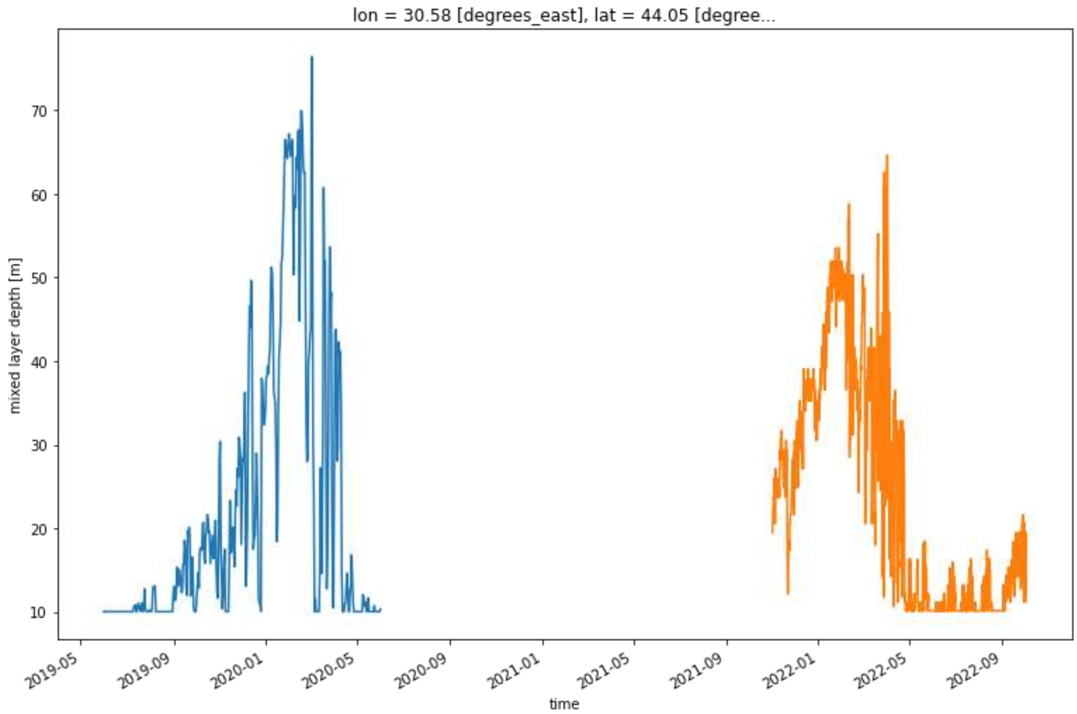


Figure 3-6 Comparison of modelled forecast data with reanalysis data fro the Black Sea.

3.3 Currents

Currents are directed South-East in April and more distributed in directions in September with current speeds not exceeding 0.5 m/s. At 50m and below, current speeds are below 0.2 m/s.

[6] https://doi.org/10.25423/CMCC/BLKSEA_MULTIYEAR_PHY_007_004

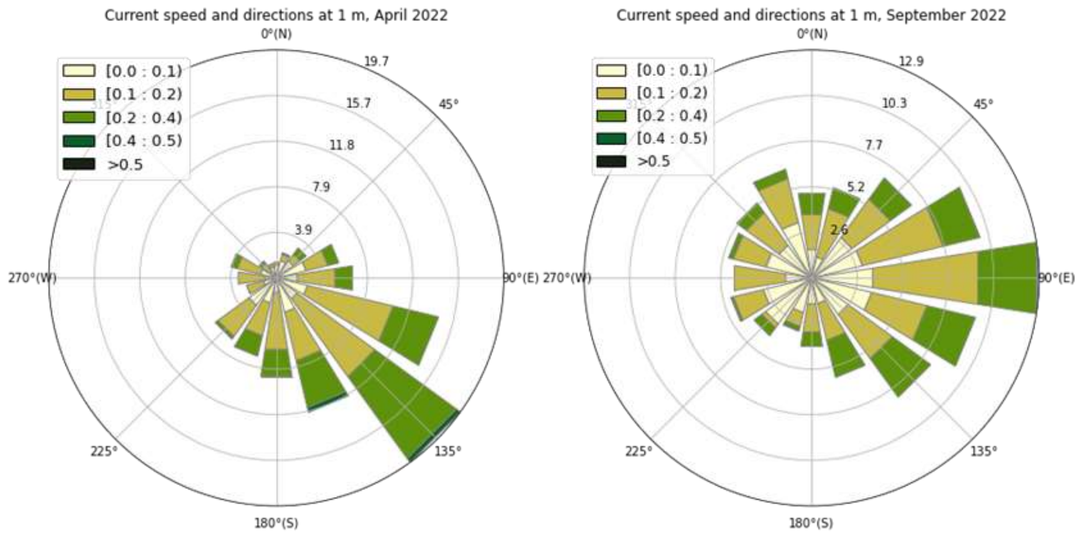


Figure 3-7 Current roses for surface currents in April and September 2022, respectively. Bars showing the direction, colours showing current speed and the legend to the upper right the frequency in %.

More details can be found in the Appendix (E.5).

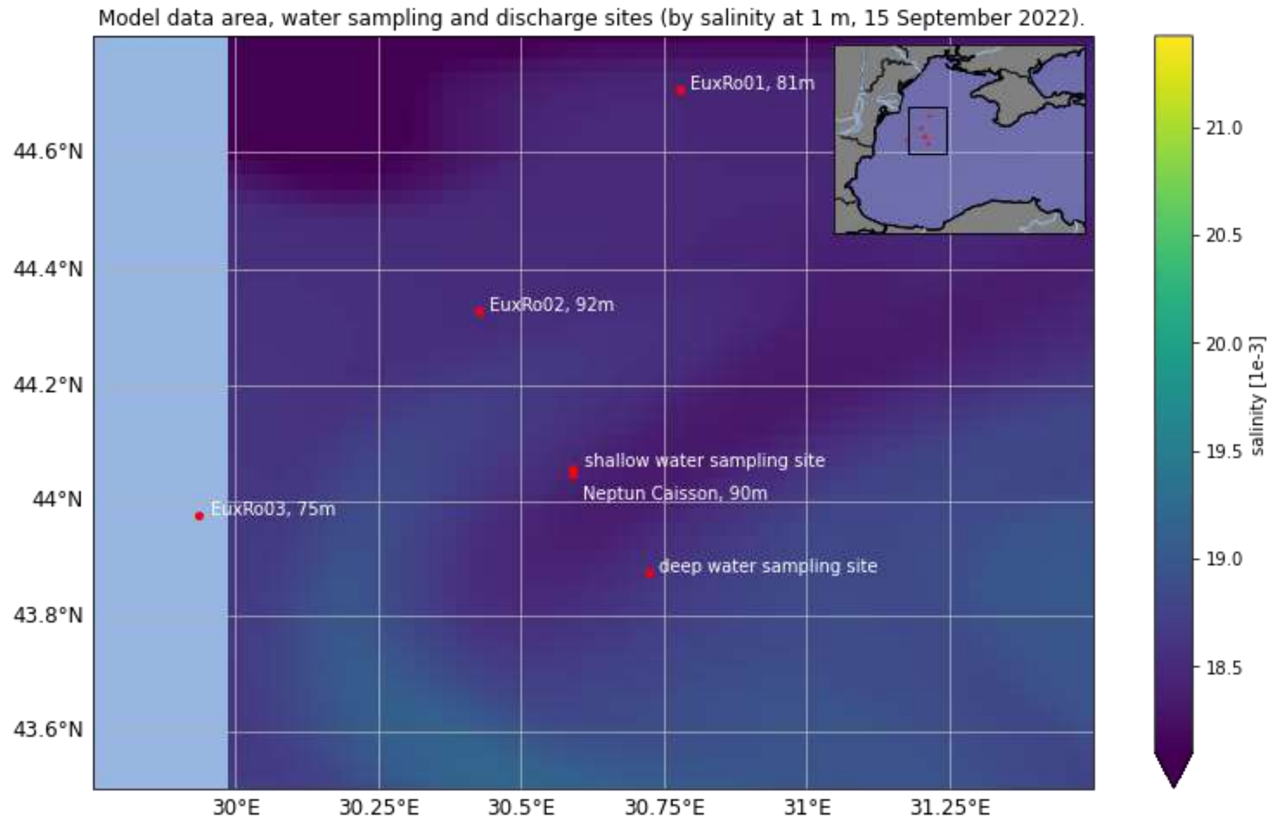


Figure 3-8 Ocean model data area and sites for water sampling, discharge (very close to shallow water sampling site) and moorings for ocean data observations from an earlier study.

The modelled data comes in a sufficient spatial and temporal resolution, is available for a long period and covers the discharge location and the surrounding waters while the observatory moorings from 2015-2018 are at a distance to the discharge locations. The modelled data was therefore assessed as the **best available data** for this study.

Summary

Environmental conditions were assessed for the model region in the Black Sea and data retrieved from a publicly available source (CMEMS). The downloaded data was produced by an ocean model and therefore compared to water sampling and reanalysis data. The data showed good agreement for temperature and salinity as well as mixed layer depth.

The Black Sea environmental conditions exhibit seasonal variations with a **cold and a warm season**. The seasons were found to be well-presented for the modelling task by the months of April (wet) and September (dry). The EIF guideline recommends that simulations are run for a month, and current data was downloaded for the two whole months.

Temperature and salinity data, as well as mixing depth data, were downloaded and assessed for a whole year to arrive at these conclusions.

Current speeds are low, so now strong transport and mixing events are expected from these conditions.

The use of measured data from an earlier study was also assessed but discarded as the moorings are at a distance from the actual discharge (see below). Wind data was not used in the study as discharge depths are at 90 and 130m. Oxygen profiles were taken from the water sample field campaign from September 17 through 20, 2018, which provided by OMV Petrom (Exxon, 2019).

4 Study scenarios

4.1 General discharge conditions

All results not reported in this Chapter are summarised in the Appendix.

↓	↑
Discharge through caisson, 90m depth, 500mm diameter, downwards	Discharge through pipeline, 138m depth, 300mm diameter, upwards

Before the discharge parameters in the table below were agreed on, SINTEF performed short simulations at different depths and with several caisson diameters.

A smaller caisson and thus discharge diameter does not change the overall EIF and transport result significantly, but results in slightly better mixing and lower chemical concentrations in the water column as the direct result.

A reduction of discharge diameter from 750 mm to 500 mm produces similar results at 90 m discharge depth versus 100 m for the larger diameter. This means, with a reduced diameter it is possible to reduce the discharge depth to favourable conditions for oxygen levels and still assure wanted behaviour of the discharge plume (no surfacing).

All simulations were performed with low salinity produced water to force surfacing behaviour. Lower salinity produced water has a lower density as compared to the sea water it is discharged into. Figure 4-3 and Figure 4-4 below demonstrate unfavourable results when using a shorter (60m) caisson with a 750 and 500mm diameter. Both cases result in a PW plume rising to the surface or the upper water column, where it might affect marine flora and fauna. After this assessment and in agreement with the BAT study, the caisson depth has been kept at 90 m and 500 mm diameter for all simulations to reduce surface impacts.

Ø
750 mm

100 m

LOW

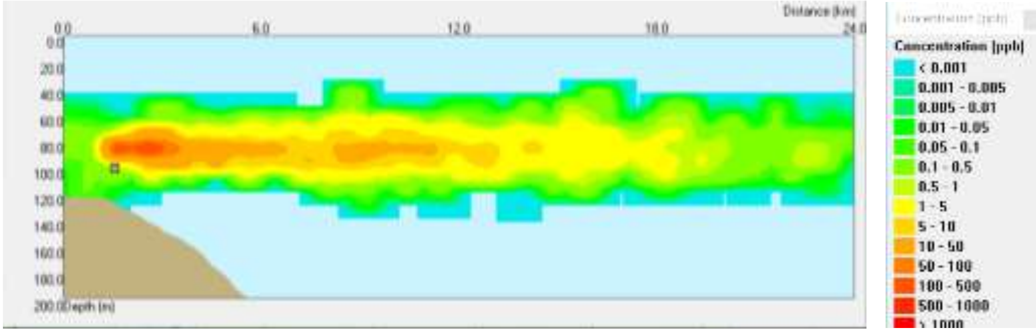


Figure 4-1 With a 750mm caisson the discharge should be at 100m depth to not surface.

Ø
500 mm

90 m

LOW

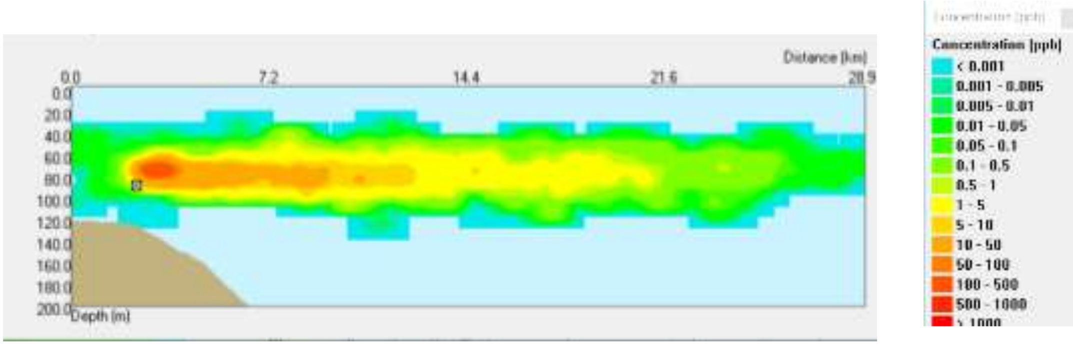


Figure 4-2 With a smaller caisson (500mm) this can be assured at 90m already.

Ø
750 mm

60 m

LOW

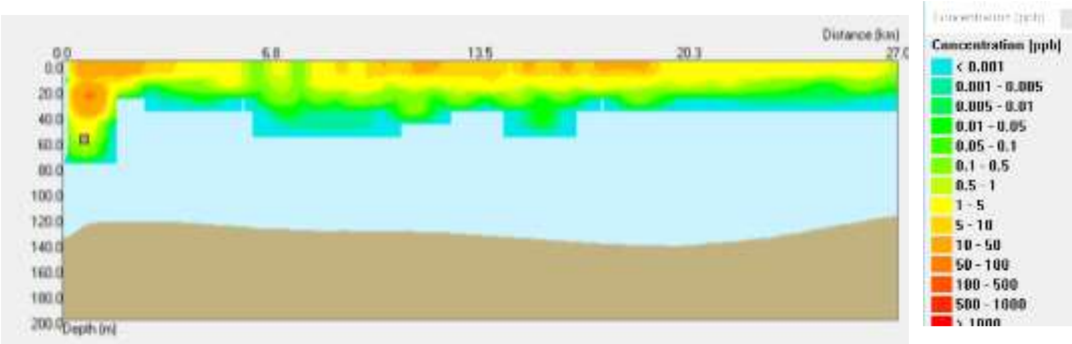


Figure 4-3 Discharged at 60m depth, higher concentration can be observed at the surface.

Ø
500 mm

60 m

LOW

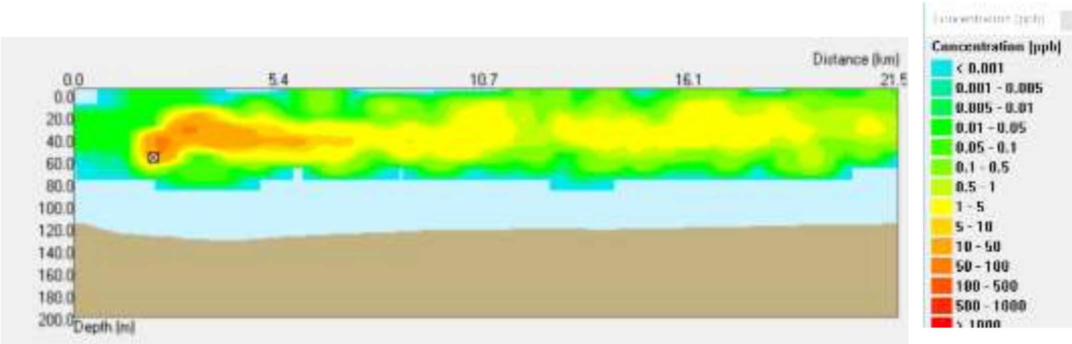


Figure 4-4 With a smaller caisson, there is still surfacing, but in lower concentrations.

4.2 Discharge scenarios

Discharge scenarios include variations such as discharge depth, discharge diameter and discharge location (caisson vs. pipeline) with different discharge profiles (chemical compositions with or without chlorinated cooling water) at the caisson and the pipeline outlet, as well as high and low salinity produced water. Most of the scenarios were simulated with September data and repeated for April for comparison of seasonal variations. The lower discharge rate resulted in less mixing and did produce very similar but less conservative results.

4.3 Input data

Table 2 describes the input data used to build the different scenarios for the study.

Table 2 Summary of input data for PW simulations: Neptun Deep discharges from Caisson and pipeline.

Field	Neptun Deep caisson	Neptun Deep pipeline
Region	Black Sea	Black Sea
Discharge Arrangement	Through **caisson** with cooling water, downwards	Through **pipeline** without cooling water, upwards*
Position [lat, lon (WGS84)]	44.0477982N, 30.5891991E	44.037899N, 30.6065998E
Release depth [m]	90	130
PW discharge diameter [m]	500 mm	300 mm
PW volume m^3/hour high (low)	64.45 (13.25) = 10 000 (2000) bwpd	64.45 = 10 000 (2000) bwpd
TEG water m^3/hour	0.57	0
Cooling seawater m^3/hour	317.3	0
Total release rate [m^3/hour]	382.32 (331.12)	64.45
Total release rate [m^3/day]	9175.68 (7946.88)	1546.8
Temperature (° Celsius)	22.32	33.4
Resulting Salinity (mg/l)	20.2036 cooling water and high saline PW**	28 high saline PW
Resulting Salinity (mg/l)	16.6223 cooling water and low saline PW**	6.787 low saline PW

* The pipeline discharge simulation does not account for cooling water discharges from the platform.

** The salinity for the cooling water was derived from the environmental data at 50m water depth.

4.4 Chemical data

The simulations were run for two chemical packages, ChampionX and Schlumberger. For both packages, **component toxicity** was derived from **HOCNF**[7] data. The dosing rate was assumed for the discharge concentration as it is standard in e.g. the UK, i.e. no utilisation or depletion was accounted for in the stream. PLONOR[8] (and REACH A4[9]) chemical compounds were not included in the risk assessment.

Sodium Hypochlorite (SHC) was included in some of the scenarios as it is an added chemical with a concentration of 2 ppm, 0.5ppm and 0.2 ppm (mg/L) **to the cooling water**. SHC is expected to biodegrade within hours, in the scenarios it was simulated with a **conservative biodegradation rate of 50%/day**. The caisson discharges were run with and without regarding SHC in the cooling water.

Dose rate, component mix, ecotoxicity, biodegradation rate and partitioning values for chemical components provided by two suppliers, i.e. ChampionX and Schlumberger as presented in the tables below. The EC50 or LC50 values provided are used to determine the PNEC for this component according to OSPAR and EIF guidelines. The n-octanol-water partition coefficient, K_{ow} is a partition coefficient for the two-phase system consisting of n-octanol and water. It is used as a proxy for the ability of a compound to bioaccumulate in marine fauna.

Table 3 HOCNF data for ChampionX chemicals used in the simulations. Components are anonymised.

ChampionX	Normal dose rate for product	Composition [%]	EC50/LC50 [ppm]	Biodegr. in 28 days [%]	$LogK_{OW}$
Foam inhibitor comp. 1	10ppm	60	500	60.2	1.6
Foam inhibitor comp. 2		40	51.78	75	6.25
Corrosion inhibitor comp.1	50ppm	51.2	500	60.2	1.6
Corrosion inhibitor comp.2		2.4	18	21	-0.8
Corrosion inhibitor comp.3		22.48	9	63	
Corrosion inhibitor comp.4		4.4	2	55	
Corrosion inhibitor comp.5	PLONOR			-	
Scale inhibitor comp.1	PLONOR	35			
Scale inhibitor comp.2	20 ppm	20	1000	28.2	0
Scale inhibitor comp.3	PLONOR	30			
Scale inhibitor comp.4	PLONOR	15			
TEG		100	3000	67	0.72
Sodium Hypochlorite		100	0.042	50 ($^1/_2$ day)	0.62

[7] Harmonised Offshore Chemical Notification Format (HOCNF) https://www.ospar.org/documents?d=33027

[8] OSPAR List of Substances Used and Discharged Offshore which Are Considered to Pose Little or No Risk to the Environment (PLONOR) https://www.ospar.org/documents?v=32939

[9] Annex IV of Regulation (EC) No. 1907/2006 (REACH) sets out substances that are exempted from the registration, evaluation and downstream user provisions of REACH as sufficient information is known about these substances that they are considered to cause minimum risk because of their intrinsic properties. https://ec.europa.eu/environment/chemicals/reach/reviews_en.htm

Table 4 *HOCNF data for Schlumberger chemicals used in the simulations. Components are anonymised.*

Schlumberger	Normal dose rate for product	Composition [%]	EC50/LC50 [ppm]	Biodegr. in 28 days [%]	$LogK_{OW}$
Foam inhibitor comp. 1	10 ppm	90	125	71	1.3
Foam inhibitor comp. 2		10	21	42	1.2
Scale inhibitor comp. 1	PLONOR				
Scale inhibitor comp. 2	20 ppm	30	178	10	0
Scale inhibitor comp. 3	REACH A4				
Corrosion inhibitor comp. 1	PLONOR	30			
Corrosion inhibitor comp. 2	REACH A4	15			
Corrosion inhibitor comp. 3	50 ppm	30	130	96	1.13
Corrosion inhibitor comp. 4		10	0.2	23	
Corrosion inhibitor comp. 5		10	0.96	68	
Corrosion inhibitor comp. 6	PLONOR	5			
Corrosion inhibitor comp. 7	PLONOR				
TEG		100	3000	67	0.72
Sodium Hypochlorite		100	0.042	50 ($^1/_2$ day)	0.62

When discharged through the caisson, the produced water is 'diluted' with cooling water and Tri-ethylene glycol water and chemical concentrations must be 'diluted' for the model, accordingly. When discharged through a pipeline, no dilution is applied. The direction of the discharge will affect the dispersion of the plume and has been considered in the simulations through DREAM's nearfield model. The direction is downward for the caisson discharges and upward for the pipeline discharges.

The tables below capture the discharge compositions used in the model for caisson and pipeline discharges based on the supplier chemicals ChampionX and Schlumberger, respectively.

Table 5 *Concentration for the ChampionX chemicals discharged from caisson and through pipeline.*

ChampionX	Concentrations (ppm) with PW 2000 bwpd low rate	Concentrations (ppm) with PW 10000 bwpd high rate	Concentrations (ppm) from pipeline high rate
Foam inhibitor comp.1	0.240094	1.01145	6
Foam inhibitor comp.2	0.160063	0.674304	4
Corrosion inhibitor comp.1	1.024402	4.315547	25.6
Corrosion inhibitor comp.2	0.048019	0.202291	1.2

Corrosion inhibitor comp.3	0.449777	1.894795	11.24
Corrosion inhibitor comp.4	0.088035	0.370867	2.2
Corrosion inhibitor comp.5	PLONOR	PLONOR	PLONOR
Scale inhibitor comp.1	PLONOR	PLONOR	PLONOR
Scale inhibitor comp.2	0.160063	0.674304	4
Scale inhibitor comp.3	PLONOR	PLONOR	PLONOR
Scale inhibitor comp.4	PLONOR	PLONOR	PLONOR
Tri-ethylene glycol	331	331	-
Sodium Hypochlorite	1.91653	1.659866	-

Table 6 Concentration for the Schlumberger chemicals discharged from caisson and through pipeline.

ChampionX	Concentrations (ppm) with PW 2000 bwpd low rate	Concentrations (ppm) with PW 10 000 bwpd high rate	Concentrations (ppm) from pipeline high rate
Foam inhibitor comp.1	0.360141	1.51718	9
Foam inhibitor comp.2	0.040016	0.168576	1
Scale inhibitor comp.1	PLONOR	PLONOR	PLONOR
Scale inhibitor comp.2	0.240094	1.011456	6
Scale inhibitor comp.3	PLONOR	PLONOR	PLONOR
Corrosion inhibitor comp.1	PLONOR	PLONOR	PLONOR
Corrosion inhibitor comp.2	PLONOR	PLONOR	PLONOR
Corrosion inhibitor comp.3	0.600236	2.5286	15
Corrosion inhibitor comp.4	0.200079	0.84288	5
Corrosion inhibitor comp.5	0.200079	0.84288	5
Corrosion inhibitor comp.6	PLONOR	PLONOR	PLONOR
Corrosion inhibitor comp.7	PLONOR	PLONOR	PLONOR
Tri-ethylene glycol	331	331	-
Sodium Hypochlorite	1.91653	1.659866	-

4.5 Scenario matrix (cases from presentation in blue)

A large matrix of scenarios was simulated to account for the most important conditions for the release of produced water at Neptun Deep.

	warm (September)	cold (April)	Discharge depth, diameter, direction	Chemical package	Salinity of PW	Added Sodium Hypochlorite
1a	warm (September)		Discharge through caisson, 90m depth, 500mm diameter, downwards	ChampionX	HIGH	YES
1b				ChampionX	LOW	YES
1c				ChampionX	HIGH	NO
1d				ChampionX	LOW	NO
2a				Schlumberger	HIGH	YES
2b				Schlumberger	LOW	YES
2c				Schlumberger	HIGH	NO
2d				Schlumberger	LOW	NO
3a			Discharge through pipeline, 130m depth, 300mm diameter, upwards	ChampionX	HIGH	-
3b				ChampionX	LOW	-
3c				Schlumberger	HIGH	-
3d				Schlumberger	LOW	-
4a		cold (April)	Discharge through caisson, 90m depth, 500mm diameter, downwards	ChampionX	HIGH	YES
4b				ChampionX	LOW	YES
4c				ChampionX	HIGH	NO
4d				ChampionX	LOW	NO
5a				Schlumberger	HIGH	YES
5b				Schlumberger	LOW	YES

5c			Schlumberger	HIGH	NO
5d			Schlumberger	LOW	NO
6a		Discharge through pipeline, 130m depth, 300mm diameter, upwards	ChampionX	HIGH	-

5 Results from DREAM simulations and EIF computations for Neptun Deep discharges

5.1 Chemical package – ChampionX vs. Schlumberger

Summary

The results show a significantly different performance of the two chemical packages. While the transport for these two scenarios is similar, the environmental risk from chemical concentrations in the water column is higher for the Schlumberger chemical package than for the ChampionX chemicals. The EIF as the respective reference water volume with environmental risk above 5% for the caisson discharges is 6 (maximum) and 2 (time-averaged) for the simulated ChampionX case and 219 (maximum) and 129 (time-averaged) for the Schlumberger case. For the pipeline discharges we have EIF results of 10 (maximum) and 4 (time-averaged) for the simulated ChampionX case and 257 (maximum) and 181 (time-averaged) for the Schlumberger case. All simulations for September (warm season), high PW rate and high salinity.

All cases show components from the corrosion inhibitor as the main contributor to environmental risk.

In Norway, discharges from the Norwegian Continental Shelf are followed-up according to their EIF. Discharges with an EIF over 100 are supposed to further investigate possibilities to reduce this number significantly. EIF below 10 are considered less important for follow up if there are cases with higher EIF.

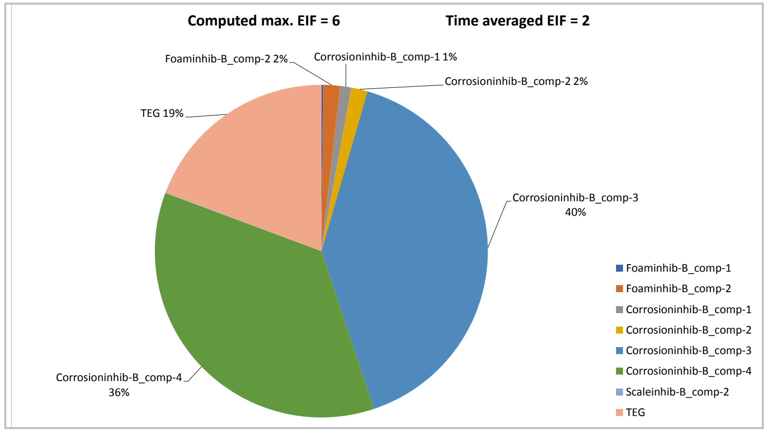
5.1.1 Discharge through caisson

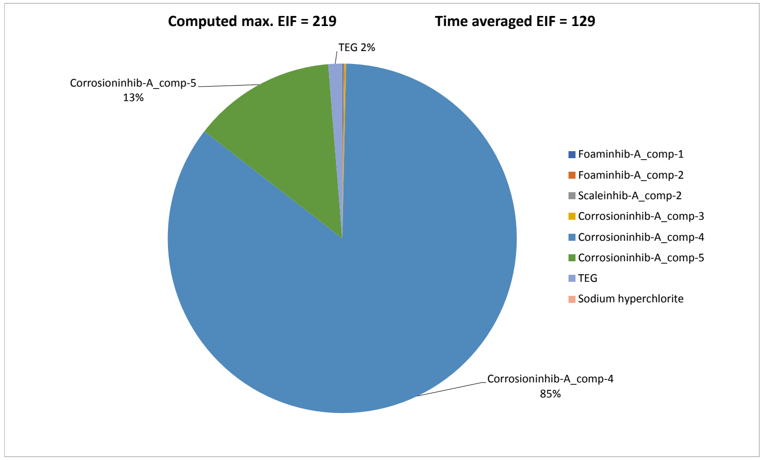
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*1c**	Warm (September)		Caisson		ChampionX	HIGH	NO	6 (2)	Corrosion inhibitor
1d						LOW	NO	4 (1.3)	Corrosion inhibitor
*2c**	Warm (September)		Caisson		Schlumberger	HIGH	NO	219 (129)	Corrosion inhibitor
2d						LOW	NO	195 (126)	Corrosion inhibitor
4c	Cold (April)		Caisson		ChampionX	HIGH	NO	0 (0)	None
4d						LOW	NO	0 (0)	None
5c	Cold (April)		Caisson		Schlumberger	HIGH	NO	86 (54)	Corrosion inhibitor
5d						LOW	NO	86 (45)	Corrosion inhibitor

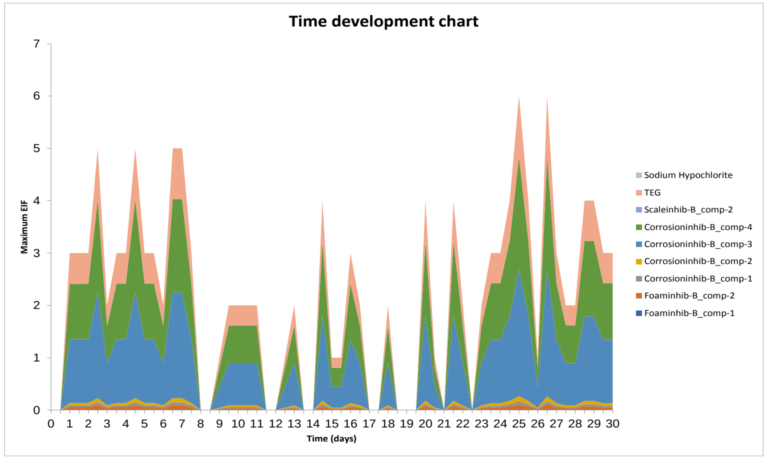
* Cases shown in Bucharest meeting

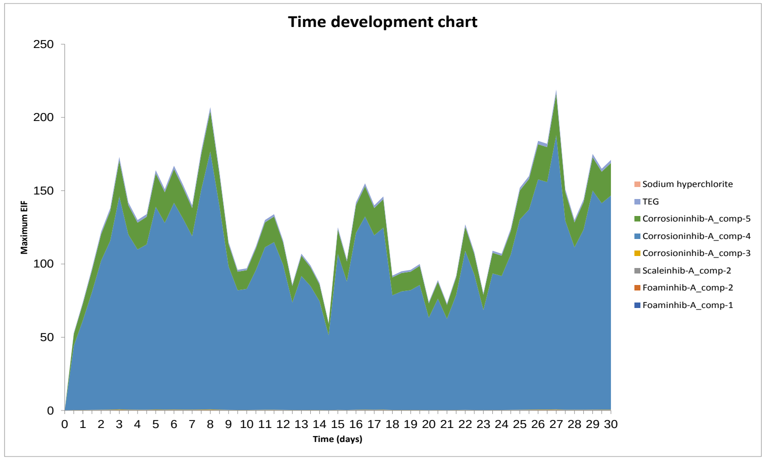
Case 1c, ChampionX, max. EIF: 6, time averaged EIF: 2

Case 2c, Schlumberger, max. EIF: 219, time averaged EIF: 129





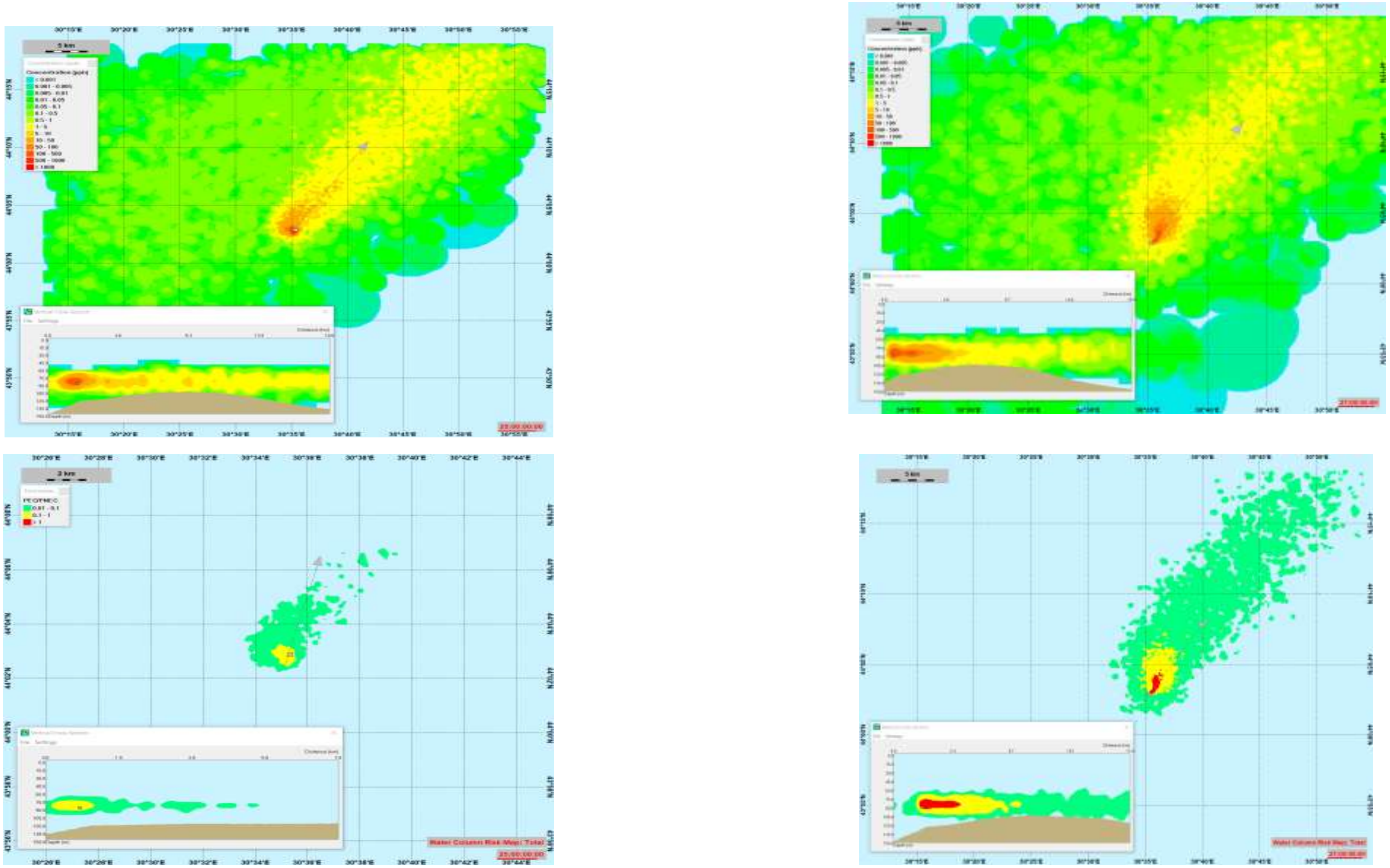




EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. ChampionX on the left, Schlumberger on the right.

Case 1c, ChampionX, max. EIF: 6, time averaged EIF: 2

Case 2c, Schlumberger, max. EIF: 219, time averaged EIF: 129



Transport and concentrations of chemicals (PEC) of the discharge in the water column at the time of maximum EIF in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

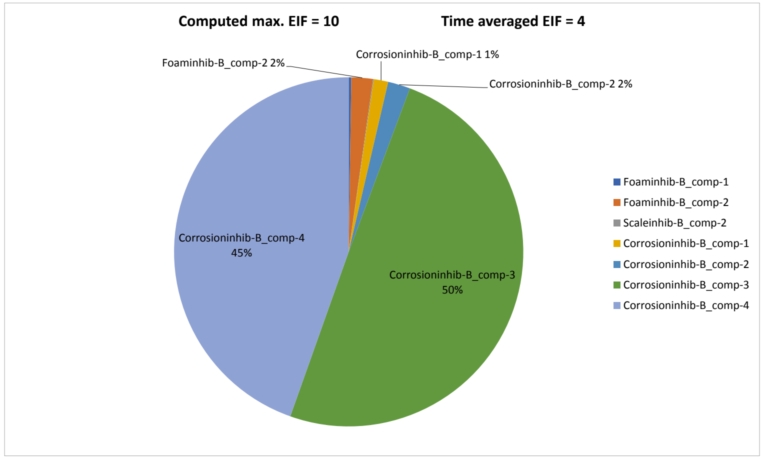
5.1.2 Discharge through pipeline

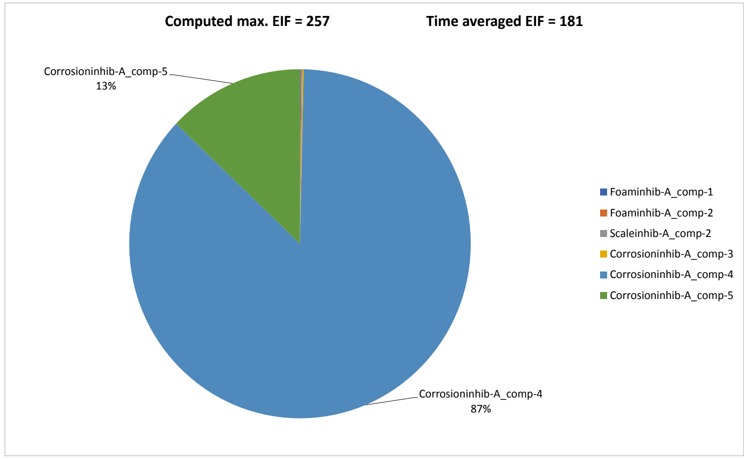
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*3a**	Warm (September)				ChampionX	HIGH	NO	10 (4)	Corrosion inhibitor
*3c**					Schlumberger	HIGH	NO	257 (181)	Corrosion inhibitor
3b	Warm (September)				ChampionX	LOW	NO	3 (0.6)	Corrosion inhibitor
3d					Schlumberger	LOW	NO	254 (156)	Corrosion inhibitor
6a	Cold (April)				ChampionX	HIGH	NO	11 (3)	Corrosion inhibitor

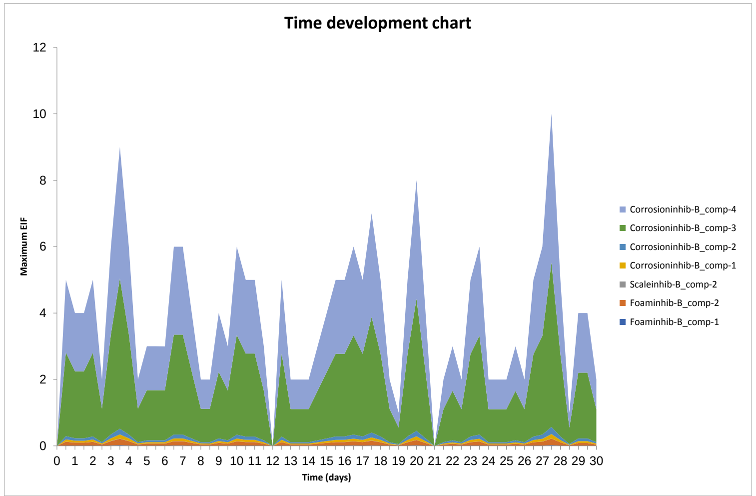
* Cases shown below

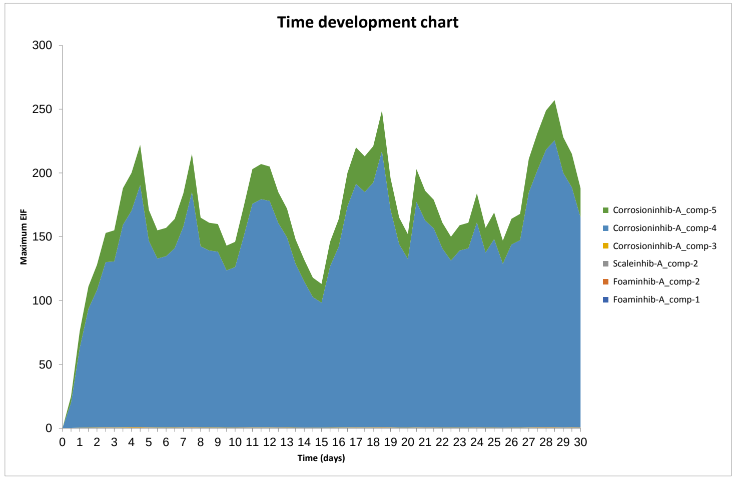
Case 3a, ChampionX, max. EIF: 10, time averaged EIF: 4

Case 3c, Schlumberger, max. EIF: 257, time averaged EIF: 181



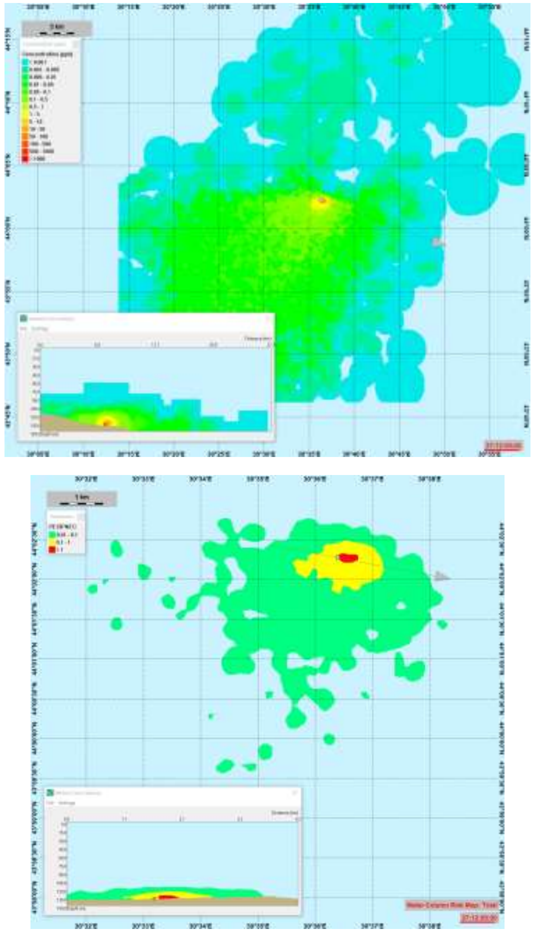




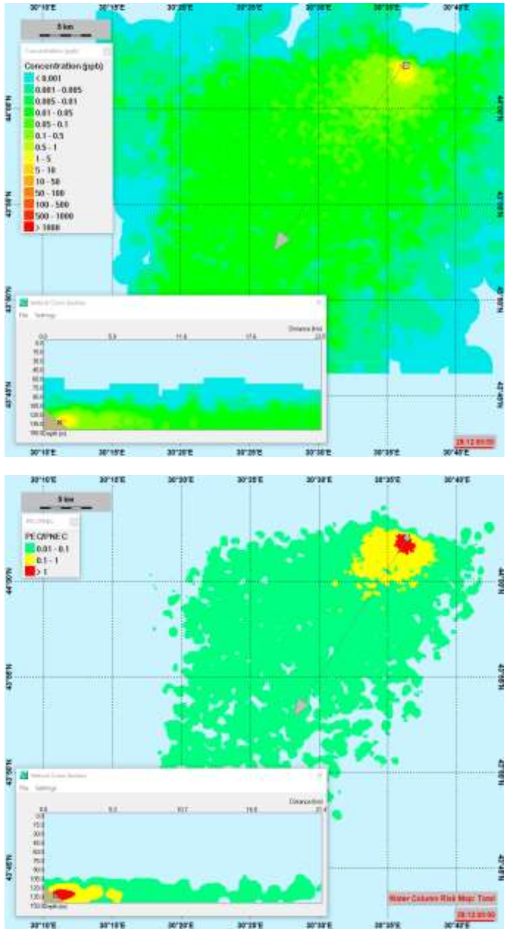


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. ChampionX on the left, Schlumberger on the right.

Case 3a, ChampionX, max. EIF: 10, time averaged EIF: 4



Case 3c, Schlumberger, max. EIF: 257, time averaged EIF: 181



Transport and concentrations of chemicals (PEC) of the discharge in the water column ***at the time of maximum EIF*** *in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.*

5.2 Adding Sodium Hypochlorite to the discharge

(Taking Sodium Hypochlorite concentration in the cooling water into account)

Summary

The DREAM model features oxygen demand from biodegradation as one of the simulation results. As the Black Sea is known for anoxic conditions at greater depths, this feature was used to assess the biodegradability of the discharge chemicals, specifically Sodium Hypochlorite (SHC), which is highly biodegradable at oxidated seawater conditions. Sodium Hypochlorite (SHC) was included in some of the scenarios as it is an added chemical with a concentration of 2 ppm (mg/L) to the cooling water. SHC is expected to biodegrade within hours and therefore to be discharged at lower concentrations. In the cases below SHC was simulated with a conservative biodegradation rate of only 50% per day. Discharge concentrations for SHC were assessed at 2ppm, 0.5 ppm and 0.2 ppm.

As discharge of SHC up to 0.2 ppm is allowed under NTPA 001 Legislation, SHC was removed for some simulations. Results show that the oxygen demand is low so that available oxygen at the discharge is sufficient to assume full biodegradation at the studied water depths.

Without Sodium Hypochlorite, environmental risk is dominated by the chemical components of the corrosion inhibitor. This applies to both chemical packages that are considered for the operations, with the chemical package from Schlumberger producing an EIF (water volume with environmental risk) higher that the chemical package from ChampionX. The added Sodium Hypochlorite dominates the risk due to its low PNEC of 0.042 **ppm** which is applied as 0.042 **ppb** in DREAM according to EIF guidelines which require a safety factor of 1000 as these chemicals have not been tested for more than 3 species to build a species sensitivity distribution.

Thus, the results below are conservative with respect to biodegradation rate and PNEC. Providing a PNEC from testing with more different relevant species will remove the requirement of the safety factor (ppm → ppb) and change results accordingly. As there is no cooling water discharged from the pipeline, there no results shown for that case. EIFs from the pipeline discharge and caisson could be roughly added as cooling water is discharged overboard anyway.

5.2.1 Chemical package from ChampionX

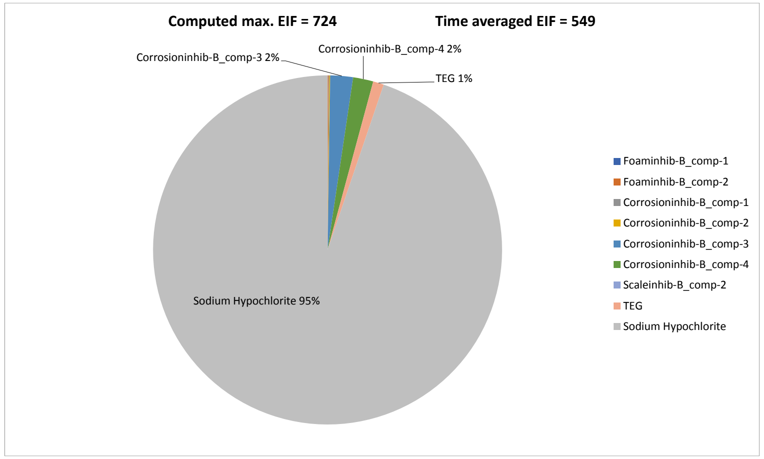
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
1a*	Warm (September)		Caisson		ChampionX	HIGH	YES	724 (549)	Sodium Hypochlorite
1c*						HIGH	NO	6 (2)	Corrosion Inhibitor
1b						LOW	YES	679 (557)	Sodium Hypochlorite
1d						LOW	NO	4(1)	Corrosion Inhibitor

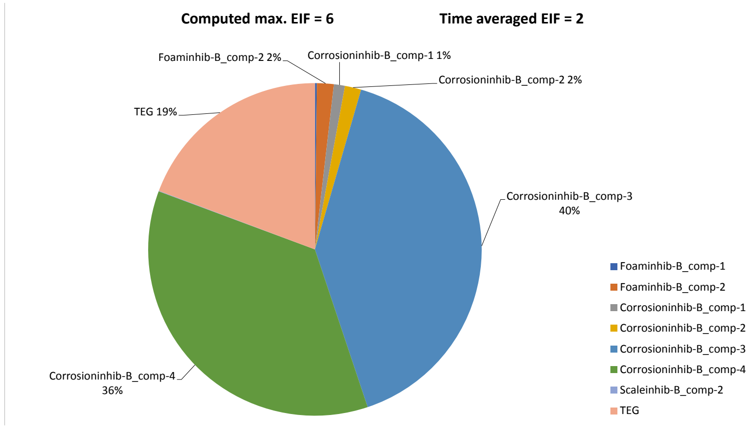
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
4a	Cold (April)					HIGH	YES	650 (546)	Sodium Hypochlorite
4c						HIGH	NO	0 (0)	None
4b						LOW	YES	665 (580)	Sodium Hypochlorite
4d						LOW	NO	0 (0)	None

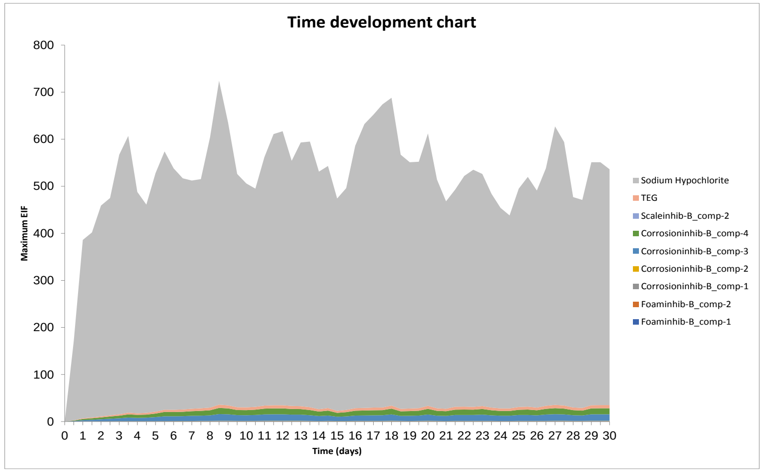
* Cases shown below

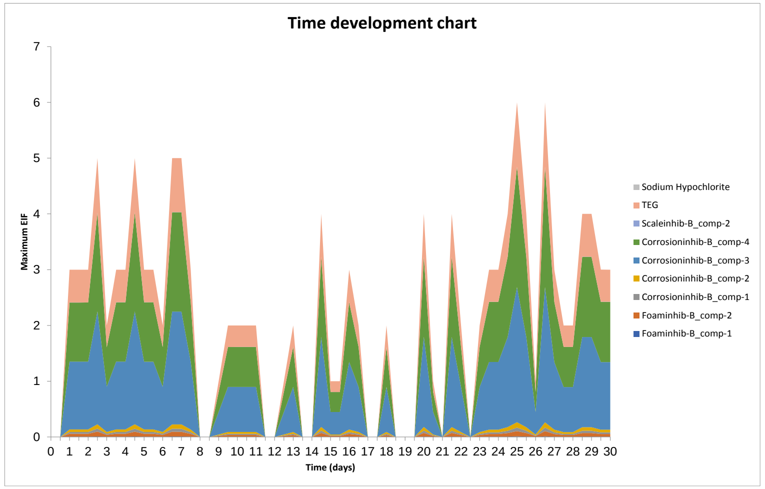
Case 1a, WITH added Sodium Hypochlorite, max. EIF: 724, time averaged EIF: 549

Case 1c, WITHOUT added Sodium Hypochlorite, max. EIF: 6, time averaged EIF: 2



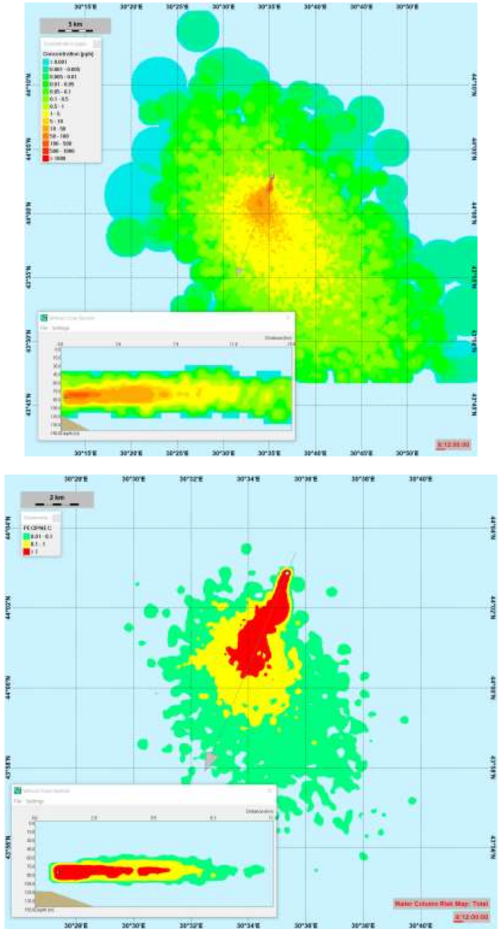




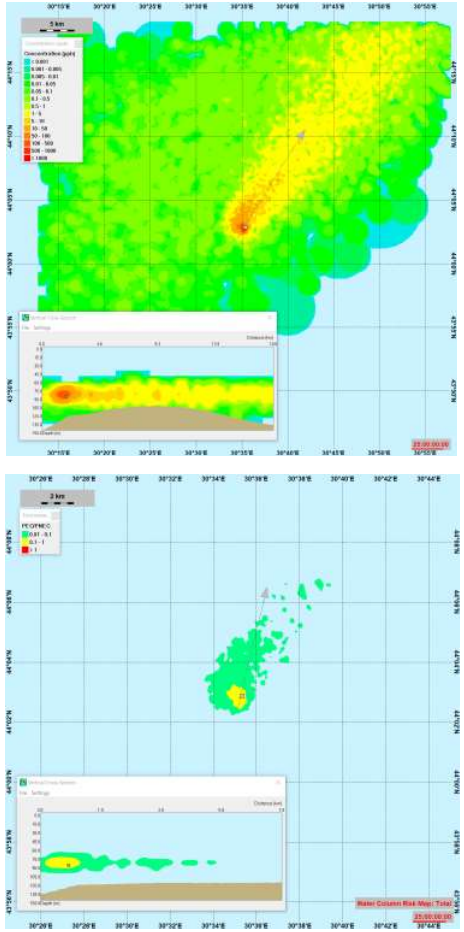


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. With Sodium Hypochlorite concentration of 2ppm on the left, without on the right.

**Case 1a, WITH added Sodium Hypochlorite,
max. EIF: 724, time averaged EIF: 549**



**Case 1c, WITHOUT added Sodium Hypochlorite,
max. EIF: 6, time averaged EIF: 2**



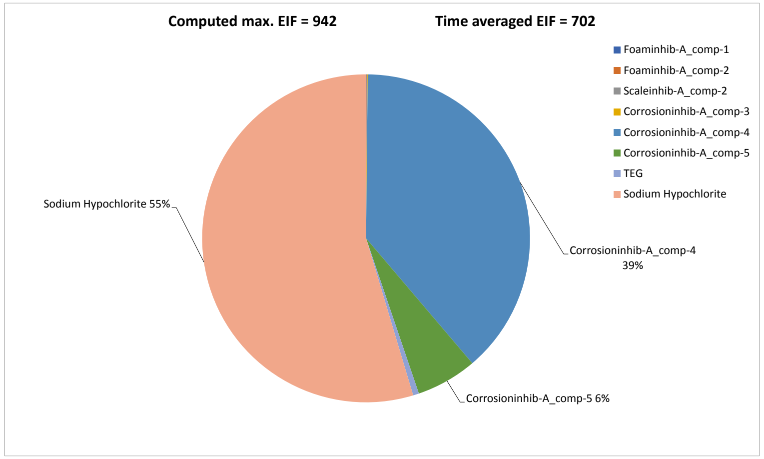
Transport and concentrations of chemicals (PEC) of the discharge in the water column **at the time of maximum EIF** in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

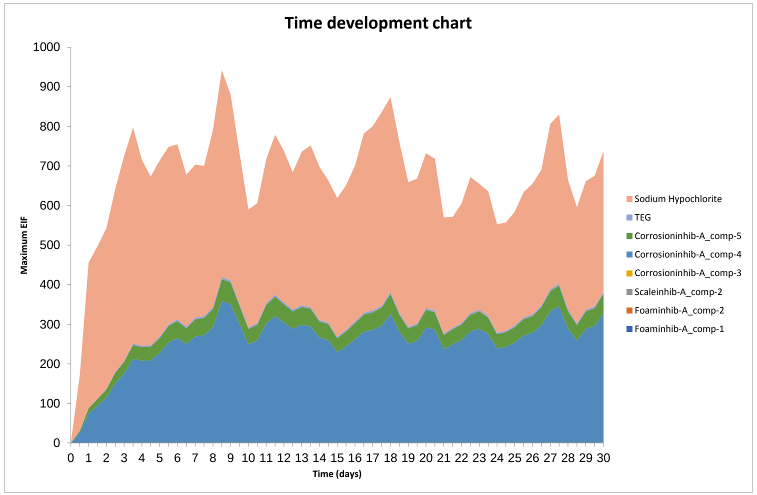
5.2.2 Chemical package from Schlumberger

case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*2a**	Warm (September)		Caisson		Schlumberger	HIGH	YES	942 (702)	Sodium Hypochlorite
*2c**						HIGH	NO	219 (129)	Corrosion Inhibitor
2b						LOW	YES	954 (708)	Sodium Hypochlorite
2d						LOW	NO	195 (126)	Corrosion Inhibitor
5a	Cold (April)					HIGH	YES	782 (654)	Sodium Hypochlorite
5c						HIGH	NO	86 (54)	Corrosion Inhibitor
5b						LOW	YES	806 (683)	Sodium Hypochlorite
5d						LOW	NO	86 (45)	Corrosion Inhibitor

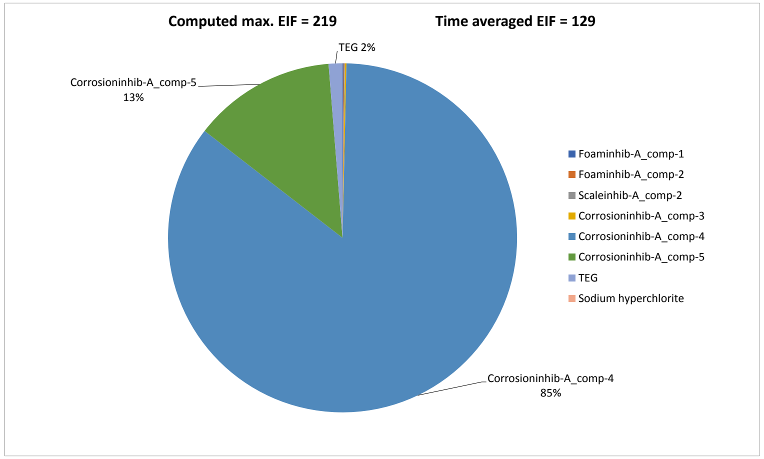
* Cases shown below

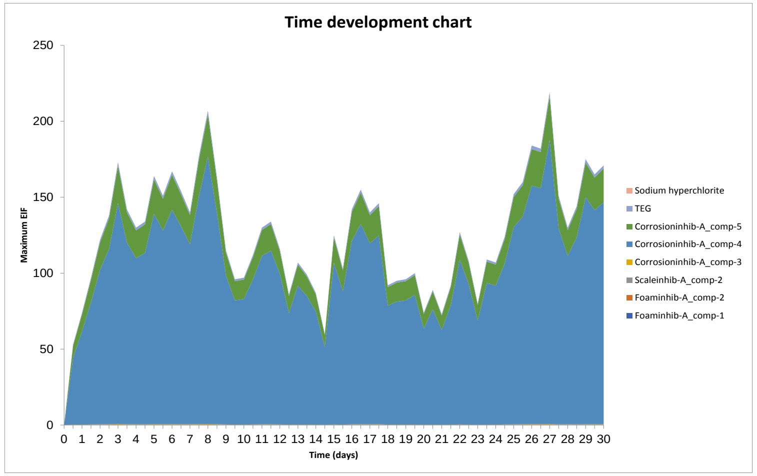
Case 2a, WITH added Sodium Hypochlorite, max. EIF: 724, time averaged EIF: 549





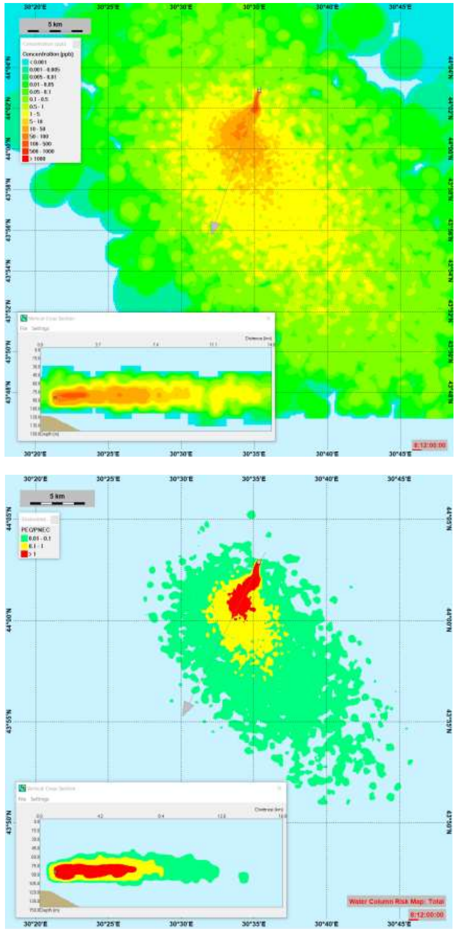
Case 2c, WITHOUT added Sodium Hypochlorite, max. EIF: 219, time averaged EIF: 129



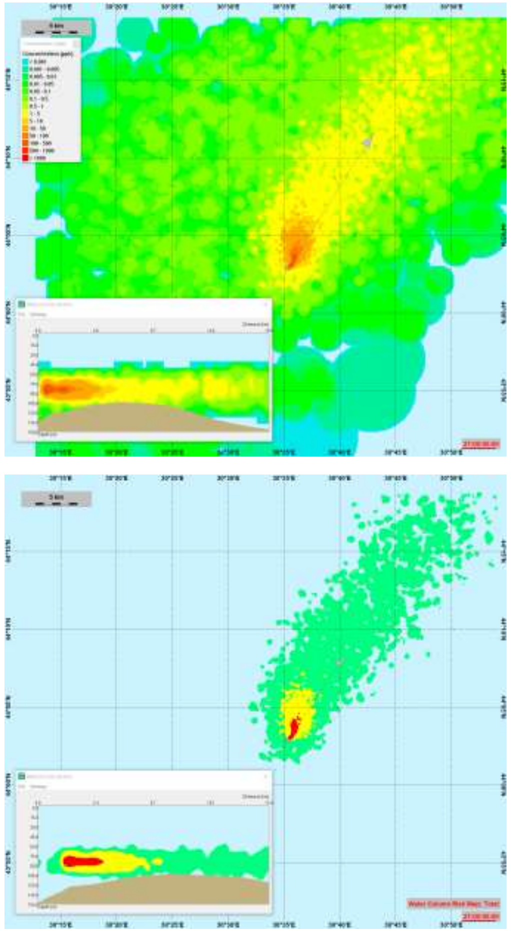


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. With Sodium Hypochlorite concentration of 2ppm on the left, without on the right.

Case 2a, WITH added Sodium Hypochlorite, max. EIF: 724, time averaged EIF: 549



Case 2c, WITHOUT added Sodium Hypochlorite, max. EIF: 219, time averaged EIF: 129



Transport and concentrations of chemicals (PEC) of the discharge in the water column **at the time of maximum EIF** in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

5.3 Warm vs. cold months

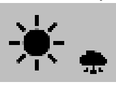
Summary

The simulations for the colder months, represented by April, show significantly lower risk for the environment than the cases that were run with the September data (representing the warmer months). This applies to both chemical packages, ChampionX, where there is no computed environmental risk for the caisson discharges without SHC, as well as Schlumberger, where the risk for the caisson discharges is reduced. This effect is not seen for the pipeline discharges, where the EIF stays about the same.

This can be explained by the different current regimes in the two months / seasons, which is more pronounced in the upper water layer and less in the bottom layers, where current speeds are low.

The results underpin the better performance of the ChampionX chemical package.

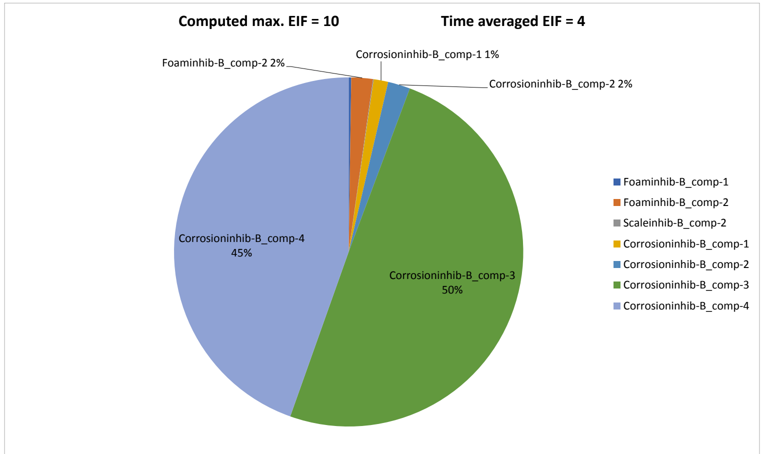
5.3.1 Chemical package from ChampionX

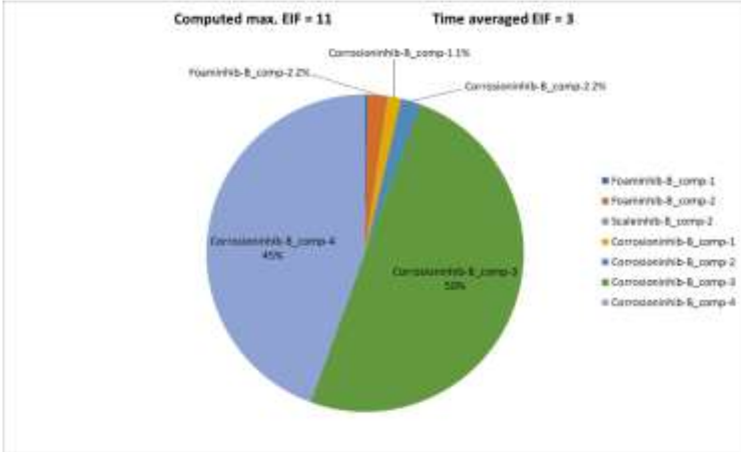
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
1c	Warm (September)		Caisson		ChampionX	HIGH	NO	6 (2)	Corrosion Inhibitor
4c	Cold (April)					HIGH	NO	0 (0)	-
1d	Warm (September)					LOW	NO	4 (1.3)	Corrosion Inhibitor
4d	Cold (April)					LOW	NO	0 (0)	-
*3a**	Warm (September)		Pipeline			HIGH	NO	10 (4)	Corrosion Inhibitor
*6a**	 dry					HIGH	NO	11 (3)	Corrosion Inhibitor
3b						LOW	NO	3 (0.6)	Corrosion Inhibitor

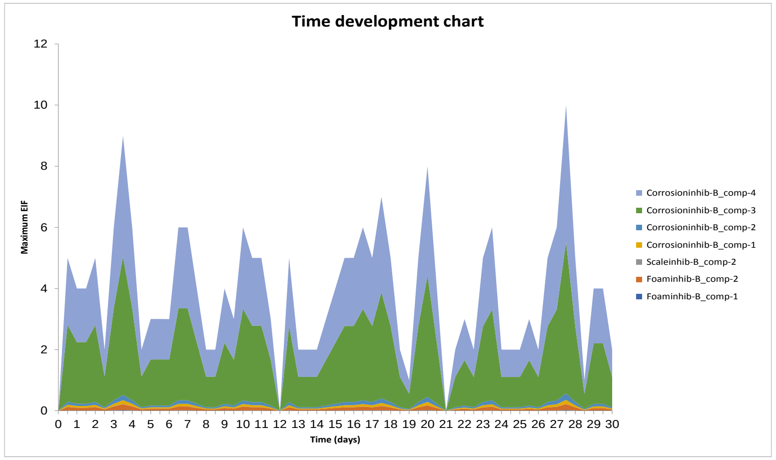
* Cases shown below

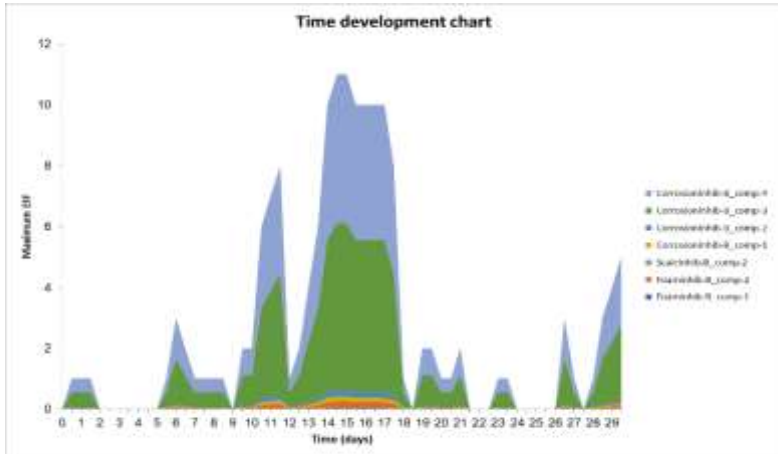
Case 3a, ChampionX, September, pipeline max. EIF: 10, time averaged EIF: 4

Case 6a, ChampionX, April, pipeline max. EIF: 11, time averaged EIF: 3





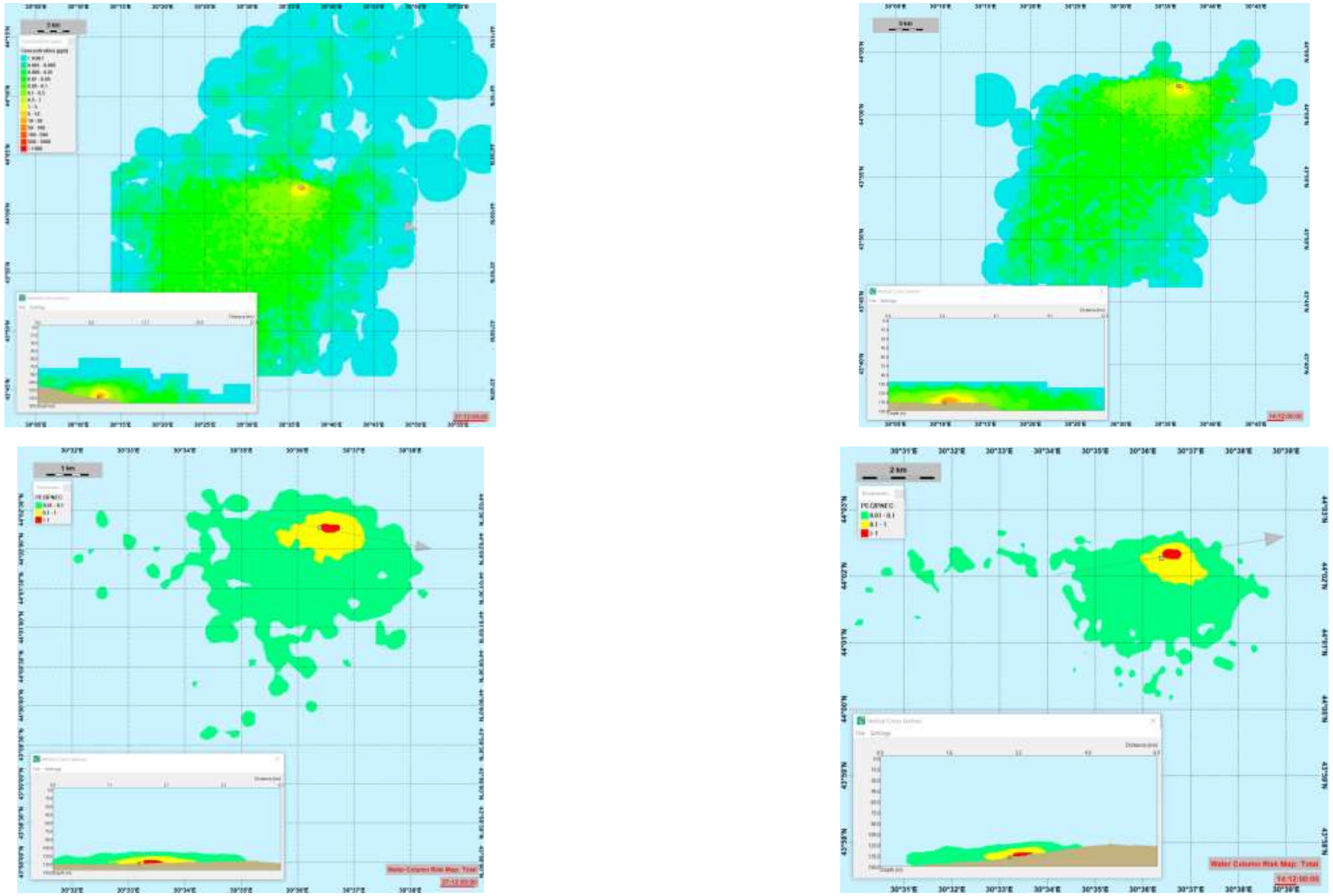




EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. September simulations for pipeline discharge on the left, April simulation for the same case on the right.

Case 3a, ChampionX, September, pipeline max. EIF: 10, time averaged EIF: 4

Case 6a, ChampionX, April, pipeline max. EIF: 11, time averaged EIF: 3



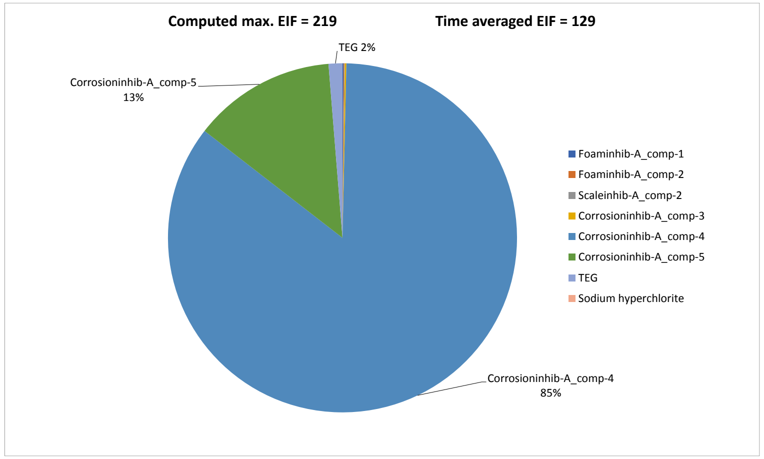
Transport and concentrations of chemicals (PEC) of the discharge in the water column at the time of maximum EIF in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

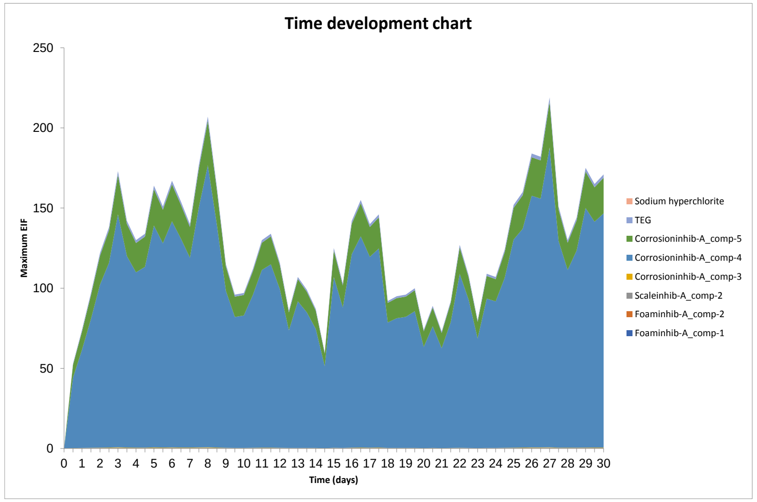
5.3.2 Chemical package from Schlumberger

case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
2c*	Warm (September)		Caisson		Schlumberger	HIGH	NO	219 (129)	Corrosion Inhibitor
5c*	Cold (April)					HIGH	NO	86 (54)	Corrosion Inhibitor
2d	Warm (September)					LOW	NO	195 (126)	Corrosion Inhibitor
5d	Cold (April)					LOW	NO	86 (45)	Corrosion Inhibitor
3c	Warm (September)		Pipeline			HIGH	NO	257 (181)	Corrosion Inhibitor
3d	Warm (September)					LOW	NO	254 (156)	Corrosion Inhibitor

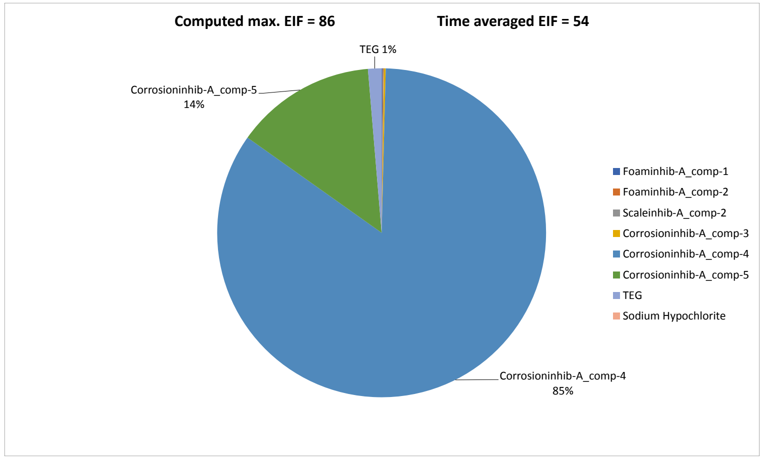
* Cases shown below

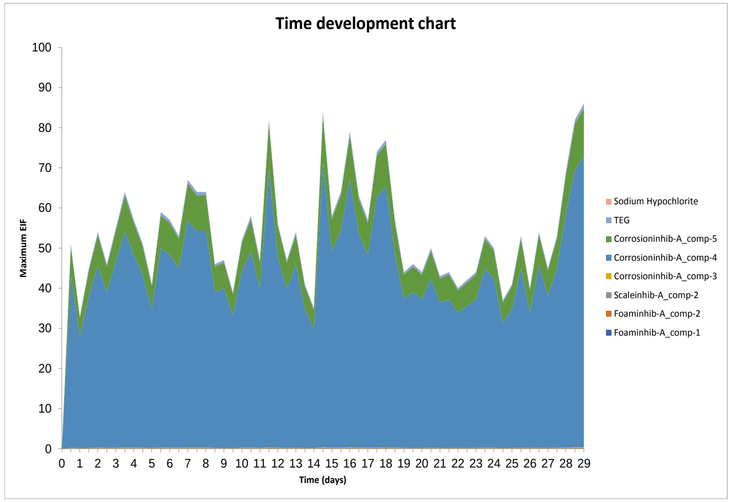
Case 2c, Schlumberger, September, caisson
max. EIF: 219, time averaged EIF: 129





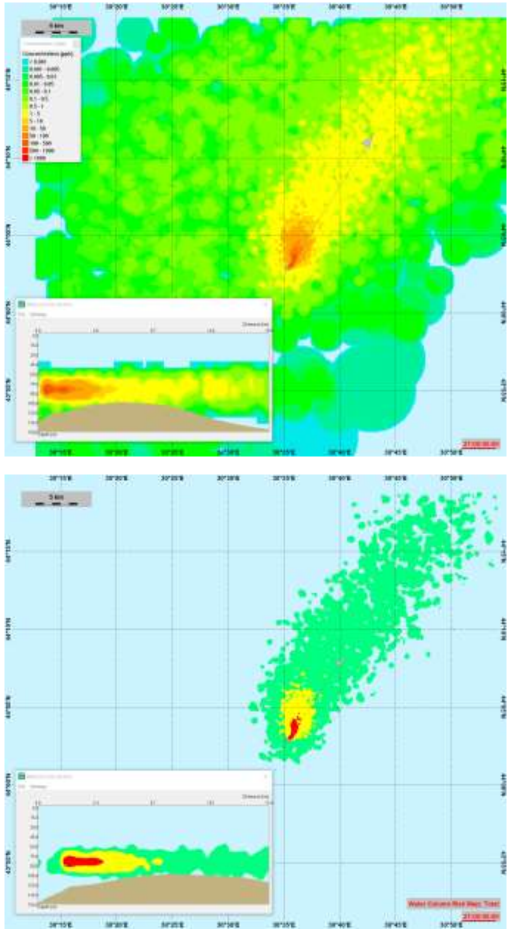
Case 5c, Schlumberger, April, caisson
max. EIF: 86, time averaged EIF: 54



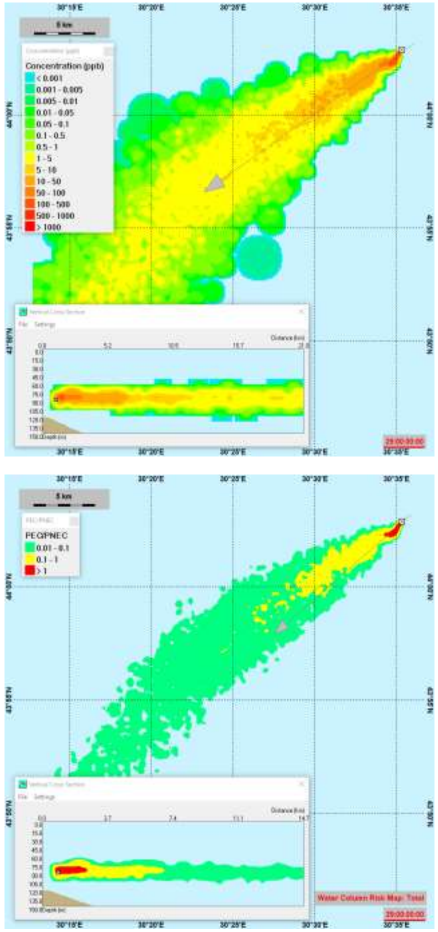


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. September simulation on the left, April on the right.

Case 2c, Schlumberger, September, caisson
max. EIF: 219, time averaged EIF: 129



Case 5c, Schlumberger, April, caisson
max. EIF: 86, time averaged EIF: 54



Transport and concentrations of chemicals (PEC) of the discharge in the water column **at the time of maximum EIF** in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

5.4 High- versus low-salinity Produced Water

Summary

The salinity of the produced water is determining for its behaviour in relation to the ambient water (sinking or floating). For the caisson discharges, the produced water was mixed with cooling water, which is sea water from 50 m water depth. The resulting salinities are slightly above and slightly below ambient sea water salinity (). For the pipeline discharges no mixing of produced water happens before discharge and the salinities are much lower than the ambient water for the low salinity produced water case. However, the temperature of the produced water is also higher which partly makes up for the high salinity. For the pipeline discharges, it was also not accounted for the discharge of the cooling water at the platform, so possible environmental risk would have to be added.

The environmental risk from the caisson discharges is slightly lower for the lower salinity produced water (due to better mixing in the upper water column) and this is even more pronounced for the pipeline cases.

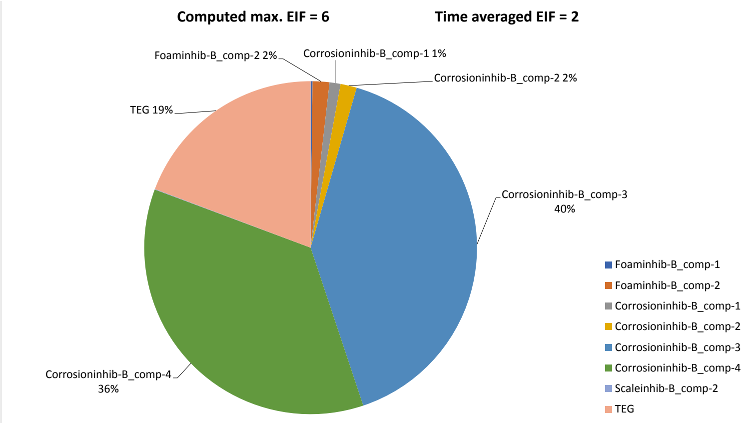
5.4.1 Discharge through caisson

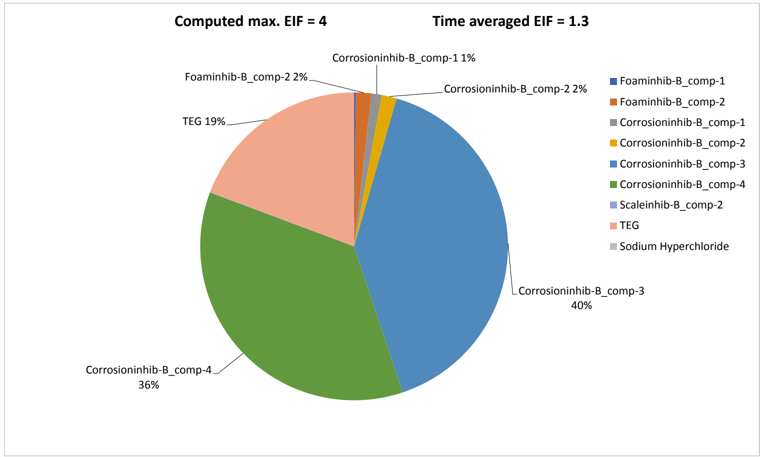
case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*1c**	Warm (September)		Caisson		ChampionX	HIGH	NO	6 (2)	Corrosion Inhibitor
*1d**						LOW	NO	4 (1.3)	Corrosion Inhibitor
2c					Schlumberger	HIGH	NO	219 (129)	Corrosion Inhibitor
2d						LOW	NO	195 (126)	Corrosion Inhibitor

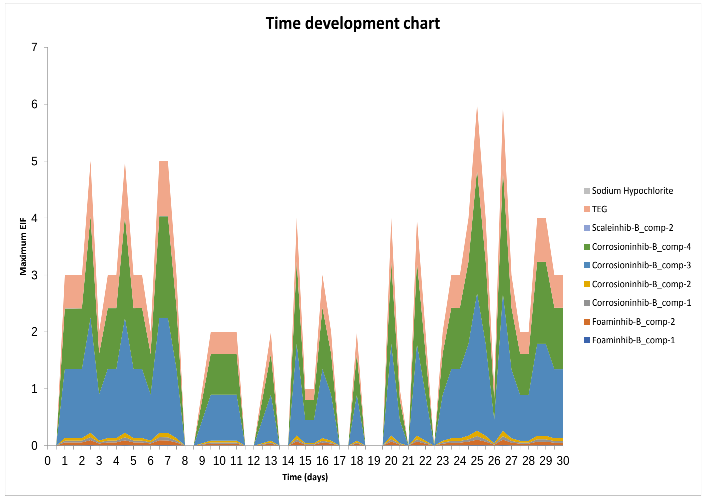
* Cases shown below

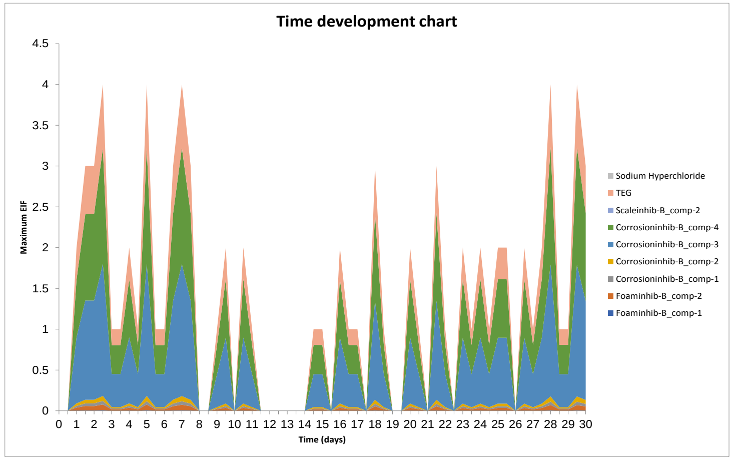
Case 1c, ChampionX, high-salinity PW
max. EIF: 6, time averaged EIF: 2

Case 1d, ChampionX, low-salinity PW
max. EIF: 4, time averaged EIF: 1.3



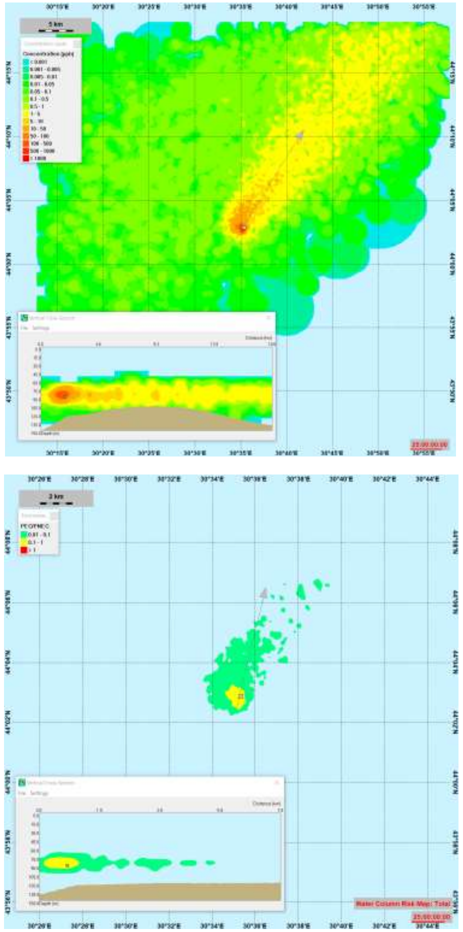




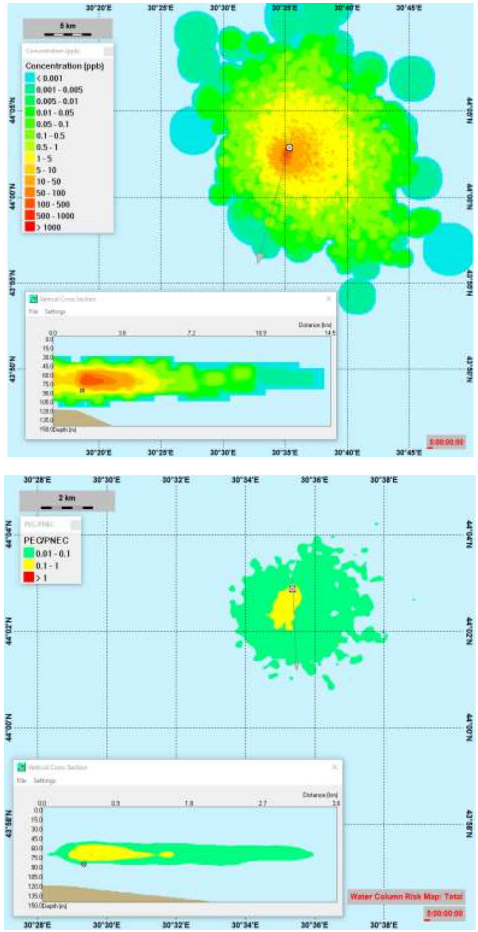


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. With high-salinity PW and ChampionX chemicals on the left, with low-salinity PW on the right.

Case 1c, ChampionX, high-salinity PW
max. EIF: 6, time averaged EIF: 2



Case 1d, ChampionX, low-salinity PW
max. EIF: 4, time averaged EIF: 1.3



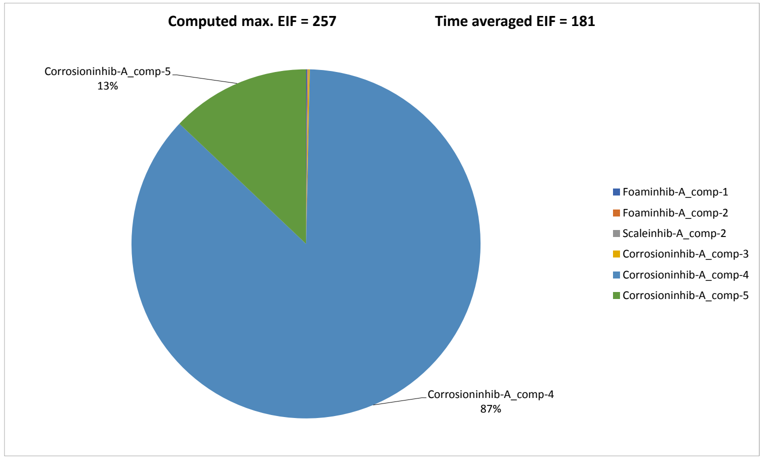
Transport and concentrations of chemicals (PEC) of the discharge in the water column at the time of maximum EIF in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

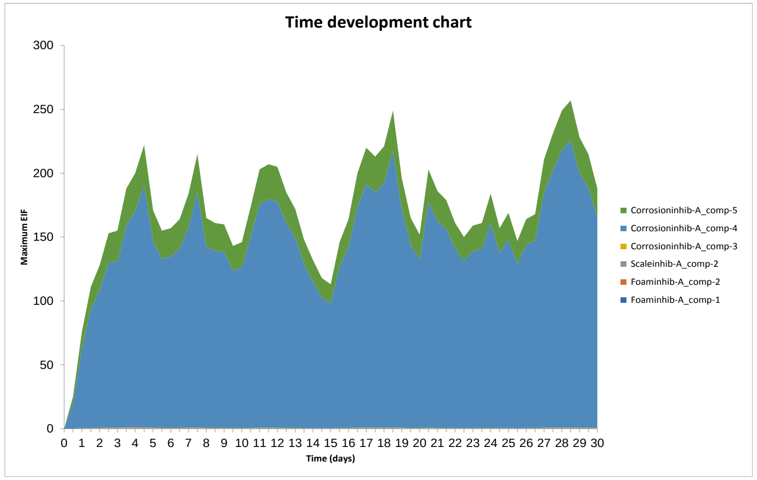
5.4.2 Discharge through pipeline

case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
3a	Warm (September)		Pipeline		ChampionX	HIGH	NO	10 (4)	Corrosion Inhibitor
3b						LOW	NO	3 (0.6)	Corrosion Inhibitor
*3c**					Schlumberger	HIGH	NO	257 (181)	Corrosion Inhibitor
*3d**						LOW	NO	254 (156)	Corrosion Inhibitor
6a	Cold (April)				ChampionX	HIGH	NO	11 (3)	Corrosion inhibitor

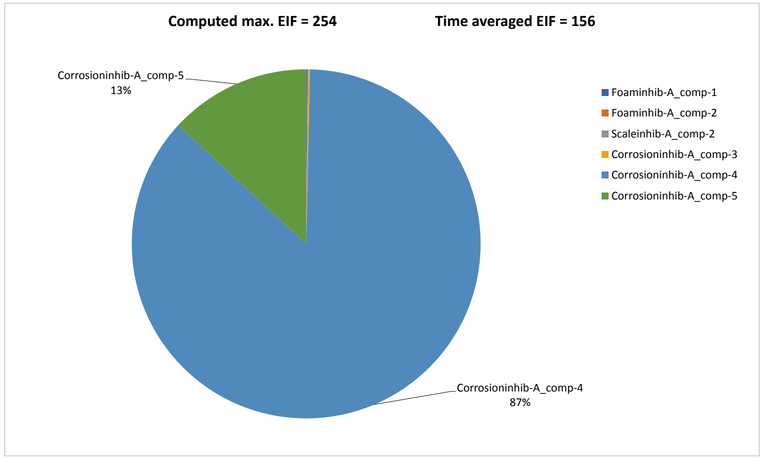
* Cases shown below

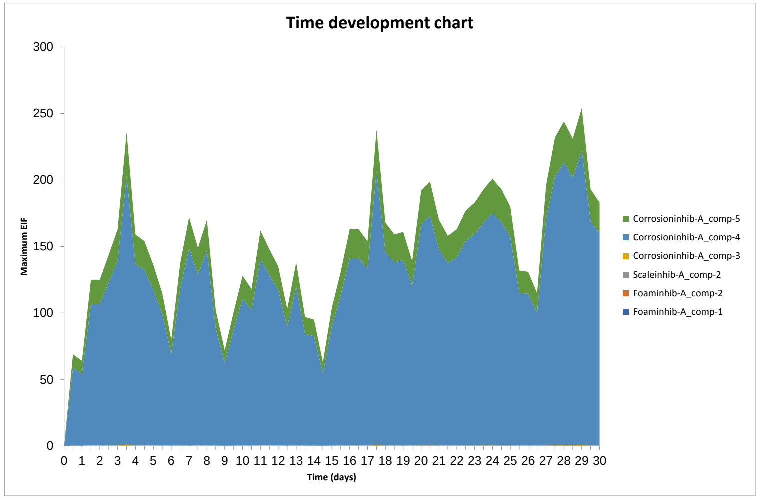
Case 3c, Schlumberger, high-salinity PW
max. EIF: 257, time averaged EIF: 181





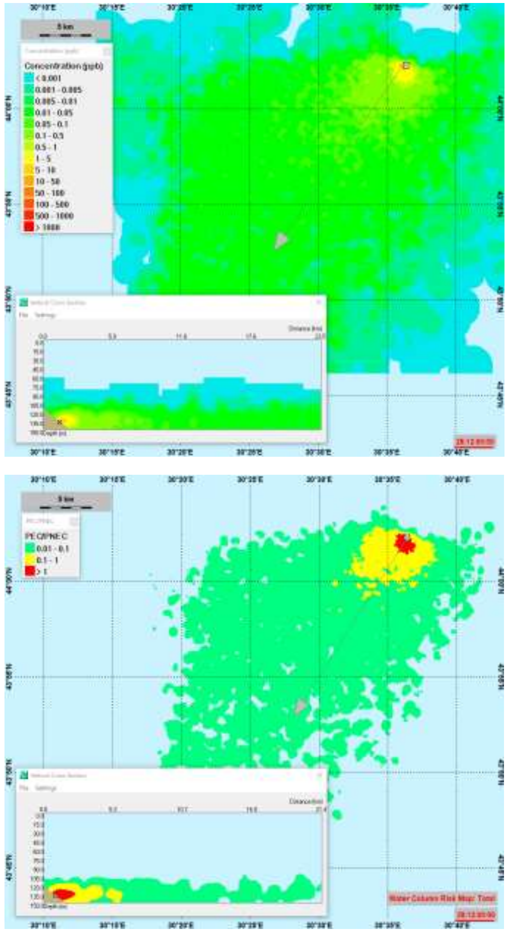
Case 3d, Schlumberger, low-salinity PW
max. EIF: 254, time averaged EIF: 156



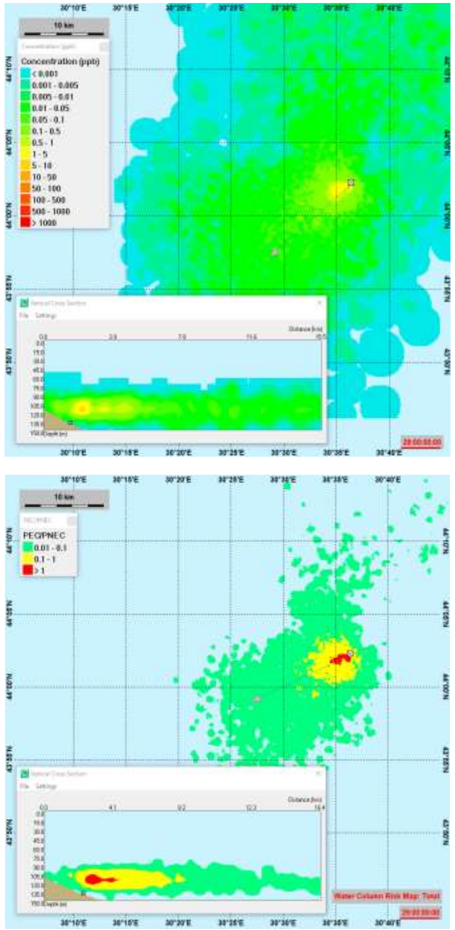


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. With high-salinity PW and Schlumberger chemicals on the left, with low-salinity PW and Schlumberger chemicals on the right.

Case 3c, Schlumberger, high-salinity PW
max. EIF: 257, time averaged EIF: 181



Case 3d, Schlumberger, low-salinity PW
max. EIF: 254, time averaged EIF: 156



Transport and concentrations of chemicals (PEC) of the discharge in the water column at the time of maximum EIF in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

5.5 Caisson versus pipeline

Summary

The pipeline discharges produce higher EIFs for all scenarios, with the exception of the ChampionX low salinity produced water discharge, for which slightly lower EIF were computed. The buoyancy behaviour of these discharges are determined by the higher temperature and salinity of the release which differ at a larger scale from the ambient conditions than the diluted water at the caisson.

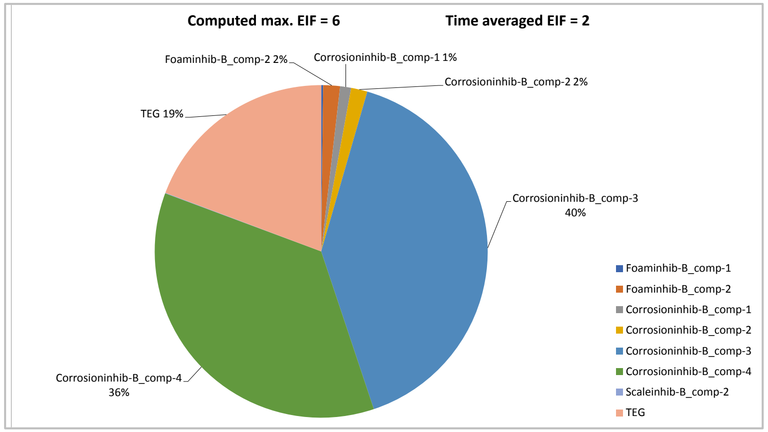
It should be considered that biodegradation at 130 m depth is slower or has almost ceased due to the oxygen conditions in the Black Sea. Additionally, the pipeline discharge scenarios do not account for the cooling water discharge at the platform, so resulting environmental risk is expected to rather compare to the cases with SHC than to the cases without as in the table below.

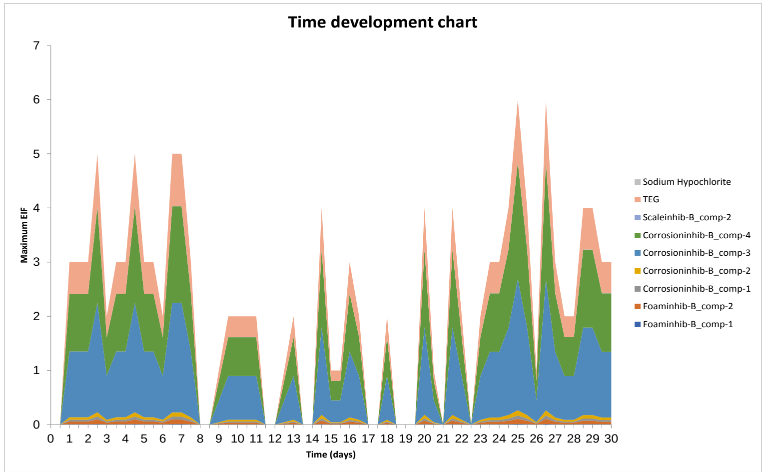
5.5.1 Chemical package from ChampionX

case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*1c**	Warm (September)		Caisson		ChampionX	HIGH	NO	6 (2)	Corrosion Inhibitor
*3a**			Pipeline			HIGH	-	10 (4)	Corrosion Inhibitor
1d			Caisson			LOW	NO	4 (1.3)	Corrosion inhibitor
3b			Pipeline			LOW	-	3 (0.6)	Corrosion Inhibitor
4c	Cold (April)		Caisson			HIGH	NO	0 (0)	None
6a			Pipeline			HIGH	-	11 (3)	Corrosion inhibitor
4d			Caisson			LOW	NO	0 (0)	None

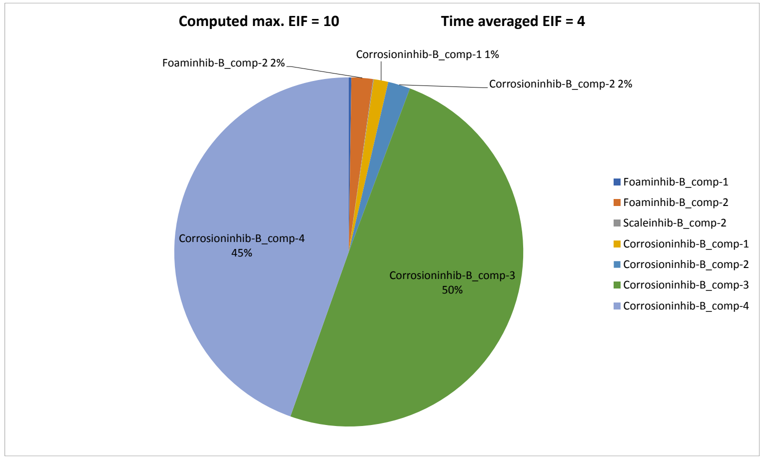
* Cases shown below

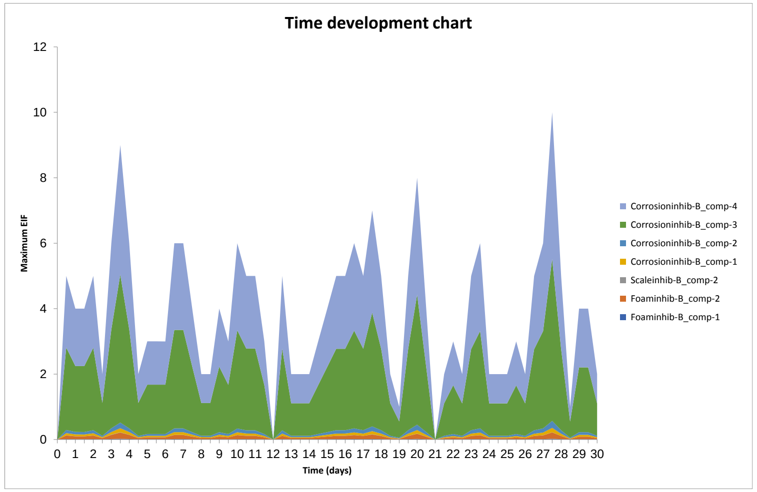
Case 1c, ChampionX, caisson
max. EIF: 6, time averaged EIF: 2





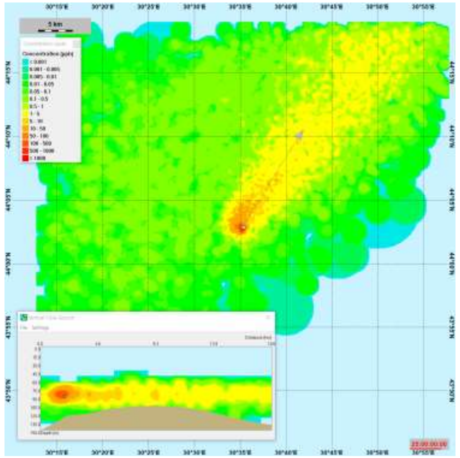
Case 3a, ChampionX, pipeline
max. EIF: 10, time averaged EIF: 4

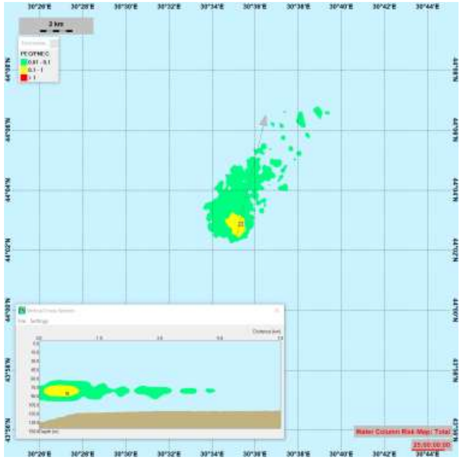




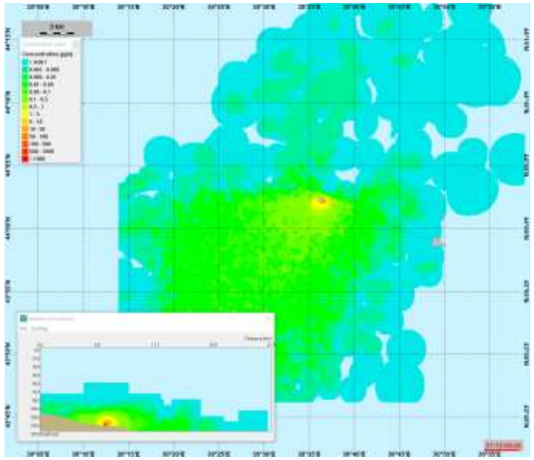
EIF contributors at the **time of maximum EIF** at the top, time-development of EIF in the lower figures. With high salinity PW and ChampionX from caisson on the left, from pipeline on the right.

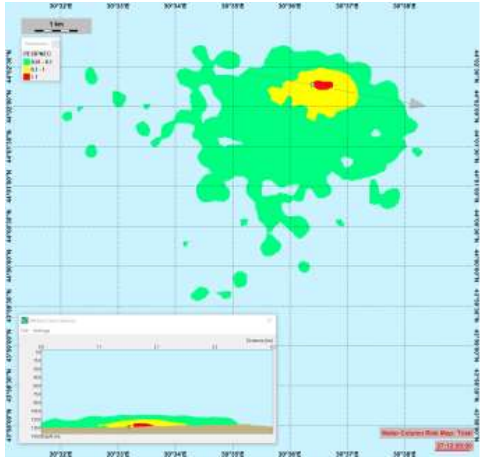
Case 1c, ChampionX, caisson
max. EIF: 6, time averaged EIF: 2





Case 3a, ChampionX, pipeline
max. EIF: 10, time averaged EIF: 4





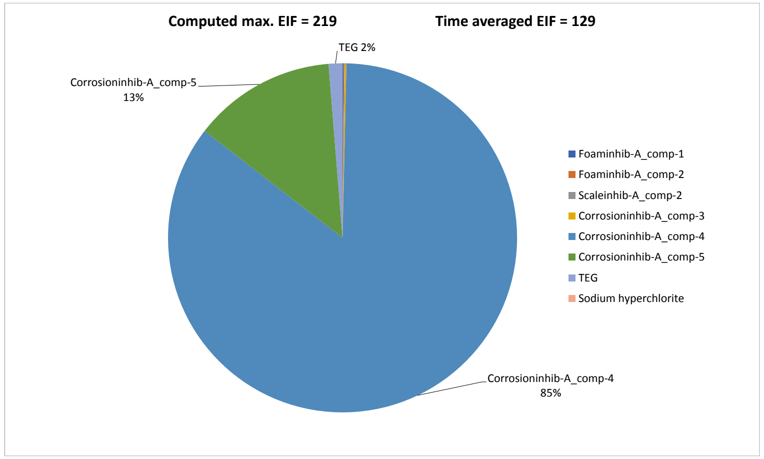
Transport and concentrations of chemicals (PEC) of the discharge in the water column **at the time of maximum EIF** in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure.

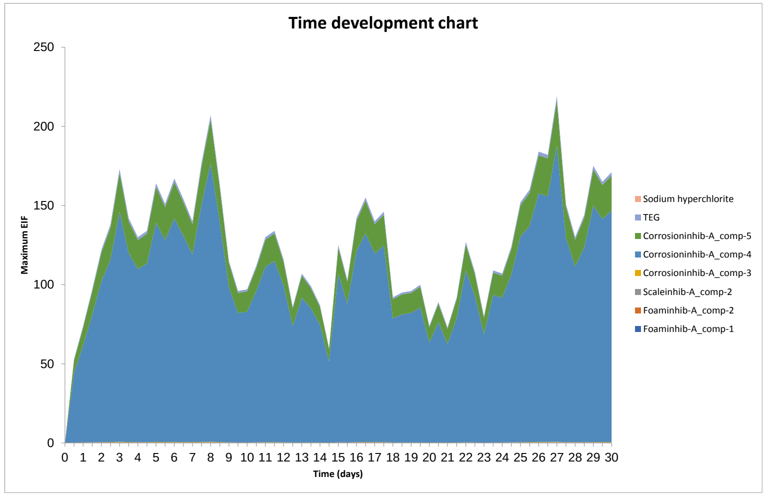
5.5.2 Chemical package from Schlumberger

case	Warm (September)	Cold (April)	Caisson	Pipeline	Chemical package	Salinity	SHC	Max EIF (time avg.)	Main risk contributor
*2c**	Warm (September)		Caisson		Schlumberger	HIGH	NO	219 (129)	Corrosion Inhibitor
*3c**			Pipeline			HIGH	-	257 (181)	Corrosion Inhibitor
2d			Caisson			LOW	NO	195 (126)	Corrosion Inhibitor
3d			Pipeline			LOW	-	254 (156)	Corrosion Inhibitor

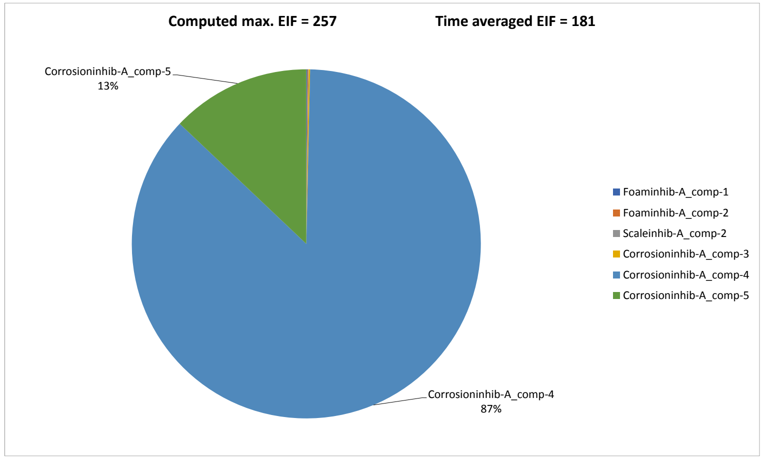
* Cases shown below

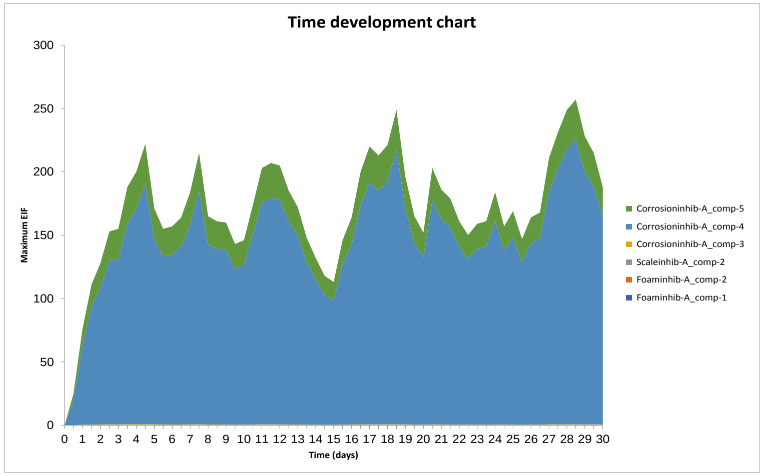
Case 2c, Schlumberger, caisson, max. EIF: 219, time averaged EIF: 129





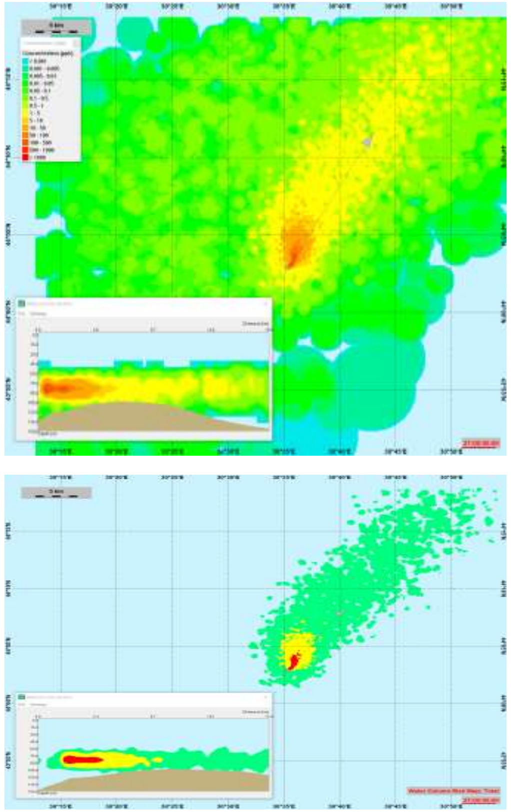
Case 3c, Schlumberger, pipeline max. EIF: 257, time averaged EIF: 181



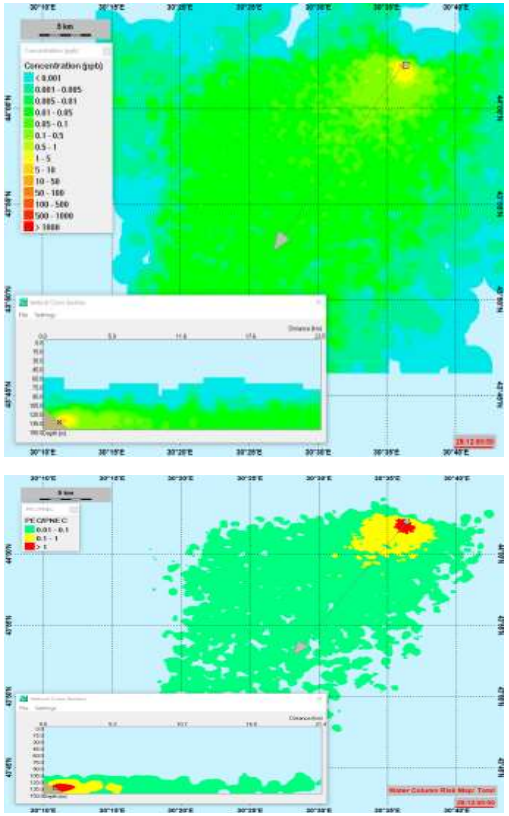


EIF contributors at the time of maximum EIF at the top, time-development of EIF in the lower figures. With Sodium Hypochlorite concentration of 2ppm on the left, without on the right.

Case 2c, Schlumberger, caisson,
max. EIF: 219, time averaged EIF: 129



Case 3c, Schlumberger, pipeline
max. EIF: 257, time averaged EIF: 181



Transport and concentrations of chemicals (PEC) of the discharge in the water column **at the time of maximum EIF** in the upper figures, translation to PEC/PNEC in the lower figures. Red areas (PEC/PNEC > 1) contribute to the EIF. Cross section along arrow in the smaller figure

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E Extra results and information

E.1 Comparison of study results with other cases

The figure below shows the cases from this study (in red and orange) compared to EIF results from Smit et al., 2011 from the Norwegian Continental Shelf in 2002 and 2008. Study cases from left to right (1a, 1b, etc) with chemical A in orange (Schlumberger) and Chemical B in red (ChampionX). With the exception of the cases that include Sodium Hypochlorite, EIF results are in the lower range with ChampionX cases producing significantly lower numbers than Schlumberger cases.

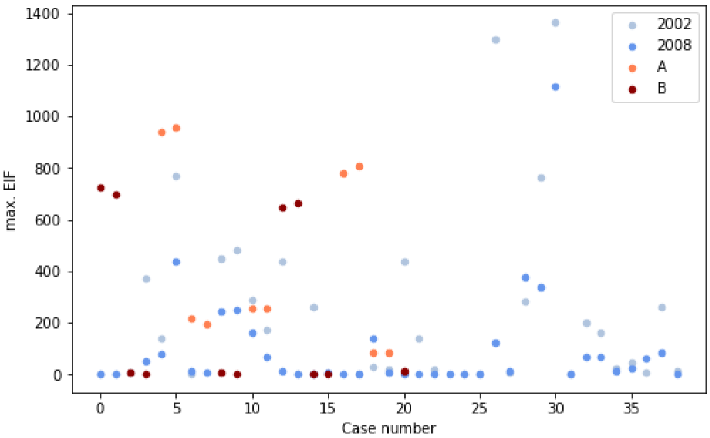


Figure A-6-1 Study results (EIF) in comparison to EIF numbers from Smit et al. 2011

E.2 Summary of study results

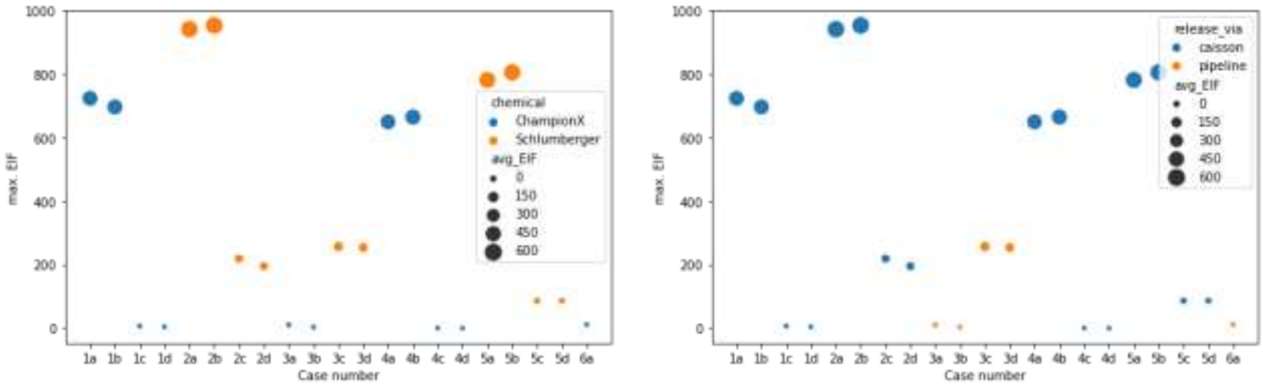


Figure A-6-2 Summary of EIF results by case number and chemical to the left, pipeline vs. caisson to the right

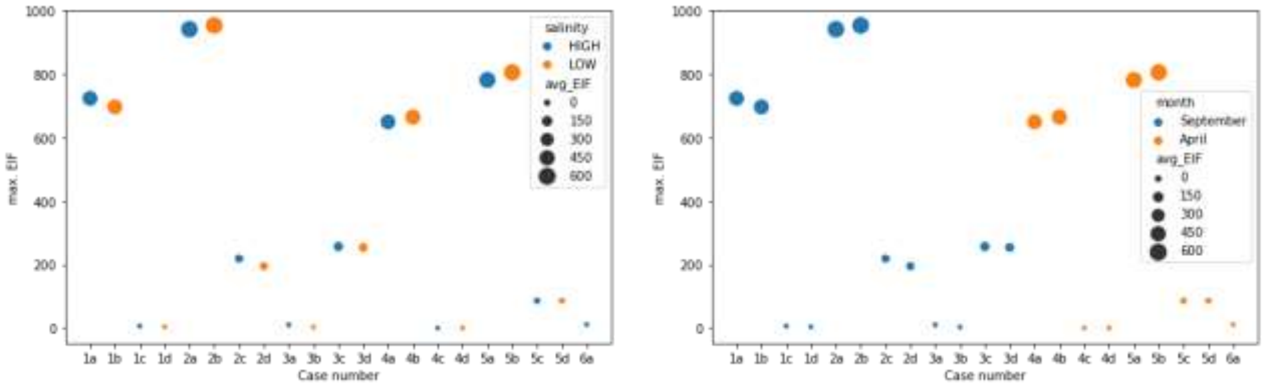


Figure A-6-3 Summary of EIF results by case number and salinity to the left, month (season) to the right

The following tables summarise all results, EIF numbers and contribution to risk are shaded with darker backgrounds meaning higher numbers.

Results for chemical B (ChampionX), caisson cases, with Sodium Hypochlorite

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
1a	ChampionX	caisson	September	HIGH	724	549	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
1a	ChampionX	caisson	September	HIGH	724	549	Foaminhibitor-B_comp.2	0.67	51.78	0.09%	1
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.1	4.32	500.00	0.06%	0
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.2	0.20	18.00	0.08%	1
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.3	1.89	9.00	2.11%	15
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.4	0.37	2.00	1.87%	14
1a	ChampionX	caisson	September	HIGH	724	549	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
1a	ChampionX	caisson	September	HIGH	724	549	TEG	331.93	3000.00	1.00%	7
1a	ChampionX	caisson	September	HIGH	724	549	Sodium Hypochlorite	1.66	0.04	94.79%	686
1b	ChampionX	caisson	September	LOW	697	557	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
1b	ChampionX	caisson	September	LOW	697	557	Foaminhibitor-B_comp.2	0.67	51.78	0.08%	1
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.1	4.32	500.00	0.06%	0
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.2	0.20	18.00	0.08%	1
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.3	1.89	9.00	2.08%	14
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.4	0.37	2.00	1.84%	13
1b	ChampionX	caisson	September	LOW	697	557	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
1b	ChampionX	caisson	September	LOW	697	557	TEG	331.93	3000.00	0.99%	7
1b	ChampionX	caisson	September	LOW	697	557	Sodium Hypochlorite	1.66	0.04	94.86%	661
4a	ChampionX	caisson	April	HIGH	650	546	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
4a	ChampionX	caisson	April	HIGH	650	546	Foaminhibitor-B_comp.2	0.67	51.78	0.04%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.1	4.32	500.00	0.03%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.2	0.20	18.00	0.04%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.3	1.89	9.00	1.00%	6
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.4	0.37	2.00	0.87%	6
4a	ChampionX	caisson	April	HIGH	650	546	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4a	ChampionX	caisson	April	HIGH	650	546	TEG	331.93	3000.00	0.48%	3
4a	ChampionX	caisson	April	HIGH	650	546	Sodium Hypochlorite	1.66	0.04	97.54%	634
4b	ChampionX	caisson	April	LOW	665	580	Foaminhibitor-B_comp.1	1.01	500.00	0.00%	0
4b	ChampionX	caisson	April	LOW	665	580	Foaminhibitor-B_comp.2	0.67	51.78	0.04%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.1	4.32	500.00	0.02%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.2	0.20	18.00	0.03%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.3	1.89	9.00	0.92%	6
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.4	0.37	2.00	0.80%	5
4b	ChampionX	caisson	April	LOW	665	580	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4b	ChampionX	caisson	April	LOW	665	580	TEG	331.93	3000.00	0.44%	3
4b	ChampionX	caisson	April	LOW	665	580	Sodium Hypochlorite	1.66	0.04	97.73%	650

Results for chemical B (ChampionX), caisson cases, without Sodium Hypochlorite

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
1c	ChampionX	caisson	September	HIGH	6	2	Foaminhibitor-B_comp 1	1.01	500.00	0.19%	0
1c	ChampionX	caisson	September	HIGH	6	2	Foaminhibitor-B_comp 2	0.67	51.78	1.63%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp 1	4.32	500.00	1.07%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp 2	0.20	18.00	1.58%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp 3	1.89	9.00	40.41%	2
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp 4	0.37	2.00	35.81%	2
1c	ChampionX	caisson	September	HIGH	6	2	Scaleinhibitor-B_comp 2	0.67	1000.00	0.05%	0
1c	ChampionX	caisson	September	HIGH	6	2	TEG	331.93	3000.00	19.27%	1
1d	ChampionX	caisson	September	LOW	4	1	Foaminhibitor-B_comp 1	1.01	500.00	0.19%	0
1d	ChampionX	caisson	September	LOW	4	1	Foaminhibitor-B_comp 2	0.67	51.78	1.63%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp 1	4.32	500.00	1.07%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp 2	0.20	18.00	1.58%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp 3	1.89	9.00	40.41%	2
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp 4	0.37	2.00	35.82%	1
1d	ChampionX	caisson	September	LOW	4	1	Scaleinhibitor-B_comp 2	0.67	1000.00	0.05%	0
1d	ChampionX	caisson	September	LOW	4	1	TEG	331.93	3000.00	19.26%	1
4c	ChampionX	caisson	April	HIGH	0	0	Foaminhibitor-B_comp 1	1.01	500.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Foaminhibitor-B_comp 2	0.67	51.78	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp 1	4.32	500.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp 2	0.20	18.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp 3	1.89	9.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp 4	0.37	2.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Scaleinhibitor-B_comp 2	0.67	1000.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	TEG	331.93	3000.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Foaminhibitor-B_comp 1	1.01	500.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Foaminhibitor-B_comp 2	0.67	51.78	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp 1	4.32	500.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp 2	0.20	18.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp 3	1.89	9.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp 4	0.37	2.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Scaleinhibitor-B_comp 2	0.67	1000.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	TEG	331.93	3000.00	0.00%	0

Results for chemical B (ChampionX), pipeline cases

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3a	ChampionX	pipeline	September	HIGH	10	4	Foaminhibitor-B_comp.1	6.00	500.00	0.24%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Foaminhibitor-B_comp.2	4.00	51.78	1.99%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Scaleinhibitor-B_comp.2	4.00	1000.00	0.07%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.1	25.60	500.00	1.34%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.2	1.20	18.00	2.06%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.3	11.24	9.00	49.73%	5
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.4	2.20	2.00	44.57%	4
3b	ChampionX	pipeline	September	LOW	3	1	Foaminhibitor-B_comp.1	6.00	500.00	0.23%	0
3b	ChampionX	pipeline	September	LOW	3	1	Foaminhibitor-B_comp.2	4.00	51.78	2.01%	0
3b	ChampionX	pipeline	September	LOW	3	1	Scaleinhibitor-B_comp.2	4.00	1000.00	0.06%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.1	25.60	500.00	1.33%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.2	1.20	18.00	1.99%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.3	11.24	9.00	49.93%	1
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.4	2.20	2.00	44.45%	1
6a	ChampionX	pipeline	April	HIGH	11	3	Foaminhibitor-B_comp.1	6.00	500.00	0.25%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Foaminhibitor-B_comp.2	4.00	51.78	2.02%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Scaleinhibitor-B_comp.2	4.00	1000.00	0.07%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.1	25.60	500.00	1.35%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.2	1.20	18.00	2.02%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.3	11.24	9.00	49.86%	5
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.4	2.20	2.00	44.44%	5

Results for chemical A (Schlumberger), caisson cases, with Sodium Hypochlorite

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2a	Schlumberger	caisson	September	HIGH	942	702	Foaminhibitor-A_comp.1	1.52	125.00	0.05%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Foaminhibitor-A_comp.2	0.17	21.00	0.03%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Scaleinhibitor-A_comp.2	1.01	178.00	0.02%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.3	2.53	130.00	0.06%	1
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.4	0.84	0.20	38.62%	364
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.5	0.84	0.96	6.00%	57
2a	Schlumberger	caisson	September	HIGH	942	702	TEG	331.33	3000.00	0.58%	5
2a	Schlumberger	caisson	September	HIGH	942	702	Sodium Hypochlorite	1.66	0.04	54.64%	515
2b	Schlumberger	caisson	September	LOW	954	708	Foaminhibitor-A_comp.1	1.52	125.00	0.05%	0
2b	Schlumberger	caisson	September	LOW	954	708	Foaminhibitor-A_comp.2	0.17	21.00	0.03%	0
2b	Schlumberger	caisson	September	LOW	954	708	Scaleinhibitor-A_comp.2	1.01	178.00	0.02%	0
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.3	2.53	130.00	0.06%	1
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.4	0.84	0.20	38.38%	366
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.5	0.84	0.96	5.94%	57
2b	Schlumberger	caisson	September	LOW	954	708	TEG	331.33	3000.00	0.57%	5
2b	Schlumberger	caisson	September	LOW	954	708	Sodium Hypochlorite	1.66	0.04	54.95%	524
5a	Schlumberger	caisson	April	HIGH	782	654	Foaminhibitor-A_comp.1	1.52	125.00	0.03%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Foaminhibitor-A_comp.2	0.17	21.00	0.02%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Scaleinhibitor-A_comp.2	1.01	178.00	0.01%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.3	2.53	130.00	0.05%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.4	0.84	0.20	22.62%	177
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.5	0.84	0.96	3.71%	29
5a	Schlumberger	caisson	April	HIGH	782	654	TEG	331.33	3000.00	0.36%	3
5a	Schlumberger	caisson	April	HIGH	782	654	Sodium Hypochlorite	1.66	0.04	73.21%	573
5b	Schlumberger	caisson	April	LOW	806	683	Foaminhibitor-A_comp.1	1.52	125.00	0.03%	0
5b	Schlumberger	caisson	April	LOW	806	683	Foaminhibitor-A_comp.2	0.17	21.00	0.02%	0
5b	Schlumberger	caisson	April	LOW	806	683	Scaleinhibitor-A_comp.2	1.01	178.00	0.01%	0
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.3	2.53	130.00	0.04%	0
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.4	0.84	0.20	21.40%	172
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.5	0.84	0.96	3.51%	28
5b	Schlumberger	caisson	April	LOW	806	683	TEG	331.33	3000.00	0.34%	3
5b	Schlumberger	caisson	April	LOW	806	683	Sodium Hypochlorite	1.66	0.04	74.64%	602

Results for chemical A (Schlumberger), caisson cases, without Sodium Hypochlorite

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2c	Schlumberger	caisson	September	HIGH	219	129	Foaminhibitor-A_comp.1	1.52	125.00	0.10%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.3	2.53	130.00	0.14%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.4	0.84	0.20	85.13%	186
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.5	0.84	0.96	13.23%	29
2c	Schlumberger	caisson	September	HIGH	219	129	TEG	331.33	3000.00	1.28%	3
2d	Schlumberger	caisson	September	LOW	195	126	Foaminhibitor-A_comp.1	1.52	125.00	0.10%	0
2d	Schlumberger	caisson	September	LOW	195	126	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
2d	Schlumberger	caisson	September	LOW	195	126	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.3	2.53	130.00	0.14%	0
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.4	0.84	0.20	85.19%	166
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.5	0.84	0.96	13.18%	26
2d	Schlumberger	caisson	September	LOW	195	126	TEG	331.33	3000.00	1.27%	2
5c	Schlumberger	caisson	April	HIGH	86	54	Foaminhibitor-A_comp.1	1.52	125.00	0.11%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.3	2.53	130.00	0.17%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.4	0.84	0.20	84.42%	73
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.5	0.84	0.96	13.85%	12
5c	Schlumberger	caisson	April	HIGH	86	54	TEG	331.33	3000.00	1.33%	1
5d	Schlumberger	caisson	April	LOW	86	45	Foaminhibitor-A_comp.1	1.52	125.00	0.11%	0
5d	Schlumberger	caisson	April	LOW	86	45	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
5d	Schlumberger	caisson	April	LOW	86	45	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.3	2.53	130.00	0.17%	0
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.4	0.84	0.20	84.41%	73
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.5	0.84	0.96	13.86%	12
5d	Schlumberger	caisson	April	LOW	86	45	TEG	331.33	3000.00	1.33%	1

Results for chemical A (Schlumberger), pipeline cases

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3c	Schlumberger	pipeline	September	HIGH	257	181	Foaminhibitor-A_comp.1	9.00	125.00	0.10%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Foaminhibitor-A_comp.2	1.00	21.00	0.07%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Scaleinhibitor-A_comp.2	6.00	178.00	0.05%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.3	15.00	130.00	0.13%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.4	5.00	0.20	86.73%	223
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.5	5.00	0.96	12.92%	33
3d	Schlumberger	pipeline	September	LOW	254	156	Foaminhibitor-A_comp.1	9.00	125.00	0.10%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Foaminhibitor-A_comp.2	1.00	21.00	0.07%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Scaleinhibitor-A_comp.2	6.00	178.00	0.05%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.3	15.00	130.00	0.14%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.4	5.00	0.20	86.54%	220
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.5	5.00	0.96	13.11%	33

E.3 Detailed results from DREAM simulations and EIF computations (in addition to Chapter 5)

E.3.1 Caisson discharge, high rate, chemical package ChampionX, September (warm season)

September	ChampionX	90 m	500 mm

E.3.1.1 Case 1a: High-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

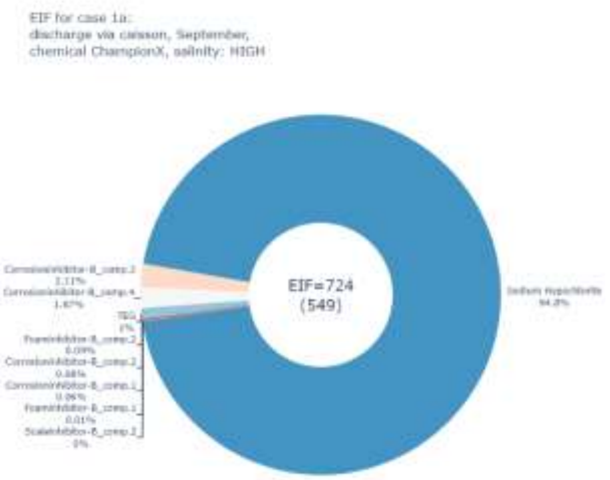
Discharge information for Case 1a.

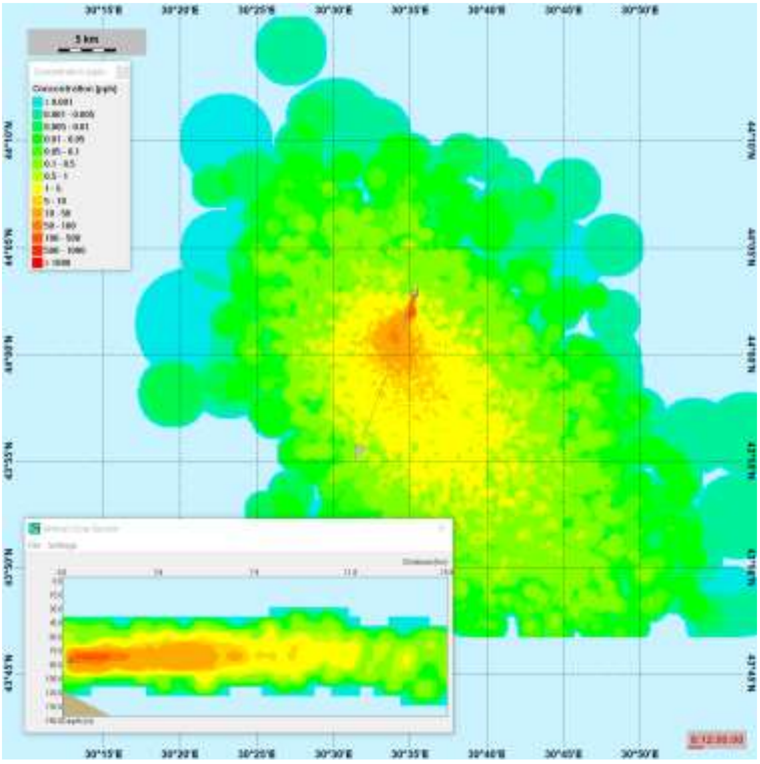
Neptun Deep Caisson	**Case 1a**
Release rate (m^3/hour):	382.32
Discharge temperature °C:	22.32
Resulting salinity (mg/L):	20.20

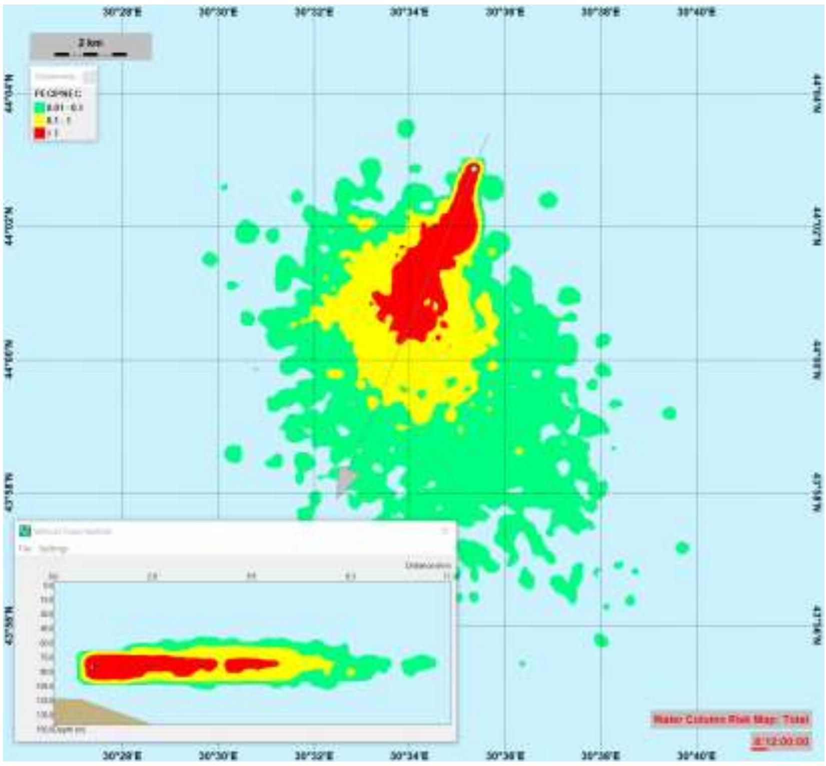
HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 1a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
1a	ChampionX	caisson	September	HIGH	724	549	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
1a	ChampionX	caisson	September	HIGH	724	549	Foaminhibitor-B_comp.2	0.67	51.78	0.09%	1
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.1	4.32	500.00	0.06%	0
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.2	0.20	18.00	0.08%	1
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.3	1.89	9.00	2.11%	15
1a	ChampionX	caisson	September	HIGH	724	549	Corrosioninhibitor-B_comp.4	0.37	2.00	1.87%	14
1a	ChampionX	caisson	September	HIGH	724	549	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
1a	ChampionX	caisson	September	HIGH	724	549	TEG	331.93	3000.00	1.00%	7
1a	ChampionX	caisson	September	HIGH	724	549	Sodium Hypochlorite	1.66	0.04	94.79%	686







Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 1a.

E.3.1.2 Case 1b: Low-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

September	ChampionX	90 m	500 mm

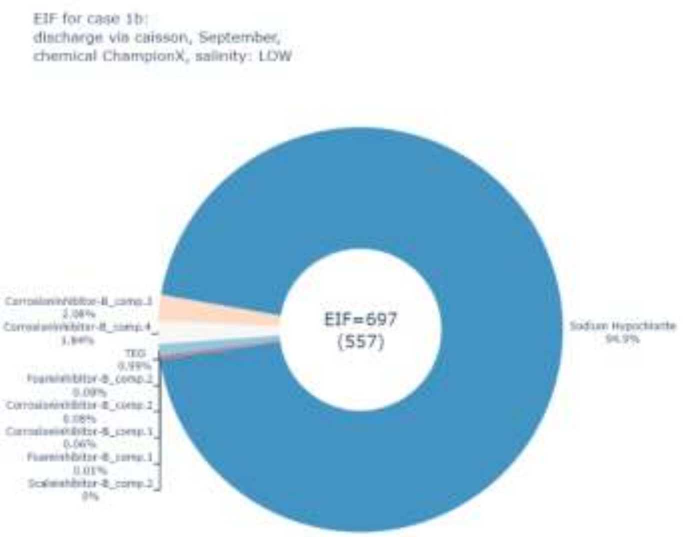
Discharge information for Case 1b.

Neptun Deep Caisson	**Case 1b**
Release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 1b.

1b	ChampionX	caisson	September	LOW	697	557	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
1b	ChampionX	caisson	September	LOW	697	557	Foaminhibitor-B_comp.2	0.67	51.78	0.08%	1
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.1	4.32	500.00	0.06%	0
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.2	0.20	18.00	0.08%	1
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.3	1.89	9.00	2.08%	14
1b	ChampionX	caisson	September	LOW	697	557	Corrosioninhibitor-B_comp.4	0.37	2.00	1.84%	13
1b	ChampionX	caisson	September	LOW	697	557	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
1b	ChampionX	caisson	September	LOW	697	557	TEG	331.93	3000.00	0.99%	7
1b	ChampionX	caisson	September	LOW	697	557	Sodium Hypochlorite	1.66	0.04	94.86%	661



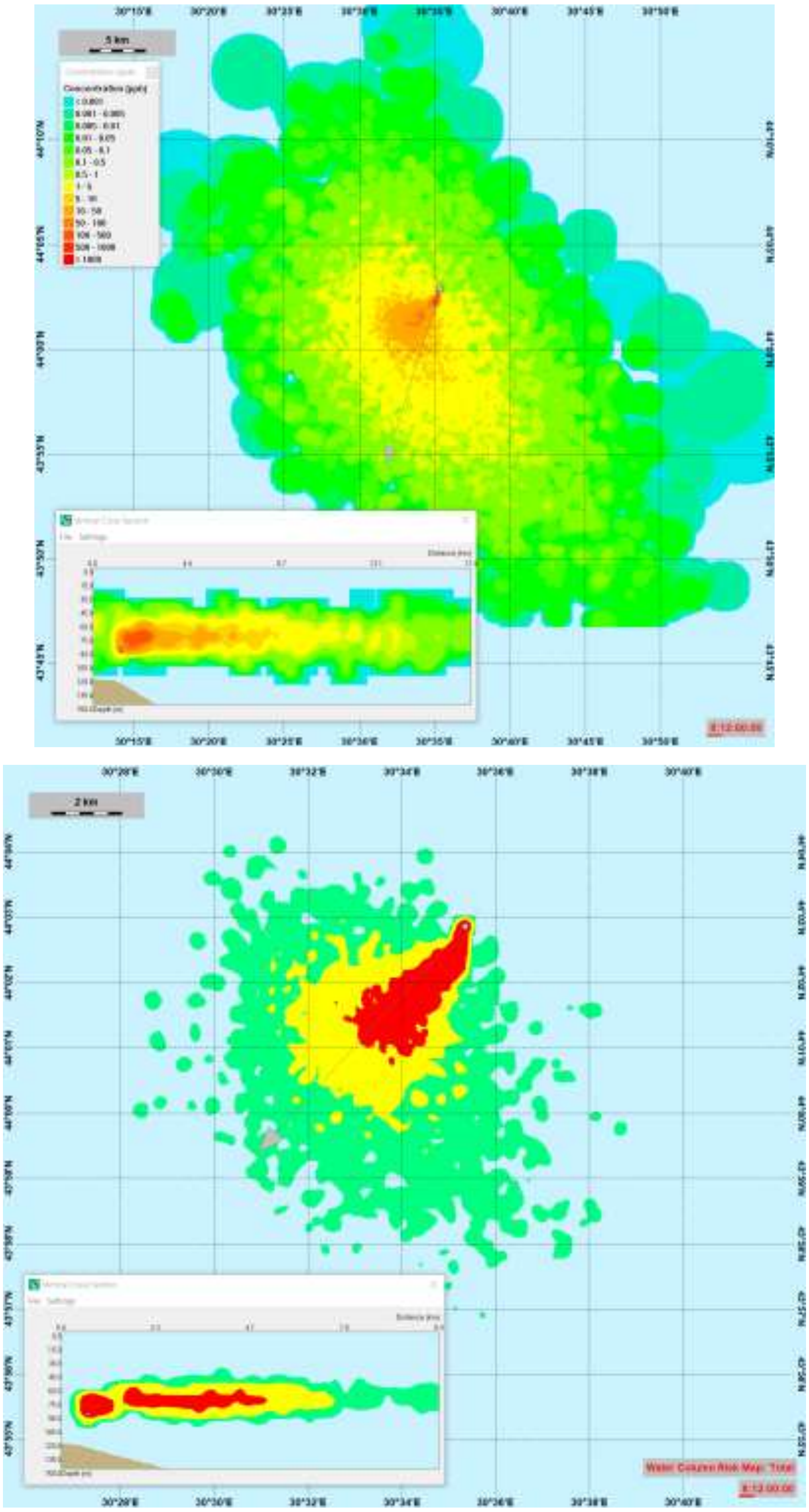


Figure A-6-4 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 1a.

E.3.1.3 Case 1c: High-salinity PW, no Sodium Hypochlorite at discharge

September	ChampionX	90 m	500 mm

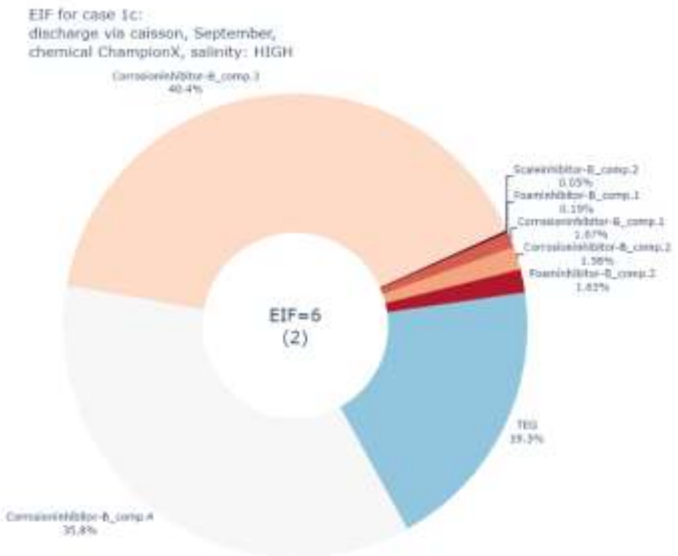
Discharge information for Case 1c.

Neptun Deep Caisson	**Case 1c**
PW release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	20.2036

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 1c.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
1c	ChampionX	caisson	September	HIGH	6	2	Foaminhibitor-B_comp.1	1.01	500.00	0.19%	0
1c	ChampionX	caisson	September	HIGH	6	2	Foaminhibitor-B_comp.2	0.67	51.78	1.63%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp.1	4.32	500.00	1.07%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp.2	0.20	18.00	1.58%	0
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp.3	1.89	9.00	40.41%	2
1c	ChampionX	caisson	September	HIGH	6	2	Corrosioninhibitor-B_comp.4	0.37	2.00	35.81%	2
1c	ChampionX	caisson	September	HIGH	6	2	Scaleinhibitor-B_comp.2	0.67	1000.00	0.05%	0
1c	ChampionX	caisson	September	HIGH	6	2	TEG	331.93	3000.00	19.27%	1



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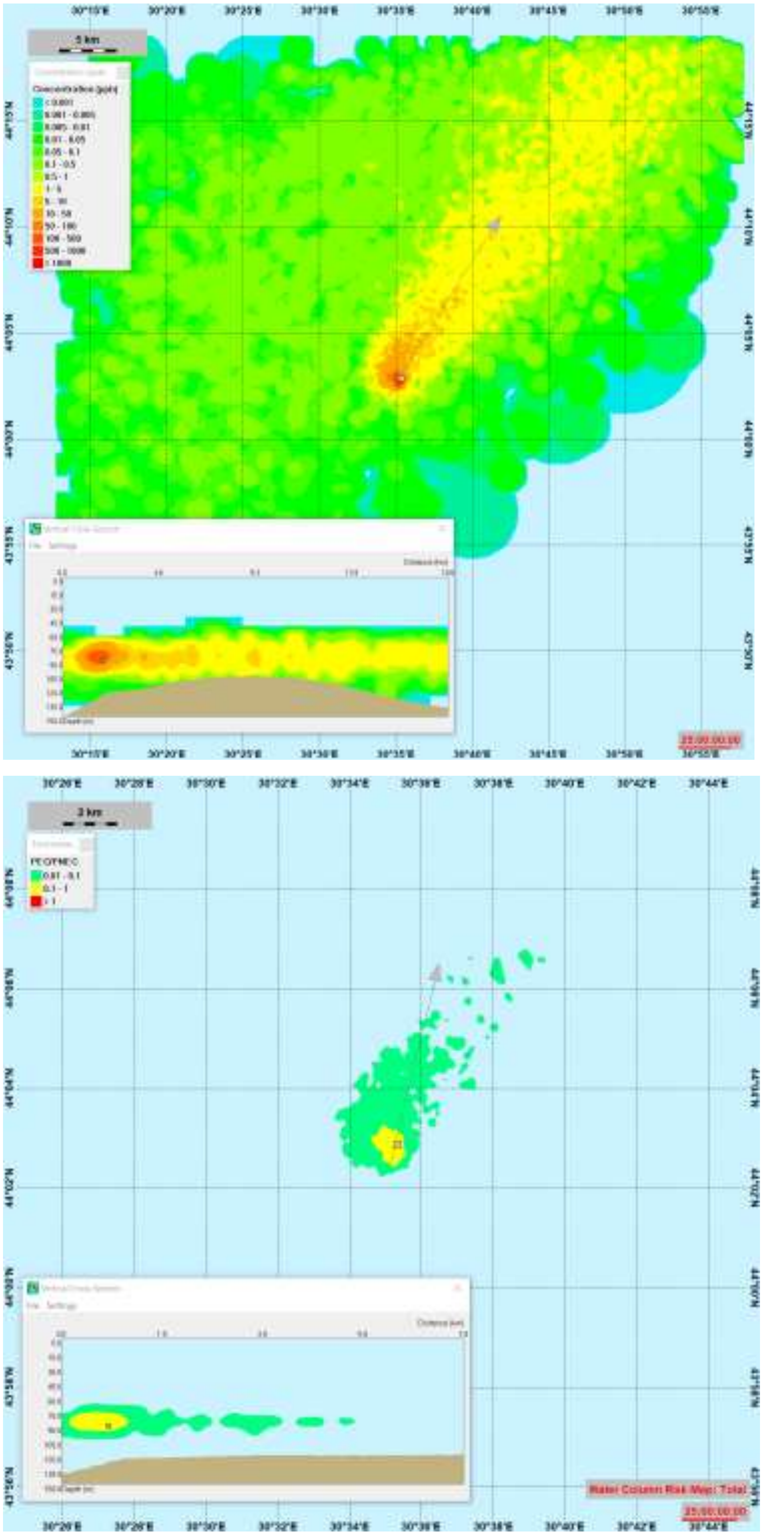


Figure A-6-5 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 1a.

E.3.1.4 Case 1d: Low-salinity PW, no Sodium Hypochlorite at discharge

September	ChampionX	90 m	500 mm

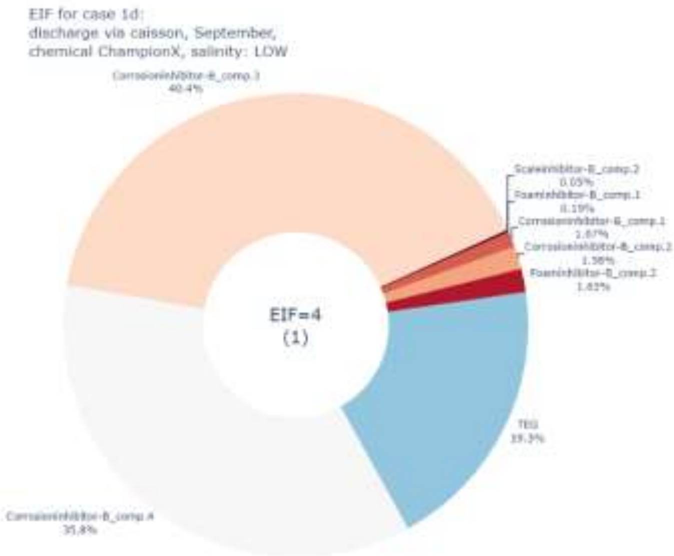
Discharge information for Case 1d.

Neptun Deep Caisson	**Case 1d**
PW release rate (m3/hour):	382.32
Temperature °C:	22.32
Salinity (mg/L):	16.6223

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 1d.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
1d	ChampionX	caisson	September	LOW	4	1	Foaminhibitor-B_comp.2	0.67	51.78	1.63%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp.1	4.32	500.00	1.07%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp.2	0.20	18.00	1.58%	0
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp.3	1.89	9.00	40.47%	2
1d	ChampionX	caisson	September	LOW	4	1	Corrosioninhibitor-B_comp.4	0.37	2.00	35.82%	1
1d	ChampionX	caisson	September	LOW	4	1	Scaleinhibitor-B_comp.2	0.67	1000.00	0.05%	0
1d	ChampionX	caisson	September	LOW	4	1	TEG	331.93	3000.00	19.28%	1



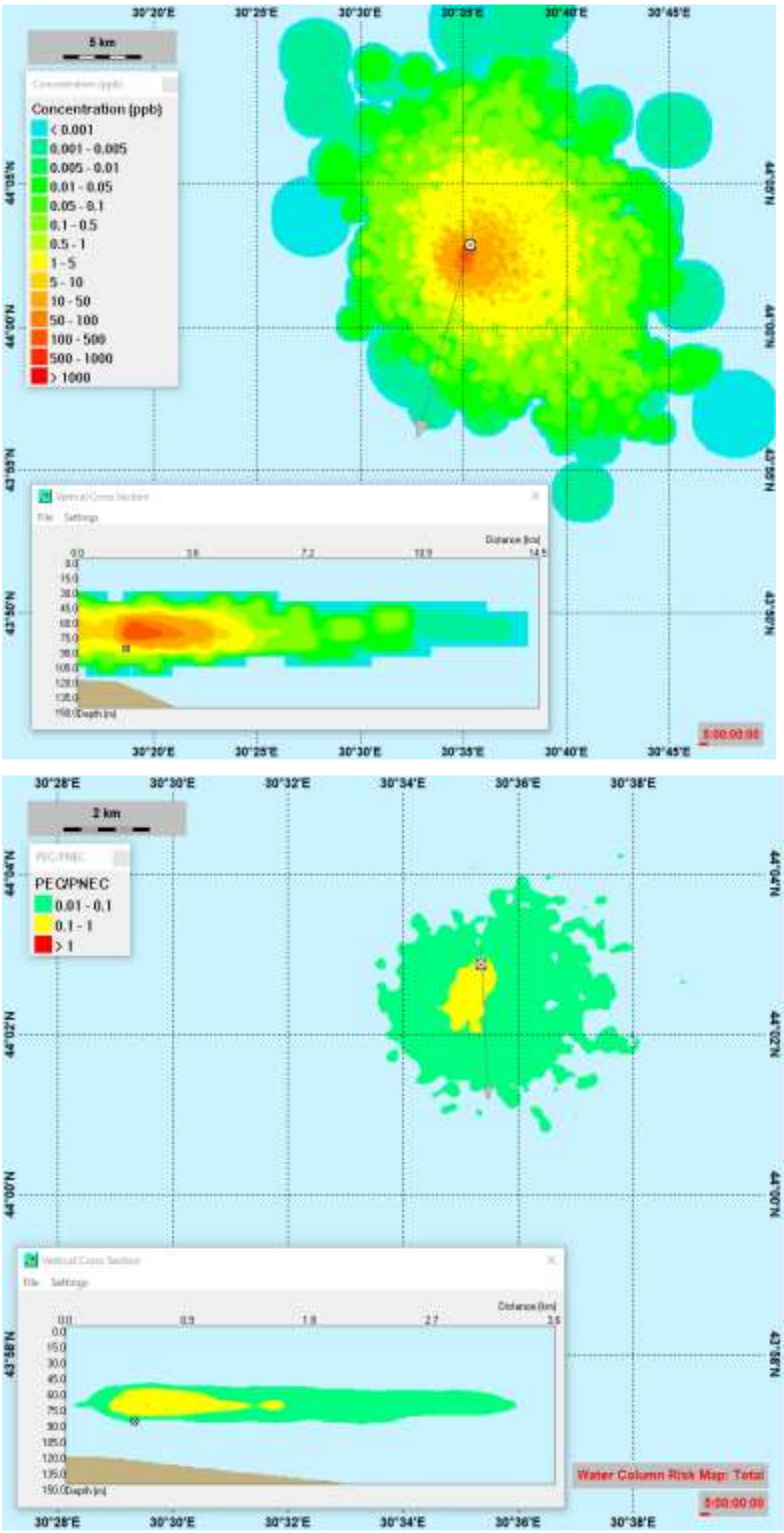


Figure A-6-6 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 1a.

E.3.2 Caisson discharge, chemical package Schlumberger, September (warm season)

September	Schlumberger	90 m	500 mm

E.3.2.1 Case 2a: High-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

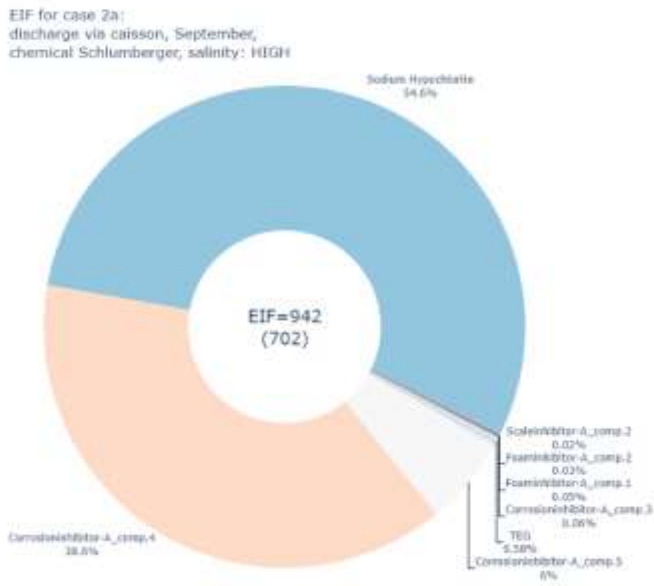
Discharge information for Case 2a.

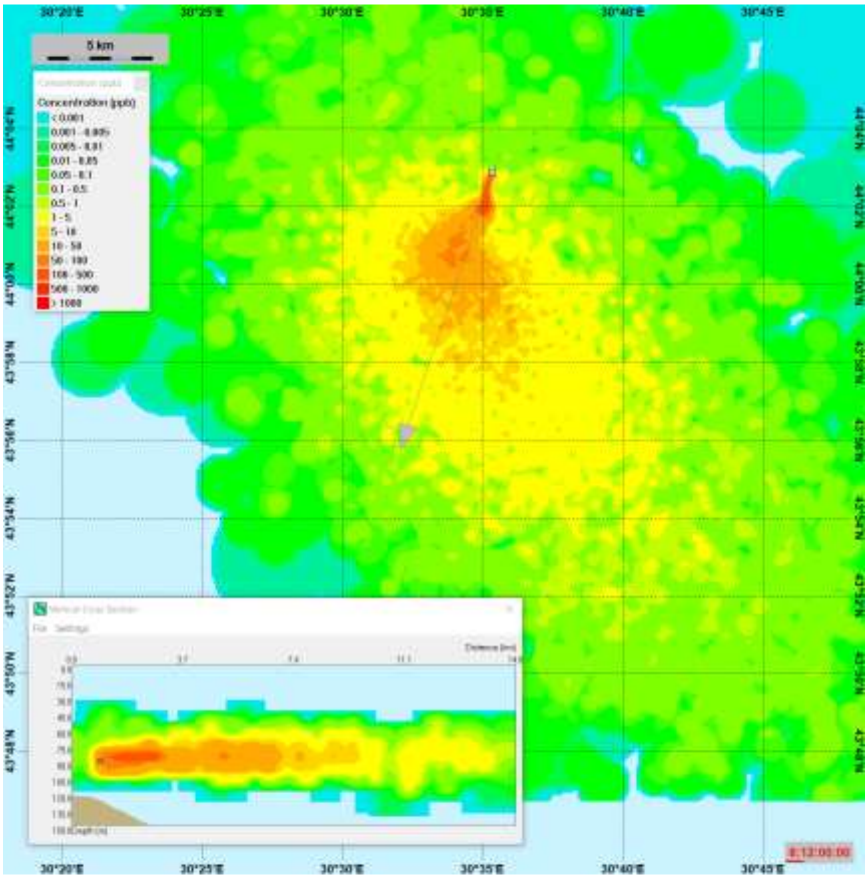
Neptun Deep Caisson	**Case 2a**
Release rate (m^3/hour):	382.32
Discharge temperature °C:	22.32
Resulting salinity (mg/L):	20.20

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 2a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2a	Schlumberger	caisson	September	HIGH	942	702	Foaminhibitor-A_comp.1	1.52	125.00	0.05%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Foaminhibitor-A_comp.2	0.17	21.00	0.03%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Scaleinhibitor-A_comp.2	1.01	178.00	0.02%	0
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.3	2.53	130.00	0.06%	1
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.4	0.84	0.20	38.62%	364
2a	Schlumberger	caisson	September	HIGH	942	702	Corrosioninhibitor-A_comp.5	0.84	0.96	6.00%	57
2a	Schlumberger	caisson	September	HIGH	942	702	TEG	331.33	3000.00	0.58%	5
2a	Schlumberger	caisson	September	HIGH	942	702	Sodium Hypochlorite	1.66	0.04	54.64%	515




5 km
Concentration (ppb)
< 0.001
0.001 - 0.005
0.005 - 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.5
0.5 - 1
1 - 5
5 - 10
10 - 50
50 - 100
100 - 500
500 - 1000
> 1000
30°20'E
30°25'E
30°30'E
30°35'E
30°40'E
30°45'E
Vertical Cross Section
Distance (km)
8:12:00:00

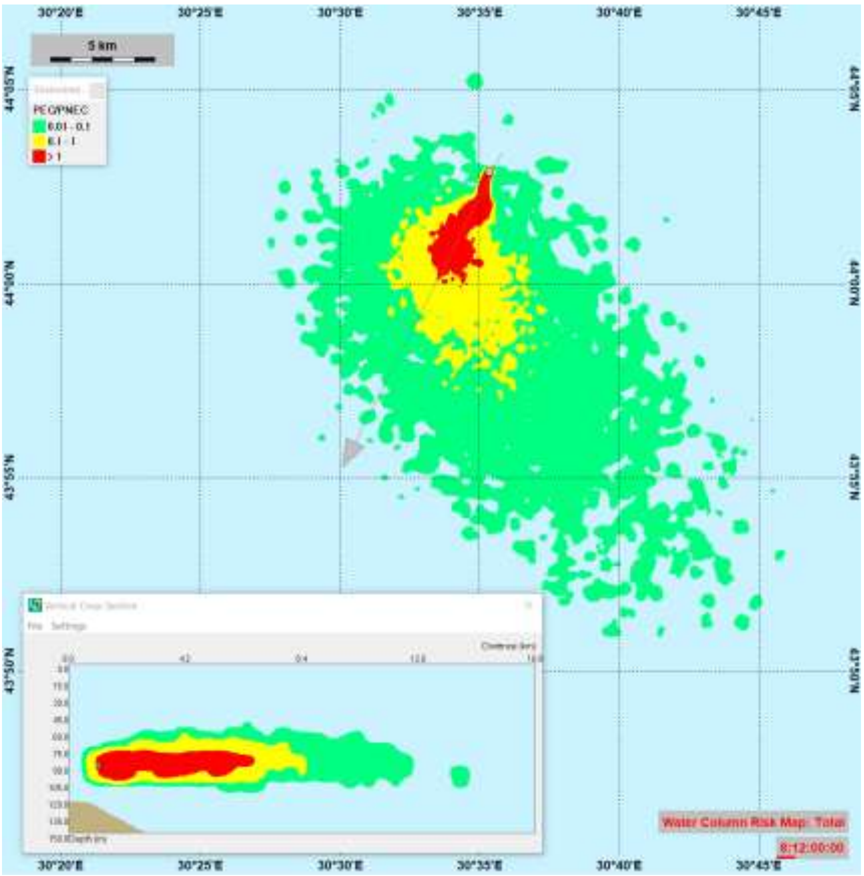

5 km
PEC/PNEC
0.01 - 0.1
0.1 - 1
> 1
30°20'E
30°25'E
30°30'E
30°35'E
30°40'E
30°45'E
44°00'N
43°55'N
43°50'N
Vertical Cross Section
Distance (km)
Water Column Risk Map: Total
8:12:00:00

Figure A-6-7 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 1a.

E.3.2.2 Case 2b: Low-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

September	Schlumberger	90 m	500 mm

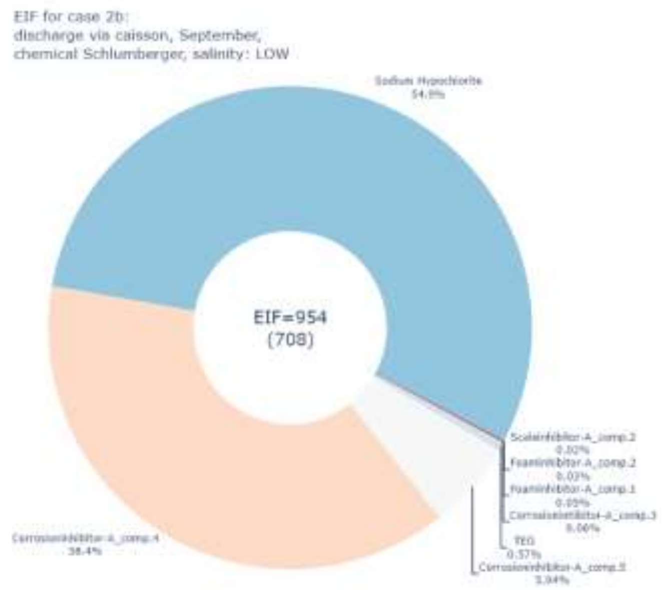
Discharge information for Case 2b.

Neptun Deep Caisson	**Case 2b**
Release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 2b.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2b	Schlumberger	caisson	September	LOW	954	708	Foaminhibitor-A_comp.1	1.52	125.00	0.05%	0
2b	Schlumberger	caisson	September	LOW	954	708	Foaminhibitor-A_comp.2	0.17	21.00	0.03%	0
2b	Schlumberger	caisson	September	LOW	954	708	Scaleinhibitor-A_comp.2	1.01	178.00	0.02%	0
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.3	2.53	130.00	0.06%	1
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.4	0.84	0.20	38.38%	366
2b	Schlumberger	caisson	September	LOW	954	708	Corrosioninhibitor-A_comp.5	0.84	0.96	5.94%	57
2b	Schlumberger	caisson	September	LOW	954	708	TEG	331.33	3000.00	0.57%	5
2b	Schlumberger	caisson	September	LOW	954	708	Sodium Hypochlorite	1.66	0.04	54.95%	524



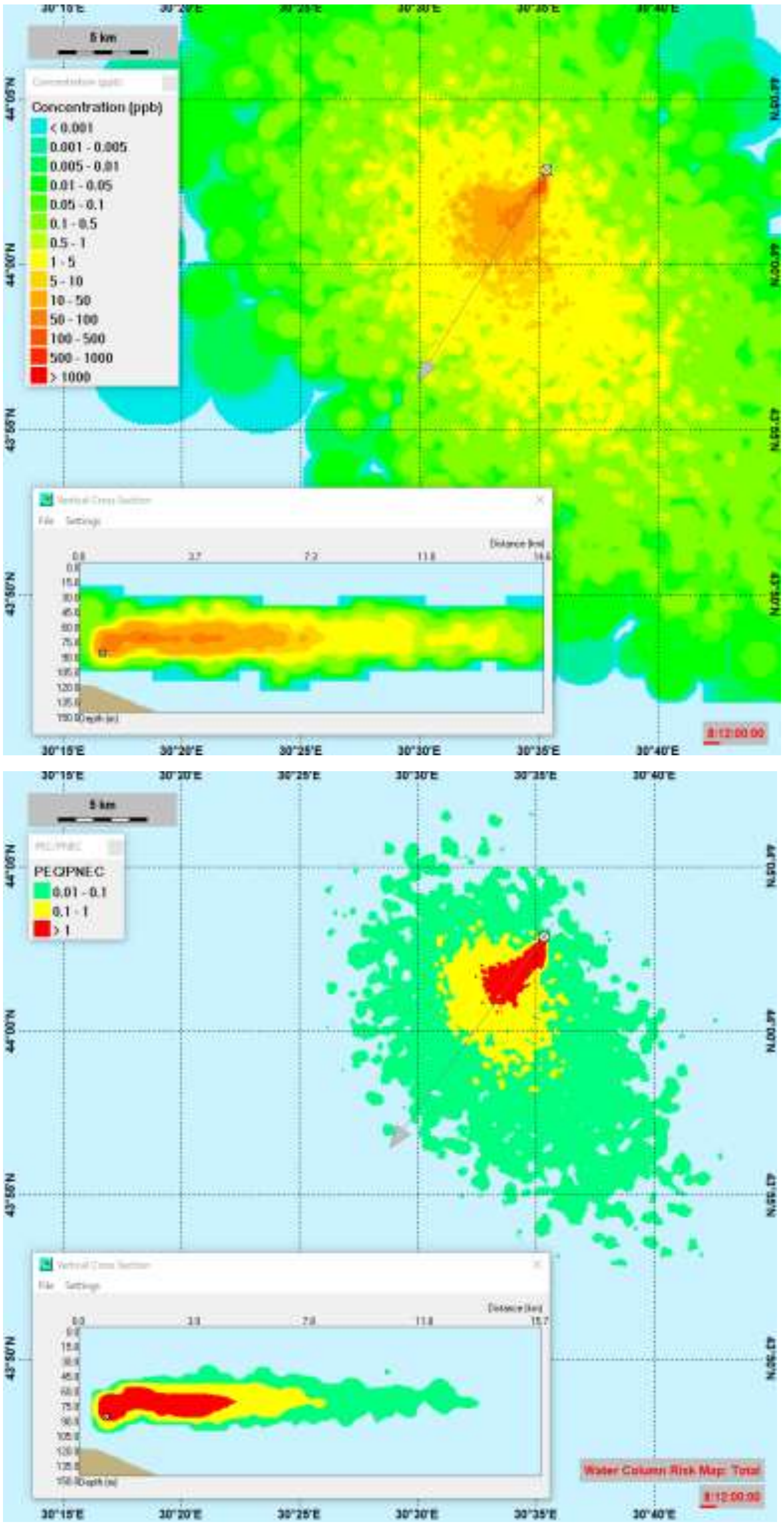


Figure A-6-8 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 2b.

E.3.2.3 Case 2c: High-salinity PW, no Sodium Hypochlorite at discharge

September	Schlumberger	90 m	500 mm

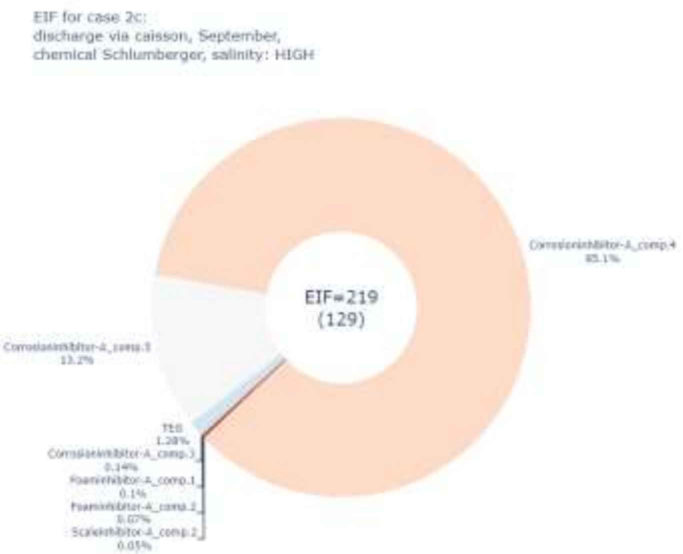
Discharge information and calculated EIF for Case 2c.

Neptun Deep Caisson	**Case 2c**
PW release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	20.2036

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 2c.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2c	Schlumberger	caisson	September	HIGH	219	129	Foaminhibitor-A_comp.1	1.52	125.00	0.10%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.3	2.53	130.00	0.14%	0
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.4	0.84	0.20	85.13%	186
2c	Schlumberger	caisson	September	HIGH	219	129	Corrosioninhibitor-A_comp.5	0.84	0.96	13.23%	29
2c	Schlumberger	caisson	September	HIGH	219	129	TEG	331.33	3000.00	1.28%	3



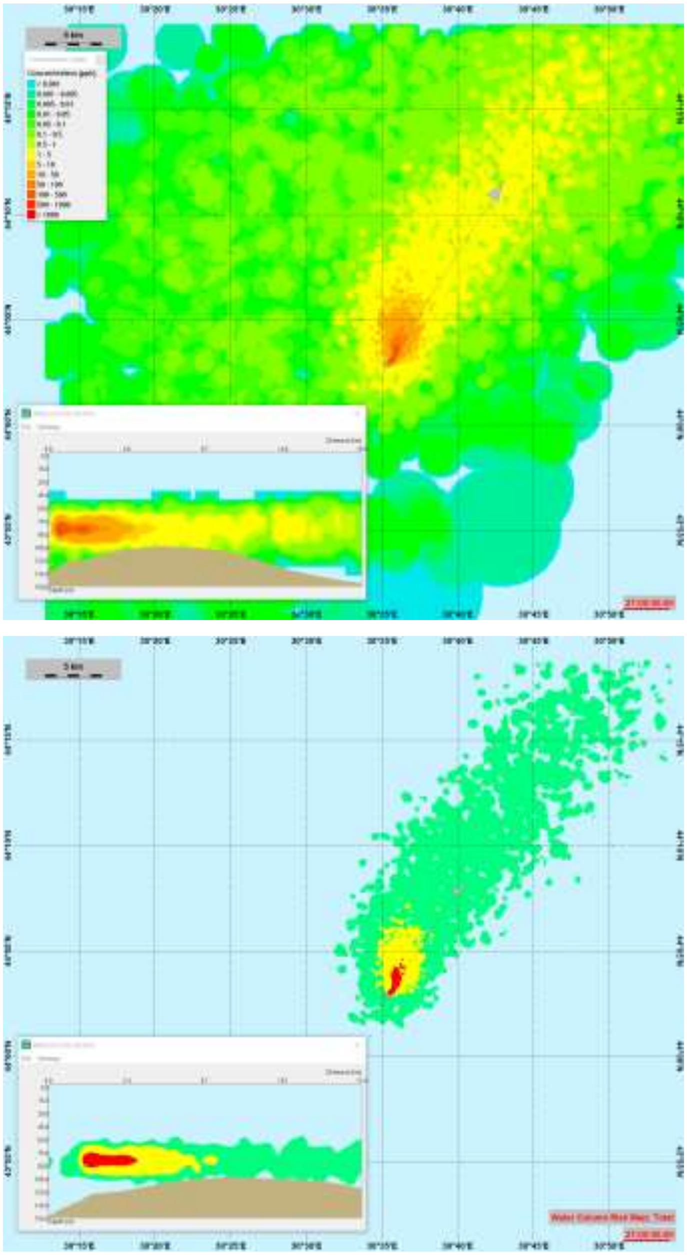


Figure A-6-9 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 2c.

E.3.2.4 Case 2d: Low-salinity PW, no Sodium Hypochlorite at discharge

September	Schlumberger	90 m	500 mm

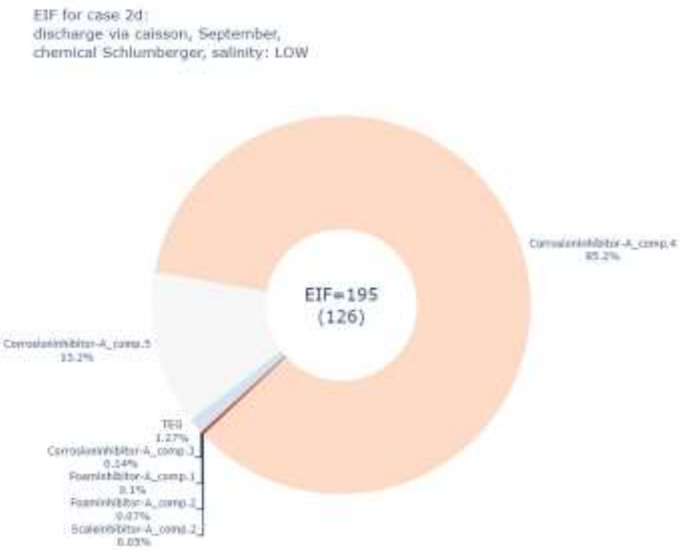
Discharge information for Case 2d.

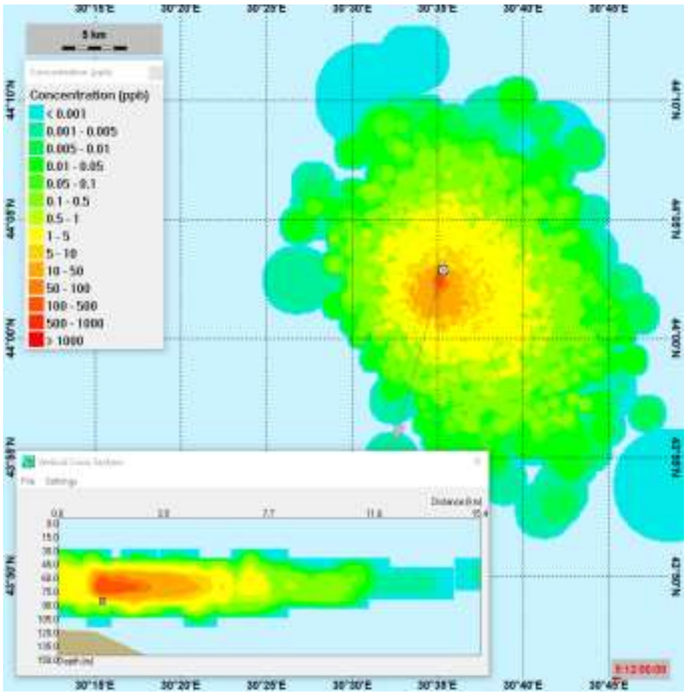
Neptun Deep Caisson	**Case 2d**
PW release rate (m3/hour):	382.32
Temperature °C:	22.32
Salinity (mg/L):	16.6223

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 2d.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
2d	Schlumberger	caisson	September	LOW	195	126	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.3	2.53	130.00	0.14%	0
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.4	0.84	0.20	85.19%	166
2d	Schlumberger	caisson	September	LOW	195	126	Corrosioninhibitor-A_comp.5	0.84	0.96	13.18%	26
2d	Schlumberger	caisson	September	LOW	195	126	TEG	331.33	3000.00	1.27%	2





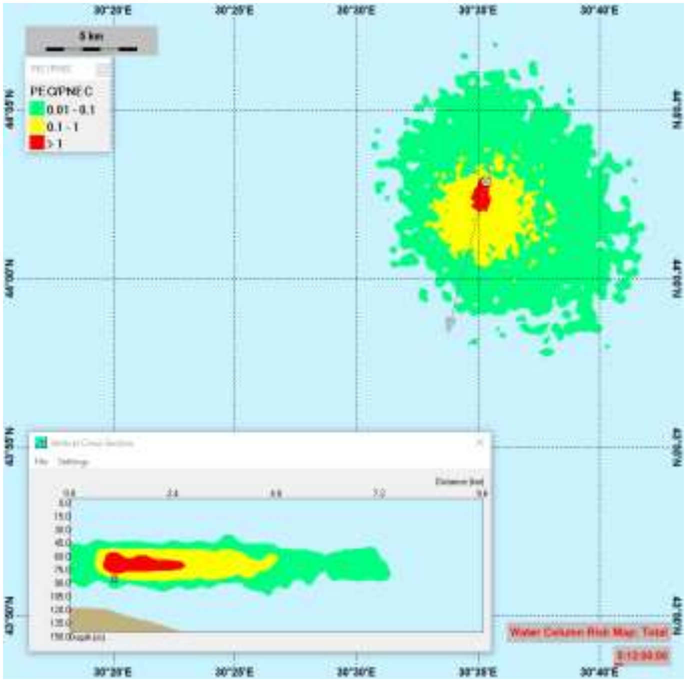


Figure A-6-10 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 2d.

E.3.3 Discharge from pipeline, chemical package ChampionX, September (warm season)

September	ChampionX	130 m	300 mm

E.3.3.1 Case 3a: High-salinity PW

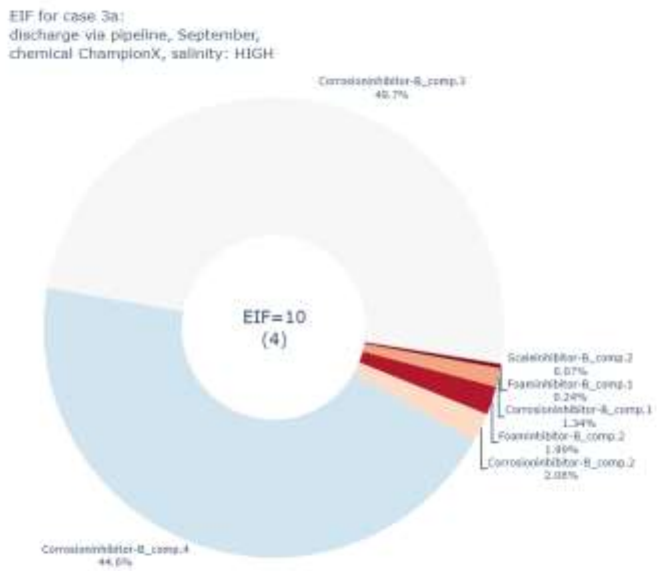
Discharge information for Case 3a.

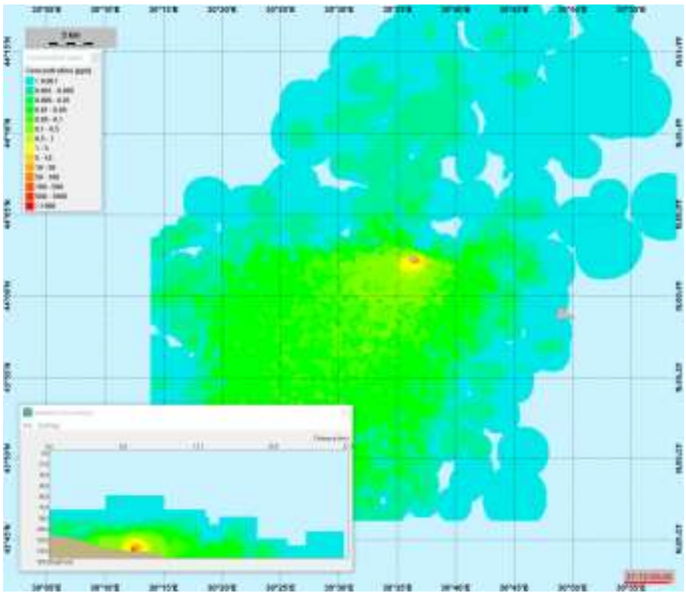
Neptun Deep Pipeline	**Case 3a**
Position	44.037899N, 30.6065998E
Release depth (m):	130 m
PW discharge diameter (m):	0.3
PW release rate (m³/hour):	64.45
Temperature °C:	33.4
Salinity (mg/L):	28

HIGH

Water column EIF results for Case 3a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3a	ChampionX	pipeline	September	HIGH	10	4	Foaminhibitor-B_comp.1	6.00	500.00	0.24%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Foaminhibitor-B_comp.2	4.00	51.78	1.99%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Scaleinhibitor-B_comp.2	4.00	1000.00	0.07%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.1	25.60	500.00	1.34%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.2	1.20	18.00	2.06%	0
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.3	11.24	9.00	49.73%	5
3a	ChampionX	pipeline	September	HIGH	10	4	Corrosioninhibitor-B_comp.4	2.20	2.00	44.57%	4





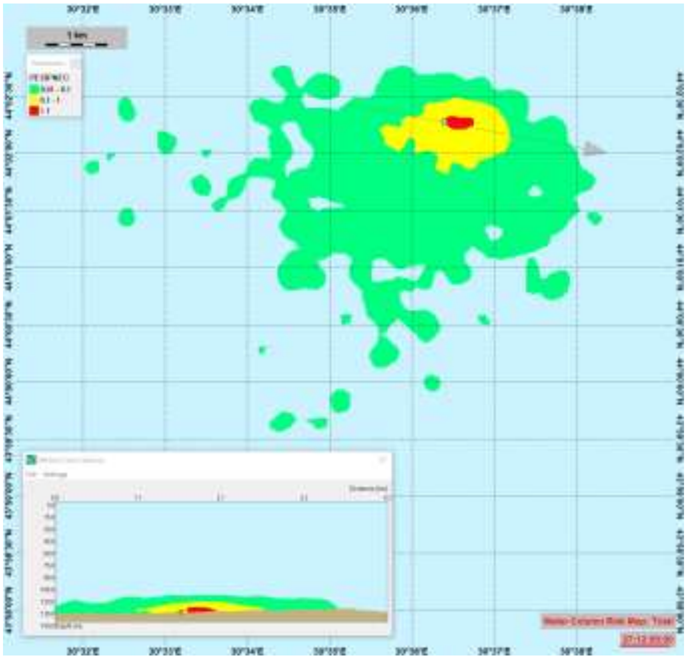


Figure A-6-11 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 3a

E.3.3.2 Case 3b: Low-salinity PW

September	ChampionX	130 m	300 mm

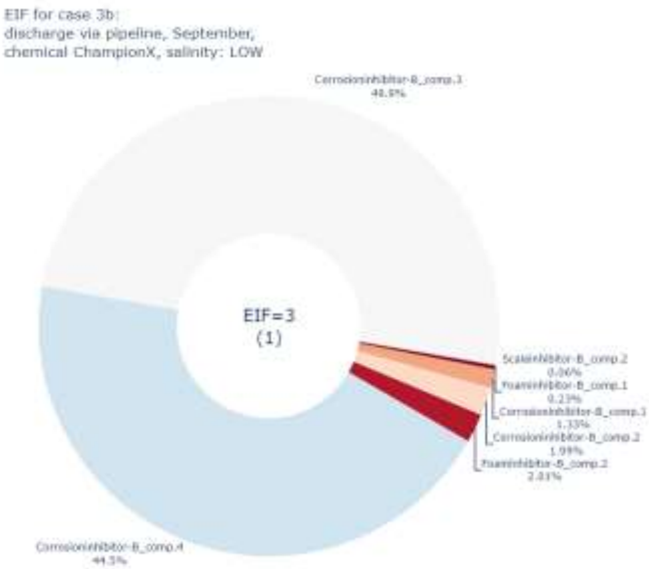
Discharge information for Case 3b.

Neptun Deep Pipeline	**Case 3b**
PW release rate (m^3/hour):	64.45
Temperature °C:	33.4
Salinity (mg/L):	28

LOW

Water column EIF results for Case 3b.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3b	ChampionX	pipeline	September	LOW	3	1	Foaminhibitor-B_comp.1	6.00	500.00	0.23%	0
3b	ChampionX	pipeline	September	LOW	3	1	Foaminhibitor-B_comp.2	4.00	51.78	2.01%	0
3b	ChampionX	pipeline	September	LOW	3	1	Scaleinhibitor-B_comp.2	4.00	1000.00	0.06%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.1	25.60	500.00	1.33%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.2	1.20	18.00	1.99%	0
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.3	11.24	9.00	49.93%	1
3b	ChampionX	pipeline	September	LOW	3	1	Corrosioninhibitor-B_comp.4	2.20	2.00	44.45%	1



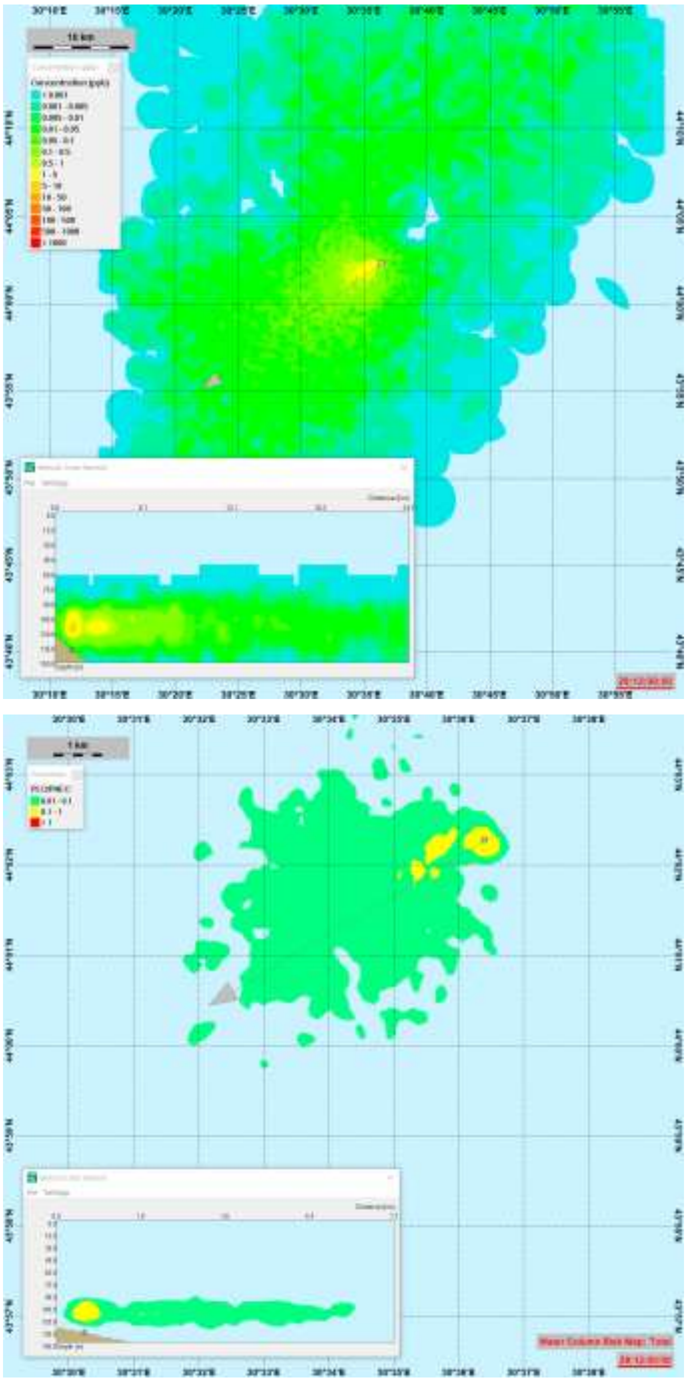


Figure A-6-12 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 3b.

E.3.4 Discharge from pipeline, chemical package Schlumberger, September (warm season)

September	Schlumberger	130 m	300 mm

E.3.4.1 Case 3c: High-salinity PW

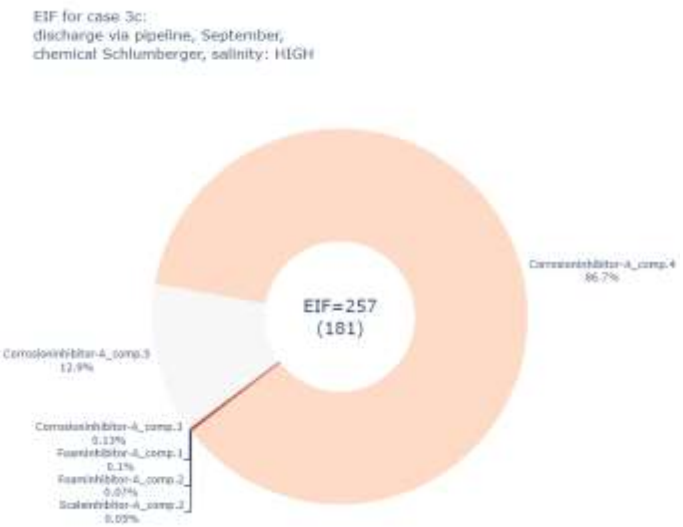
Discharge information for Case 3c.

Neptun Deep Pipeline	**Case 3c**
PW release rate (m3/hour):	64.45
Temperature °C:	33.4
Salinity (mg/L):	28

HIGH

Water column EIF results for Case 3c.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3c	Schlumberger	pipeline	September	HIGH	257	181	Foaminhibitor-A_comp.1	9.00	125.00	0.10%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Foaminhibitor-A_comp.2	1.00	21.00	0.07%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Scaleinhibitor-A_comp.2	6.00	178.00	0.05%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.3	15.00	130.00	0.13%	0
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.4	5.00	0.20	86.73%	223
3c	Schlumberger	pipeline	September	HIGH	257	181	Corrosioninhibitor-A_comp.5	5.00	0.96	12.92%	33



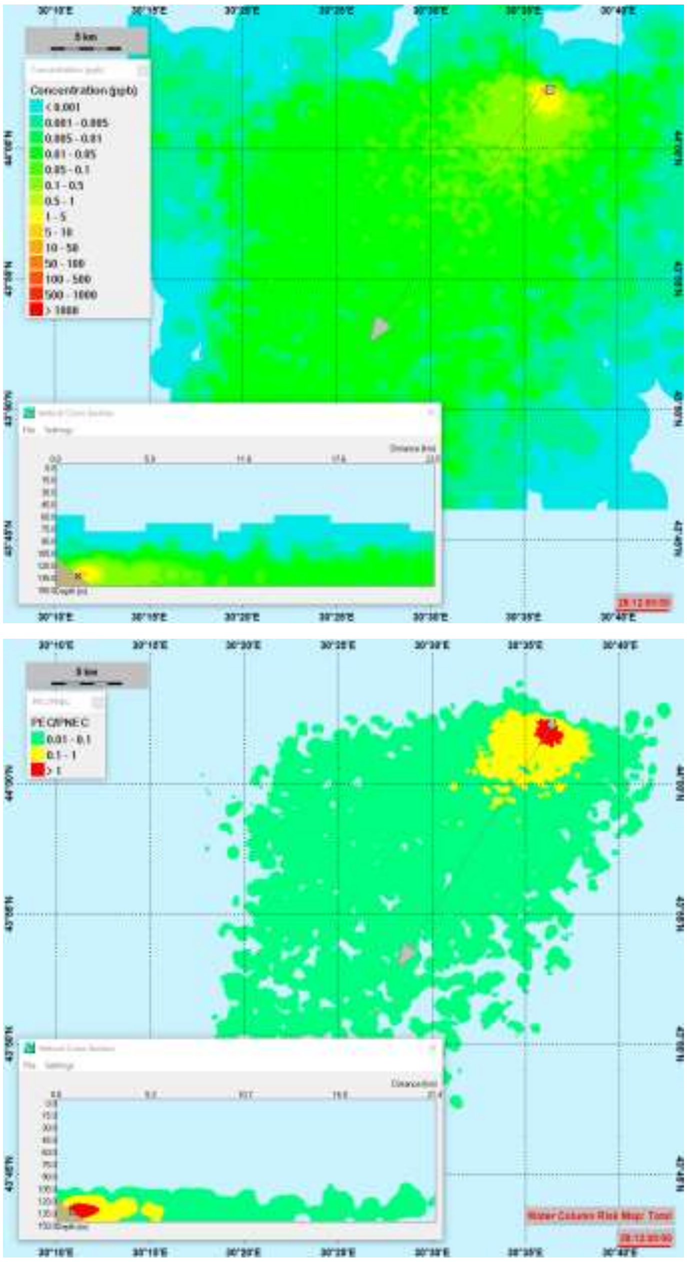


Figure A-6-13 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 3c.

E.3.4.2 Case 3d: Low-salinity PW

September	Schlumberger	130 m	300 mm

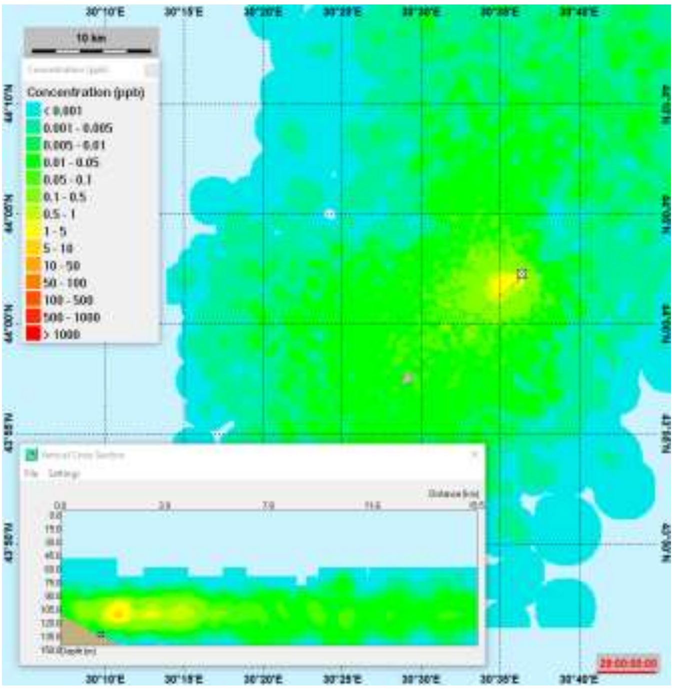
Discharge information for Case 3d.

Neptun Deep Pipeline	Case 3d
PW release rate (m^3/hour):	64.45
Temperature °C:	33.4
Salinity (mg/L):	28

LOW

Water column EIF results for Case 3d.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
3d	Schlumberger	pipeline	September	LOW	254	156	Foaminhibitor-A_comp.1	9.00	125.00	0.10%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Foaminhibitor-A_comp.2	1.00	21.00	0.07%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Scaleinhibitor-A_comp.2	6.00	178.00	0.05%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.3	15.00	130.00	0.14%	0
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.4	5.00	0.20	86.54%	220
3d	Schlumberger	pipeline	September	LOW	254	156	Corrosioninhibitor-A_comp.5	5.00	0.96	13.11%	33



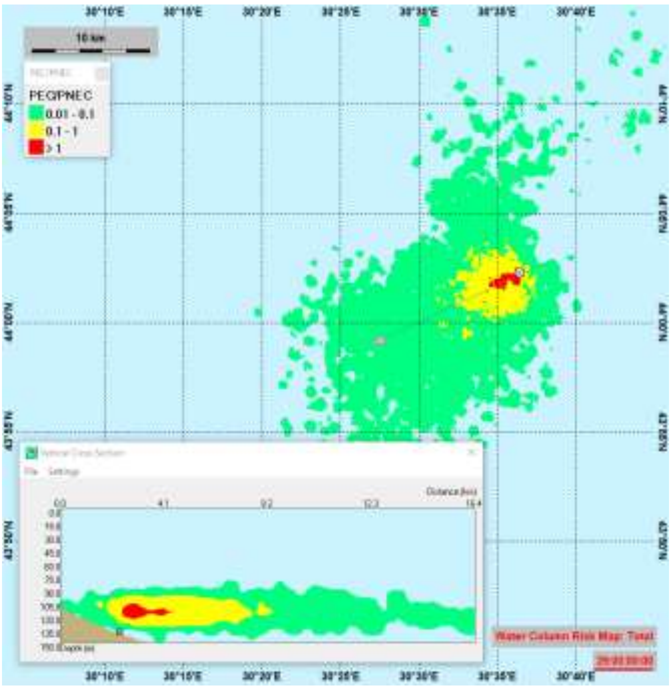


Figure A-6-14 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 3d.

E.3.5 Caisson discharge, chemical package ChampionX, April (cold season)

dry			Ø
April	ChampionX	90 m	500 mm

E.3.5.1 Case 4a: High-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

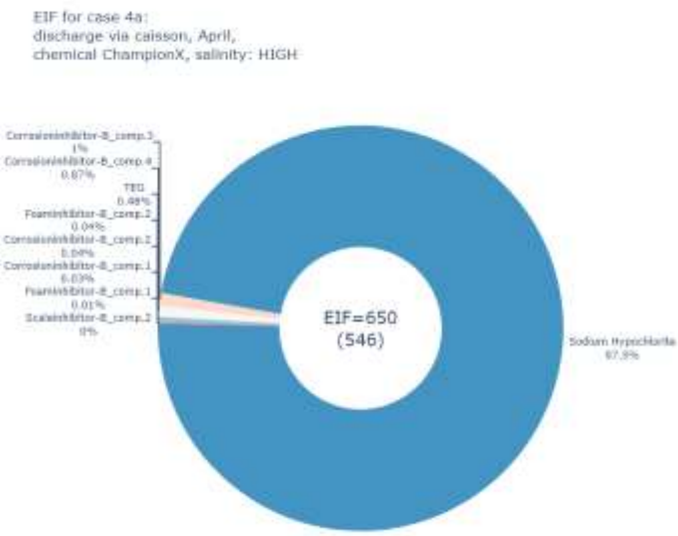
Discharge information for Case 4a.

Neptun Deep Caisson	**Case 4a**
Release rate (m^3/hour):	382.32
Discharge temperature °C:	22.32
Resulting salinity (mg/L):	20.20

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 4a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
4a	ChampionX	caisson	April	HIGH	650	546	Foaminhibitor-B_comp.1	1.01	500.00	0.01%	0
4a	ChampionX	caisson	April	HIGH	650	546	Foaminhibitor-B_comp.2	0.67	51.78	0.04%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.1	4.32	500.00	0.03%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.2	0.20	18.00	0.04%	0
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.3	1.89	9.00	1.00%	6
4a	ChampionX	caisson	April	HIGH	650	546	Corrosioninhibitor-B_comp.4	0.37	2.00	0.87%	6
4a	ChampionX	caisson	April	HIGH	650	546	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4a	ChampionX	caisson	April	HIGH	650	546	TEG	331.93	3000.00	0.48%	3
4a	ChampionX	caisson	April	HIGH	650	546	Sodium Hypochlorite	1.66	0.04	97.54%	634



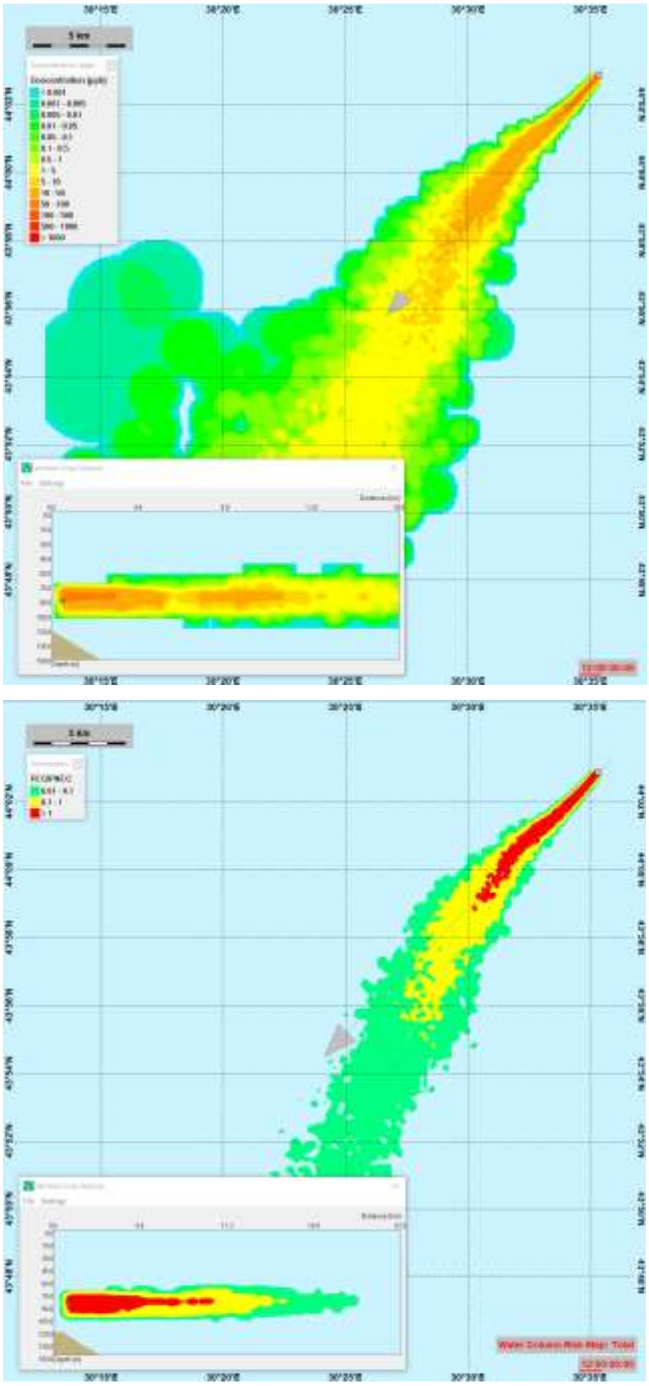


Figure A-6-15 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 4a

E.3.5.2 Case 4b: Low-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

dry			
April	ChampionX	90 m	500 mm

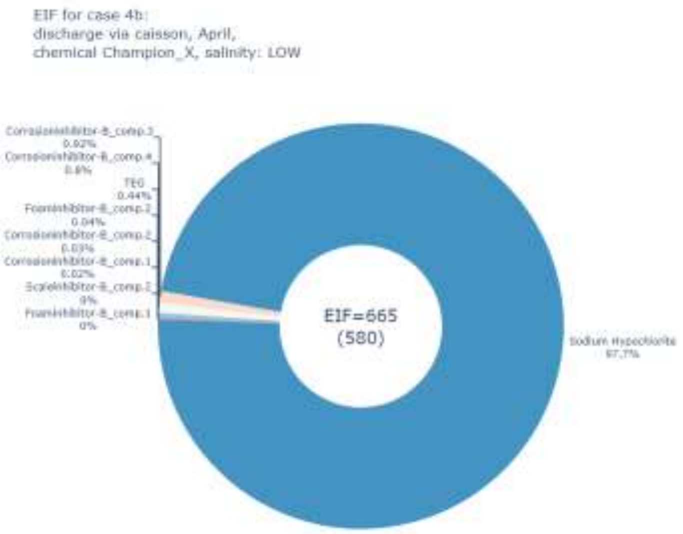
Discharge information for Case 4b.

Neptun Deep Caisson	**Case 4b**
Release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Table with water column EIF results for Case 4b.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
4b	ChampionX	caisson	April	LOW	665	580	Foaminhibitor-B_comp.1	1.01	500.00	0.00%	0
4b	ChampionX	caisson	April	LOW	665	580	Foaminhibitor-B_comp.2	0.67	51.78	0.04%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.1	4.32	500.00	0.02%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.2	0.20	18.00	0.03%	0
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.3	1.89	9.00	0.92%	6
4b	ChampionX	caisson	April	LOW	665	580	Corrosioninhibitor-B_comp.4	0.37	2.00	0.80%	5
4b	ChampionX	caisson	April	LOW	665	580	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4b	ChampionX	caisson	April	LOW	665	580	TEG	331.93	3000.00	0.44%	3
4b	ChampionX	caisson	April	LOW	665	580	Sodium Hypochlorite	1.66	0.04	97.73%	650



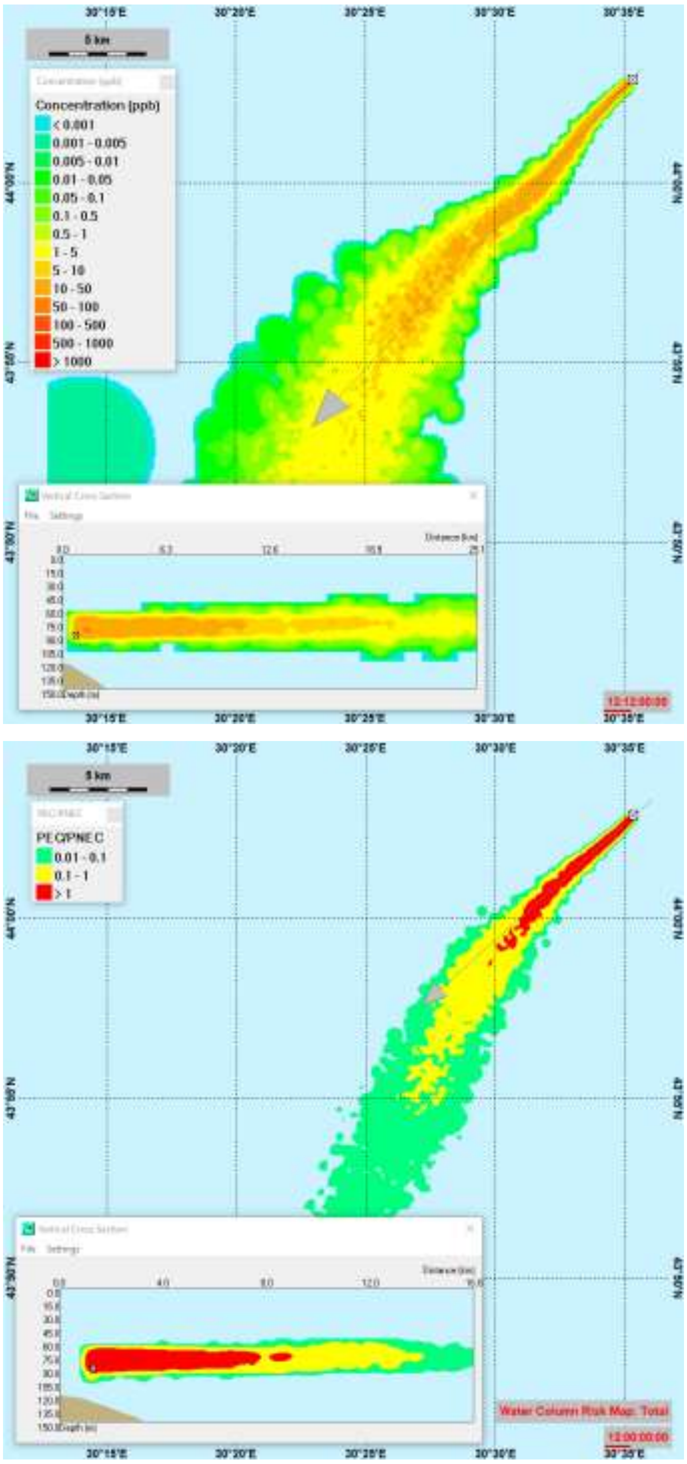


Figure A-6-16 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 4b.

E.3.5.3 Case 4c: High-salinity PW, no Sodium Hypochlorite at discharge

dry			
April	ChampionX	90 m	500 mm

Discharge information for Case 4c.

Neptun Deep Caisson	**Case 4c**
PW release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	20.2036

HIGH	Cooling water with Sodium Hypochlorite

Table with water column EIF results for Case 4c.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
4c	ChampionX	caisson	April	HIGH	0	0	Foaminhibitor-B_comp.1	1.01	500.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Foaminhibitor-B_comp.2	0.67	51.78	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp.1	4.32	500.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp.2	0.20	18.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp.3	1.89	9.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Corrosioninhibitor-B_comp.4	0.37	2.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4c	ChampionX	caisson	April	HIGH	0	0	TEG	331.93	3000.00	0.00%	0

No Pie chart as the EIF is zero.

E.3.5.4 Case 4d: Low-salinity PW, no Sodium Hypochlorite at discharge

dry			Ø
April	ChampionX	90 m	500 mm

Table 7 Discharge information for Case 4d.

Neptun Deep Caisson	**Case 4d**
PW release rate (m3/hour):	382.32
Temperature °C:	22.32
Salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Table with water column EIF results for Case 4d.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
4d	ChampionX	caisson	April	LOW	0	0	Foaminhibitor-B_comp.1	1.01	500.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Foaminhibitor-B_comp.2	0.67	51.78	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp.1	4.32	500.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp.2	0.20	18.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp.3	1.89	8.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Corrosioninhibitor-B_comp.4	0.37	2.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	Scaleinhibitor-B_comp.2	0.67	1000.00	0.00%	0
4d	ChampionX	caisson	April	LOW	0	0	TEG	331.93	3000.00	0.00%	0

No Pie chart as the EIF is zero.

E.3.6 Caisson discharge, chemical package Schlumberger, April (cold season)

dry			
April	Schlumberger	90 m	500 mm

E.3.6.1 Case 5a: High-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

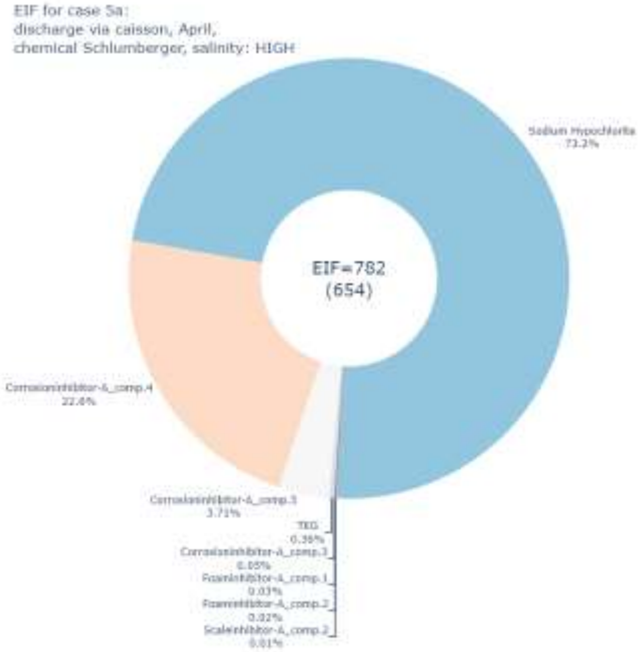
Discharge information for Case 5a.

Neptun Deep Caisson	**Case 5a**
Release rate (m^3/hour):	382.32
Discharge temperature °C:	22.32
Resulting salinity (mg/L):	20.20

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 5a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
5a	Schlumberger	caisson	April	HIGH	782	654	Foaminhibitor-A_comp.1	1.52	125.00	0.03%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Foaminhibitor-A_comp.2	0.17	21.00	0.02%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Scaleinhibitor-A_comp.2	1.01	178.00	0.01%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.3	2.53	130.00	0.05%	0
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.4	0.84	0.20	22.62%	177
5a	Schlumberger	caisson	April	HIGH	782	654	Corrosioninhibitor-A_comp.5	0.84	0.96	3.71%	29
5a	Schlumberger	caisson	April	HIGH	782	654	TEG	331.33	3000.00	0.36%	3
5a	Schlumberger	caisson	April	HIGH	782	654	Sodium Hypochlorite	1.66	0.04	73.21%	573



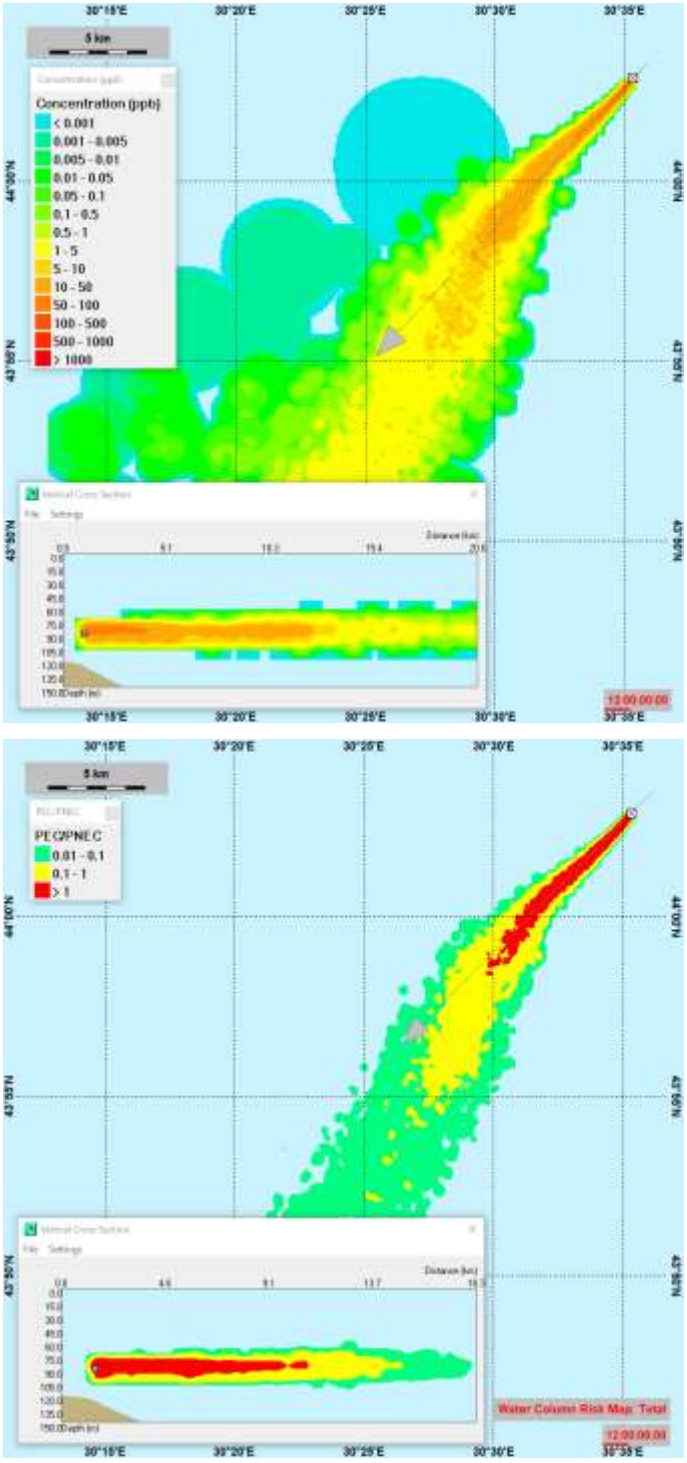


Figure A-6-17 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 5a

E.3.6.2 Case 5b: Low-salinity PW, 2 ppm Sodium Hypochlorite in cooling water

dry			
April	Schlumberger	90 m	500 mm

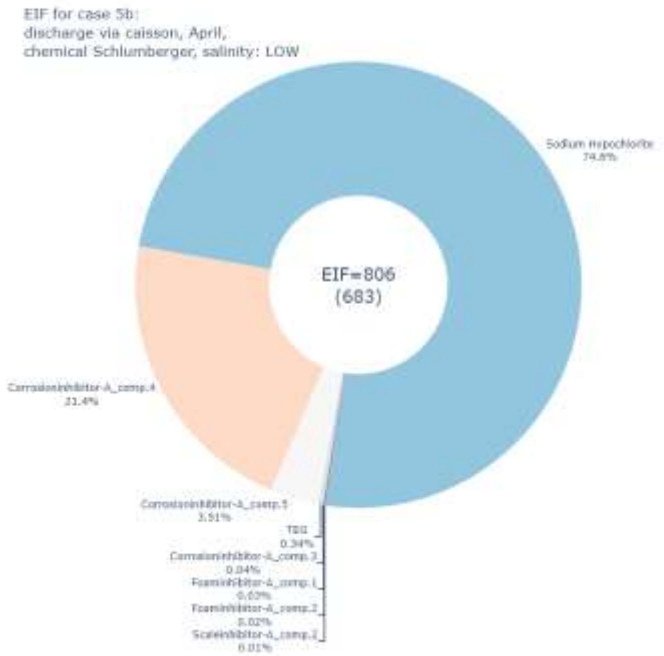
Discharge information for Case 5b.

Neptun Deep Caisson	**Case 5b**
Release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 5b.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
5b	Schlumberger	caisson	April	LOW	806	683	Foaminhibitor-A_comp.1	1.52	125.00	0.03%	0
5b	Schlumberger	caisson	April	LOW	806	683	Foaminhibitor-A_comp.2	0.17	21.00	0.02%	0
5b	Schlumberger	caisson	April	LOW	806	683	Scaleinhibitor-A_comp.2	1.01	178.00	0.01%	0
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.3	2.53	130.00	0.04%	0
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.4	0.84	0.20	21.40%	172
5b	Schlumberger	caisson	April	LOW	806	683	Corrosioninhibitor-A_comp.5	0.84	0.96	3.51%	28
5b	Schlumberger	caisson	April	LOW	806	683	TEG	331.33	3000.00	0.34%	3
5b	Schlumberger	caisson	April	LOW	806	683	Sodium Hypochlorite	1.66	0.04	74.64%	602



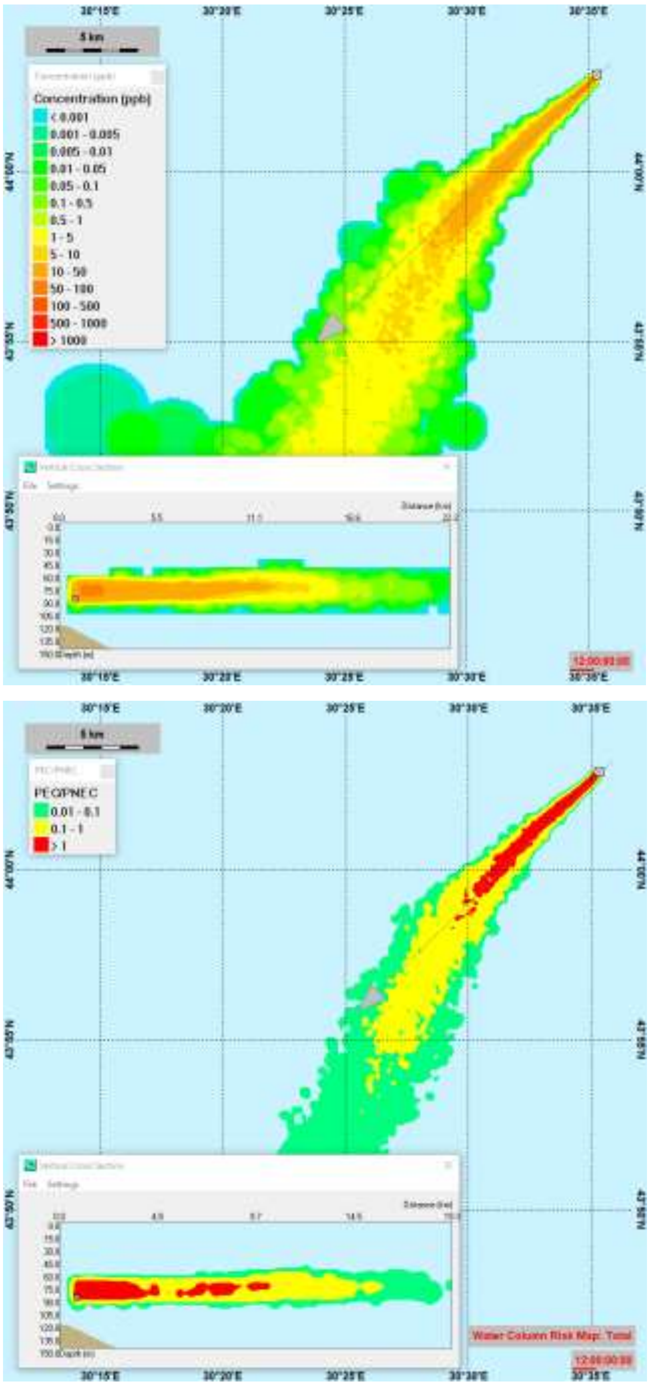


Figure A-6-18 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 5b

E.3.6.3 Case 5c: High-salinity PW, no Sodium Hypochlorite at discharge

dry			
April	Schlumberger	90 m	500 mm

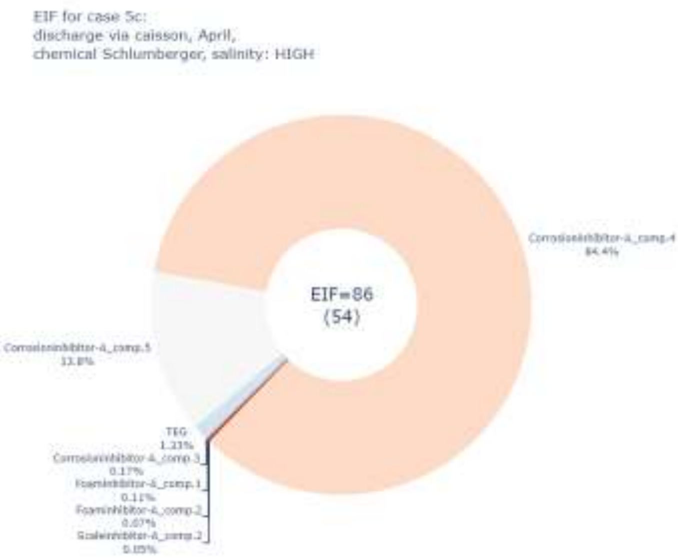
Discharge information for Case 5c.

Neptun Deep Caisson	**Case 5c**
PW release rate (m^3/hour):	382.32
Resulting discharge temperature °C:	22.32
Resulting discharge salinity (mg/L):	20.2036

HIGH	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 5c.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
5c	Schlumberger	caisson	April	HIGH	86	54	Foaminhibitor-A_comp.1	1.52	125.00	0.11%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.3	2.53	130.00	0.17%	0
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.4	0.84	0.20	84.42%	73
5c	Schlumberger	caisson	April	HIGH	86	54	Corrosioninhibitor-A_comp.5	0.84	0.96	13.85%	12
5c	Schlumberger	caisson	April	HIGH	86	54	TEG	331.33	3000.00	1.33%	1



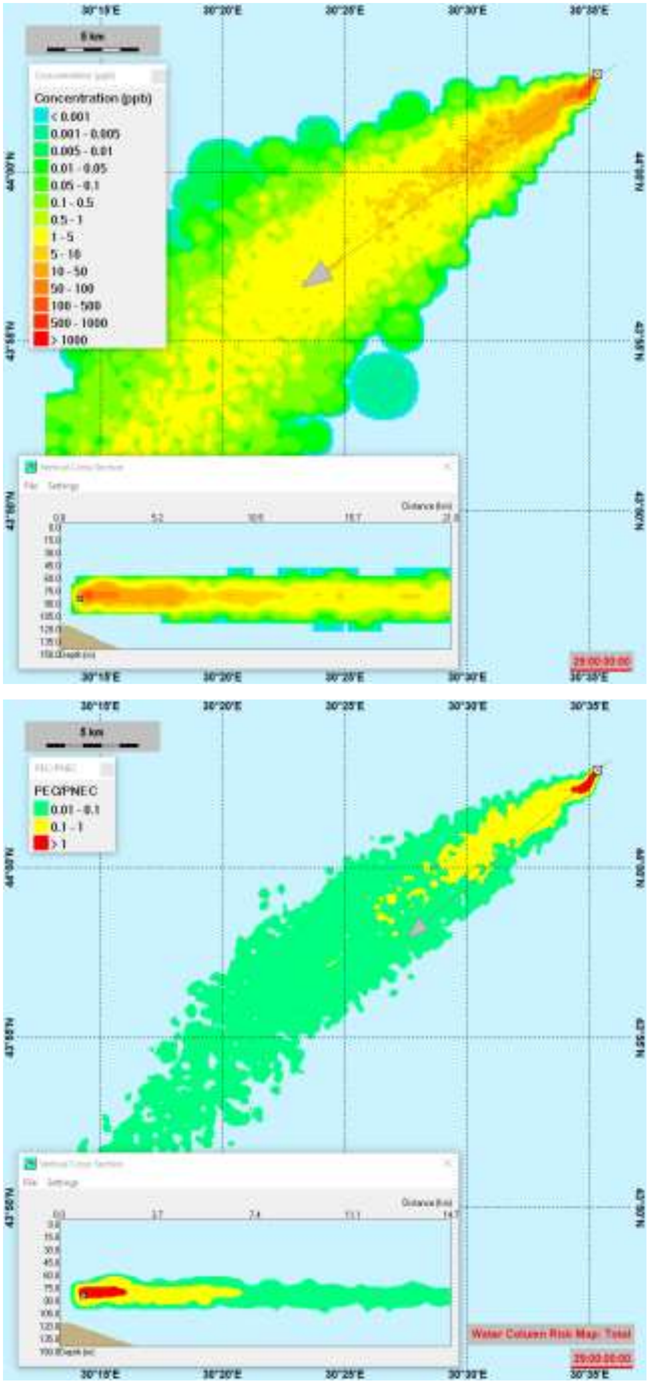


Figure A-6-19 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 5c.

E.3.6.4 Case 5d: Low-salinity PW, no Sodium Hypochlorite at discharge

dry			
April	Schlumberger	90 m	500 mm

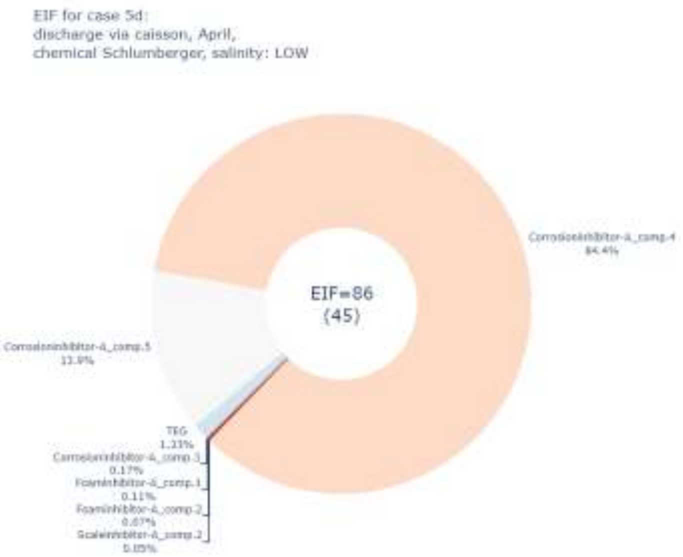
Discharge information for Case 5d.

Neptun Deep Caisson	**Case 5d**
PW release rate (m3/hour):	382.32
Temperature °C:	22.32
Salinity (mg/L):	16.62

LOW	Cooling water with Sodium Hypochlorite

Water column EIF results for Case 5d.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
5d	Schlumberger	caisson	April	LOW	86	45	Foaminhibitor-A_comp.1	1.52	125.00	0.11%	0
5d	Schlumberger	caisson	April	LOW	86	45	Foaminhibitor-A_comp.2	0.17	21.00	0.07%	0
5d	Schlumberger	caisson	April	LOW	86	45	Scaleinhibitor-A_comp.2	1.01	178.00	0.05%	0
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.3	2.53	130.00	0.17%	0
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.4	0.84	0.20	84.41%	73
5d	Schlumberger	caisson	April	LOW	86	45	Corrosioninhibitor-A_comp.5	0.84	0.96	13.86%	12
5d	Schlumberger	caisson	April	LOW	86	45	TEG	331.33	3000.00	1.33%	1



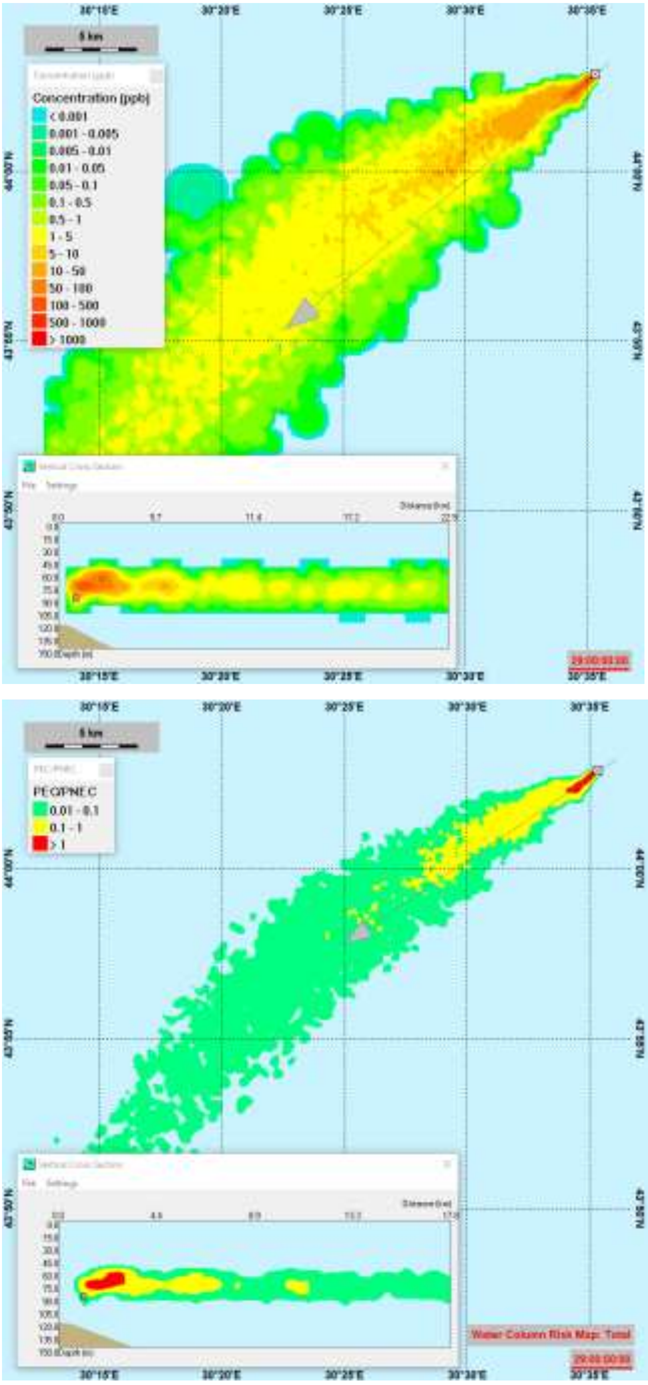
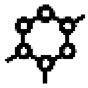


Figure A-6-20 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 5d.

E.3.7 Discharge from pipeline, chemical package ChampionX, April (cold season)

 dry			Ø
April	ChampionX	130 m	300 mm

E.3.7.1 Case 6a: High-salinity PW

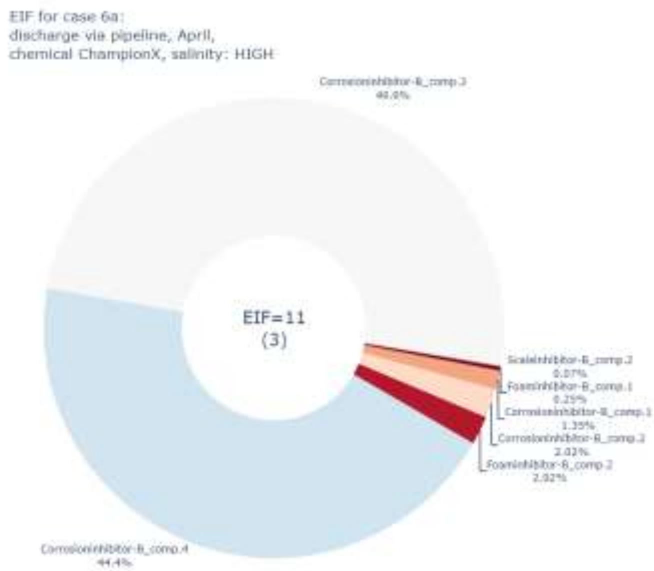
Discharge information for Case 6a.

Neptun Deep Pipeline	**Case 6a**
Position	44.037899N, 30.6065998E
Release depth (m):	130 m
PW discharge diameter (m):	0.3
PW release rate (m^3/hour):	64.45
Temperature °C:	33.4
Salinity (mg/L):	28


HIGH

Water column EIF results for Case 6a.

Case No	Chemical	via	Month	Salinity	max.EIF	avg.EIF	Components	Concentration [ppm]	PNEC [ppb]	Contribution to risk	Contribution to EIF
6a	ChampionX	pipeline	April	HIGH	11	3	Foaminhibitor-B_comp.1	6.00	500.00	0.25%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Foaminhibitor-B_comp.2	4.00	51.78	2.02%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Scaleinhibitor-B_comp.2	4.00	1000.00	0.07%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.1	25.60	500.00	1.35%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.2	1.20	18.00	2.02%	0
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.3	11.24	9.00	49.86%	5
6a	ChampionX	pipeline	April	HIGH	11	3	Corrosioninhibitor-B_comp.4	2.20	2.00	44.44%	5



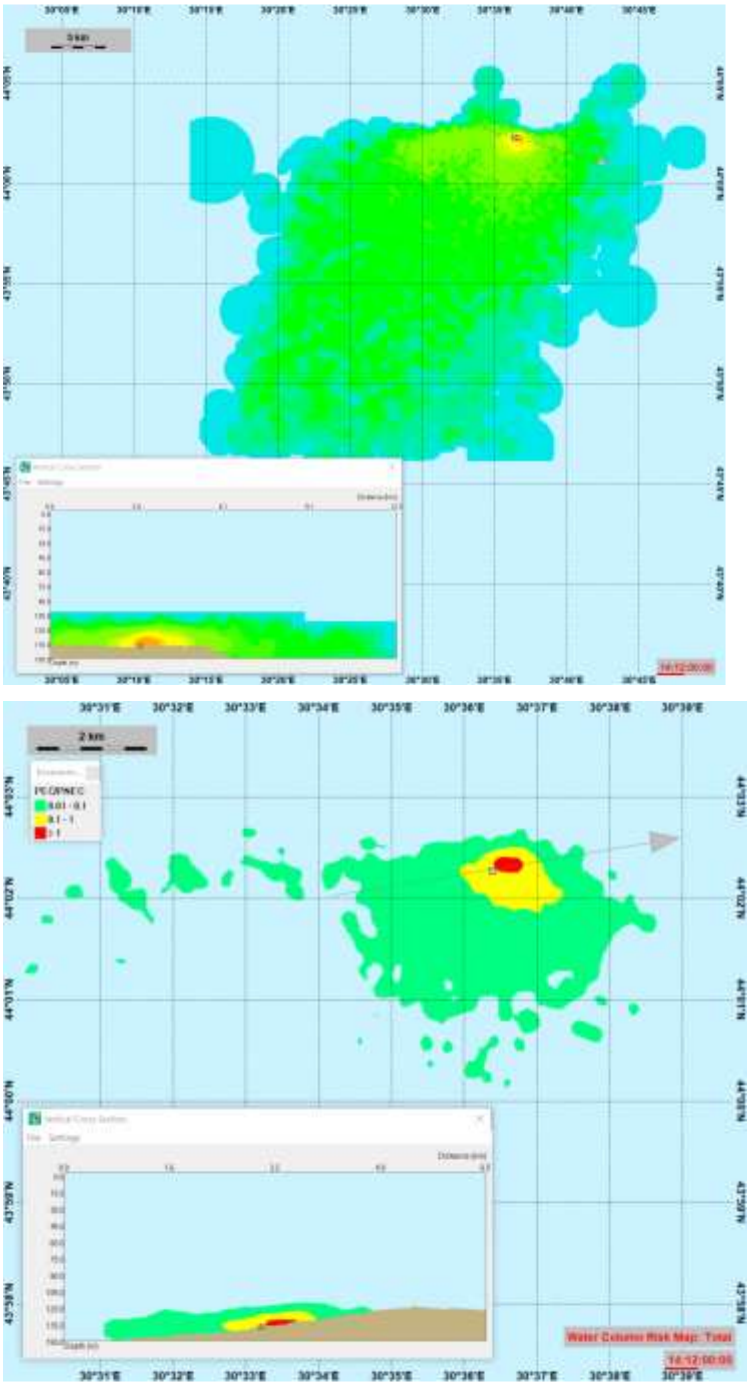


Figure A-6-21 Snapshot for the time-step with maximum EIF showing concentrations (ppb) in the water column (left) and PEC/PNEC ratio (right) during the simulation period for Case 6a.

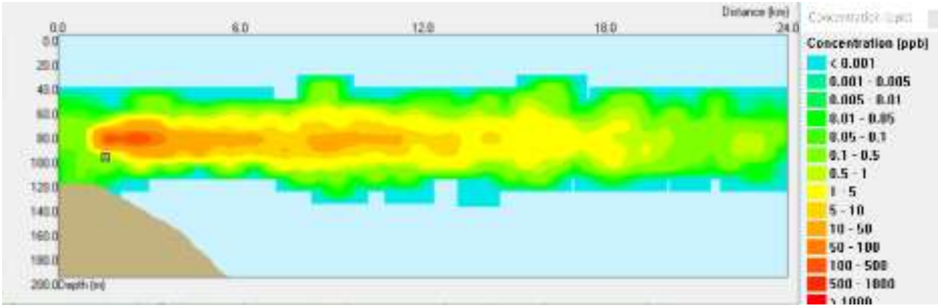
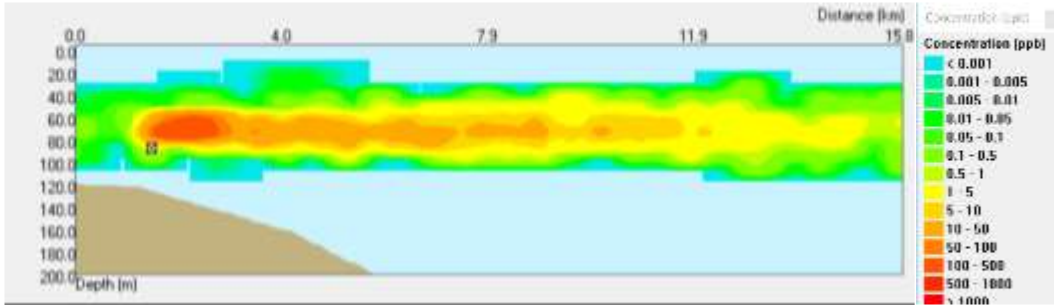
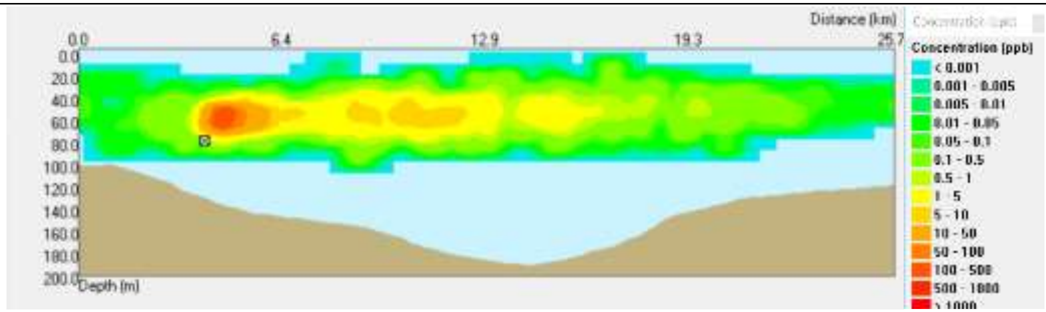
SINTEF

E.4 Effects of discharge arrangements on transport of discharge

To assess the effect of the discharge depth and the discharge diameter on the surfacing and distribution of the discharge in the water column, SINTEF performed some short simulations with varying these two parameters and low salinity produced water. The objective was to find a water depth and discharge diameter that leads to the discharge being trapped in lower water depths.

			dry	↓	Ø
Chemical package	Salinity of PW	warm (September)	cold (April)	Discharge through caisson, downwards, depth m	Discharge through caisson, downwards, diameter mm
ChampionX	LOW	X	X	60	750
ChampionX	LOW	X	X	60	750
ChampionX	LOW	X		70	750
ChampionX	LOW	X		80	750
ChampionX	LOW	X		90	750
ChampionX	LOW	X		100	750
ChampionX	LOW	X	X	60	500
ChampionX	LOW	X	X	70	500
ChampionX	LOW	X	X	80	500
ChampionX	LOW	X	X	90	500
ChampionX	LOW	X	X	60	350

The results show that reducing the caisson from 750mm to 500mm allows to reduce the discharge depth and hence the length of the caisson to 90m. All simulations were therefore performed with this depth and diameter.

↓ 	Ø	Discharge through caisson, downwards
depth	diameter	
100m	750mm	
90m	750mm	
80m	750mm	

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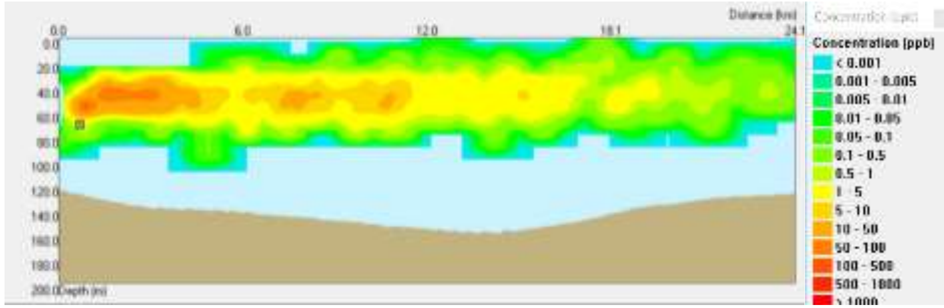
downwards</th></tr>
<tr><td>70m</td><td>750mm</td><td>
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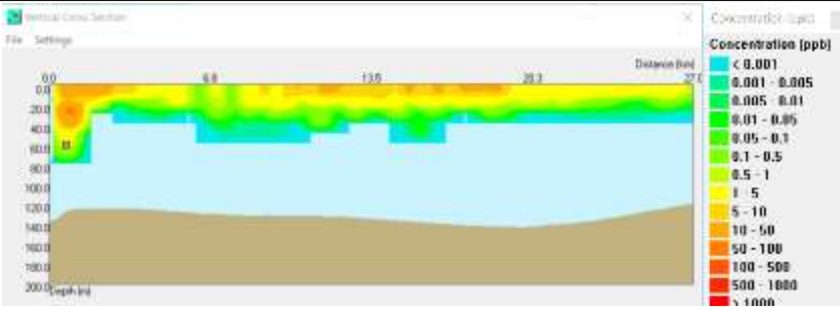
<tr><td>60m</td><td>750mm</td><td>
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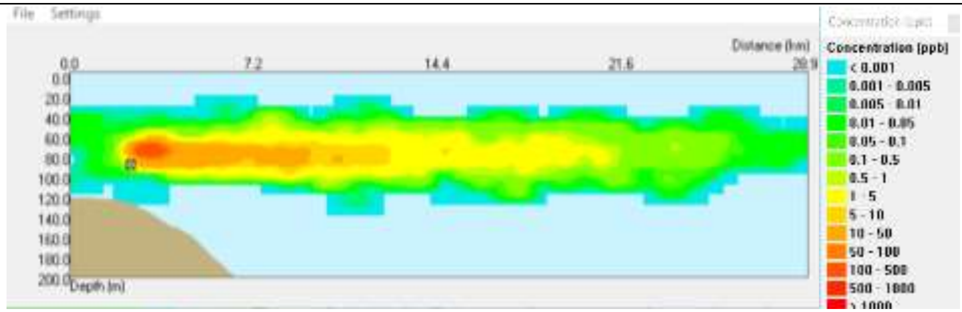
<tr><td>90m</td><td>500mm</td><td>
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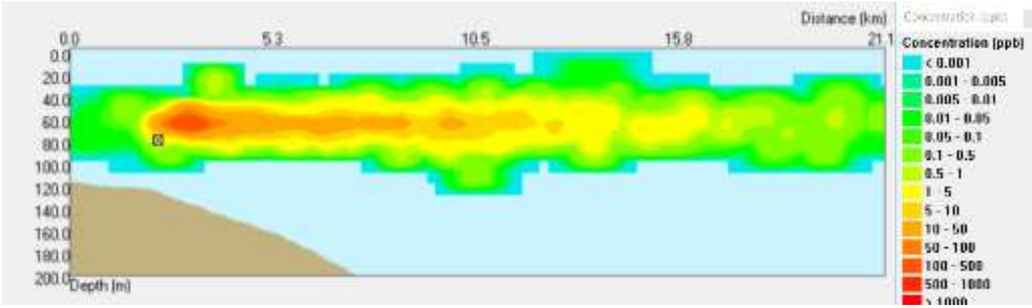
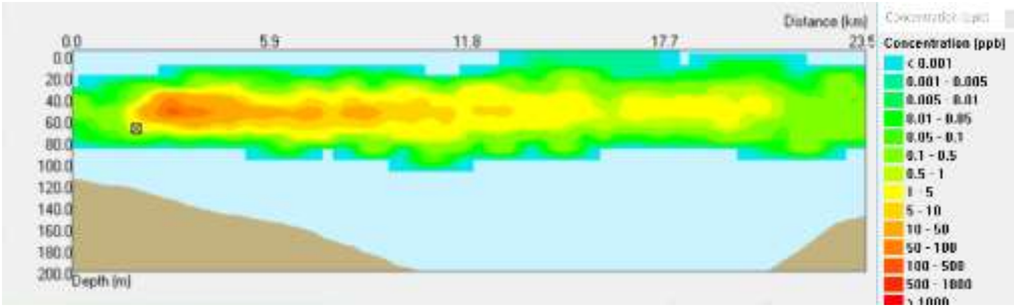
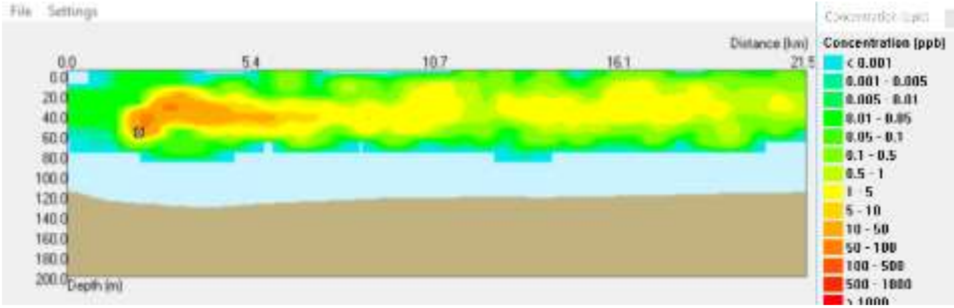
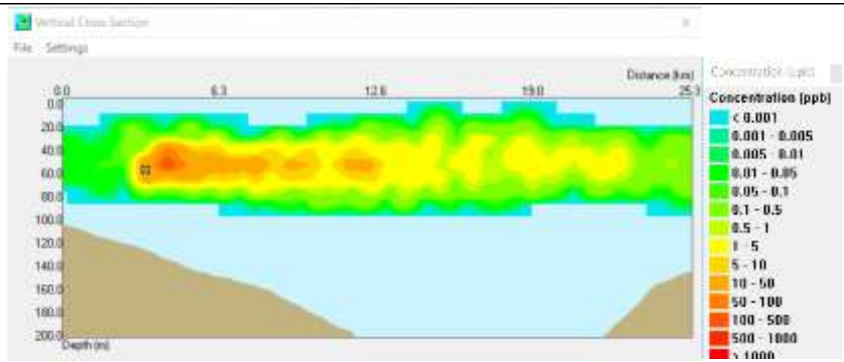
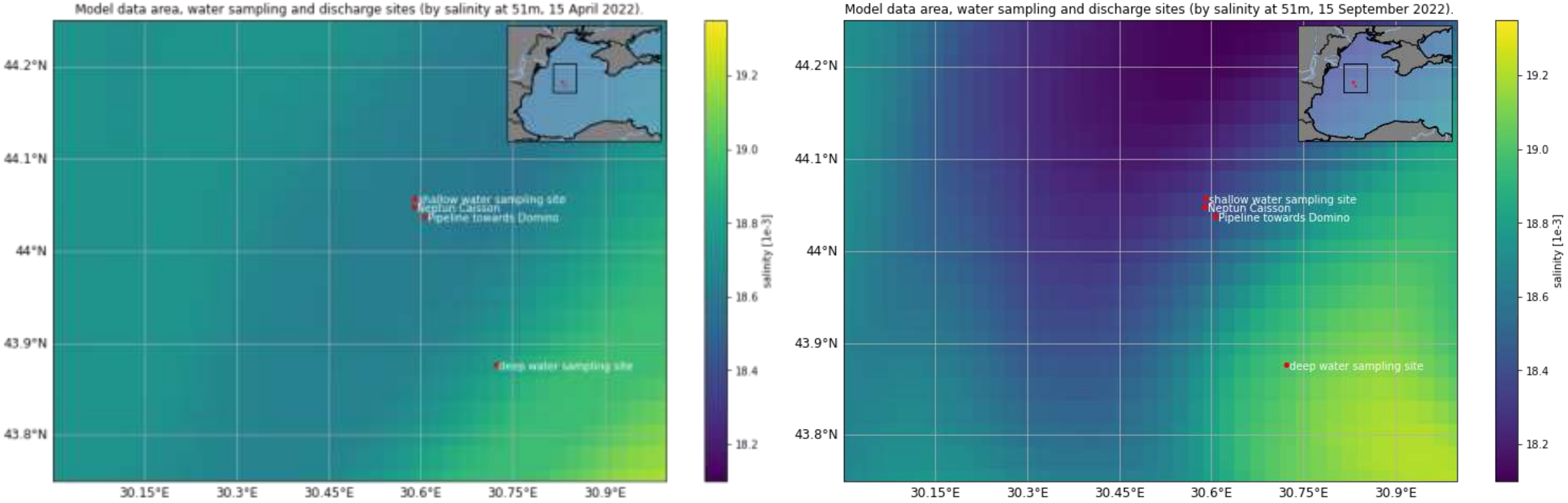
↓ 	Ø	Discharge through caisson, downwards
80m	500mm	
70m	500 mm	
60m	500 mm	

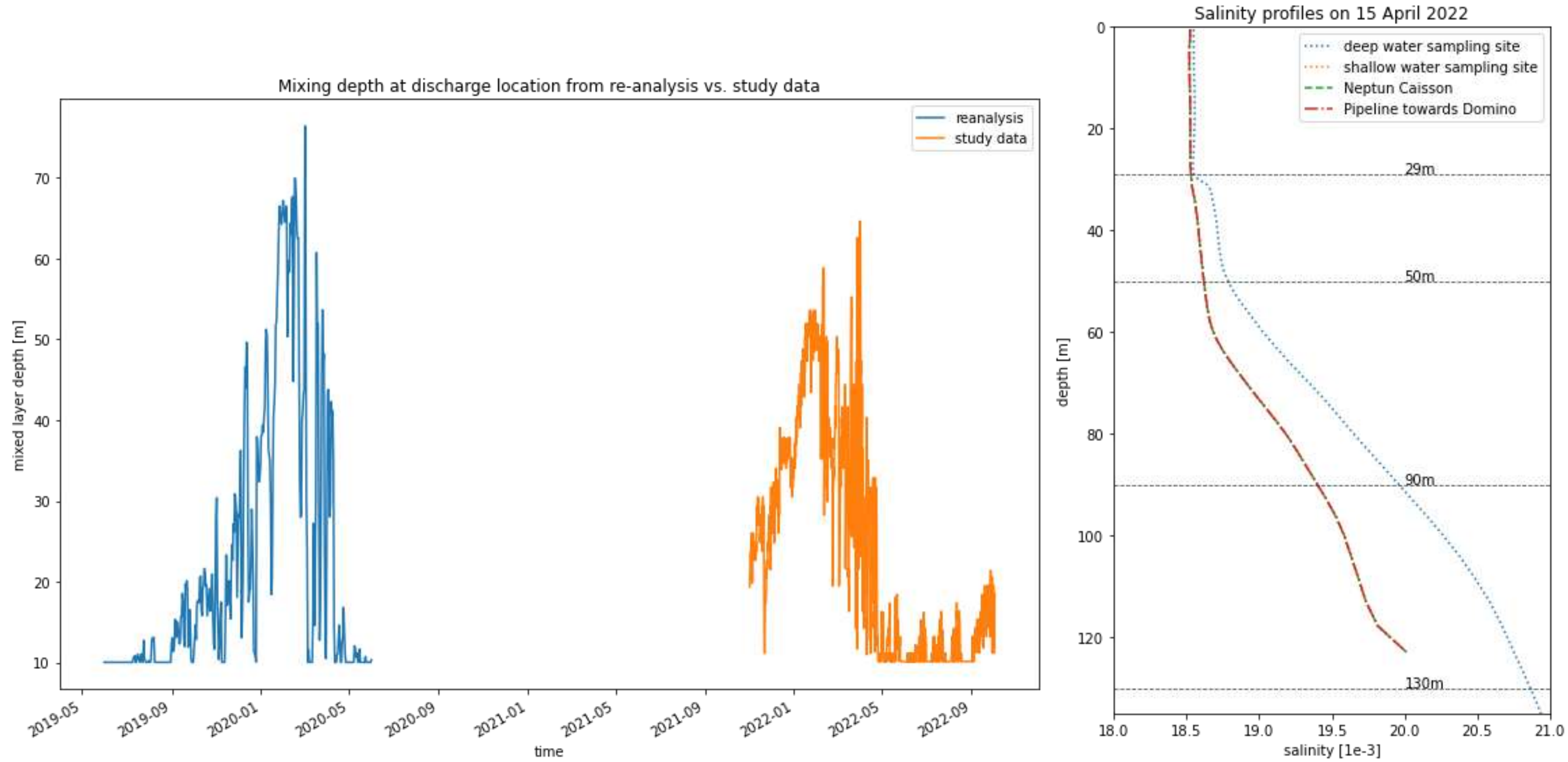
↓	Ø	Discharge through caisson, downwards
60m	300 mm	

E.5 Environmental conditions in the Black Sea at Neptun Deep area

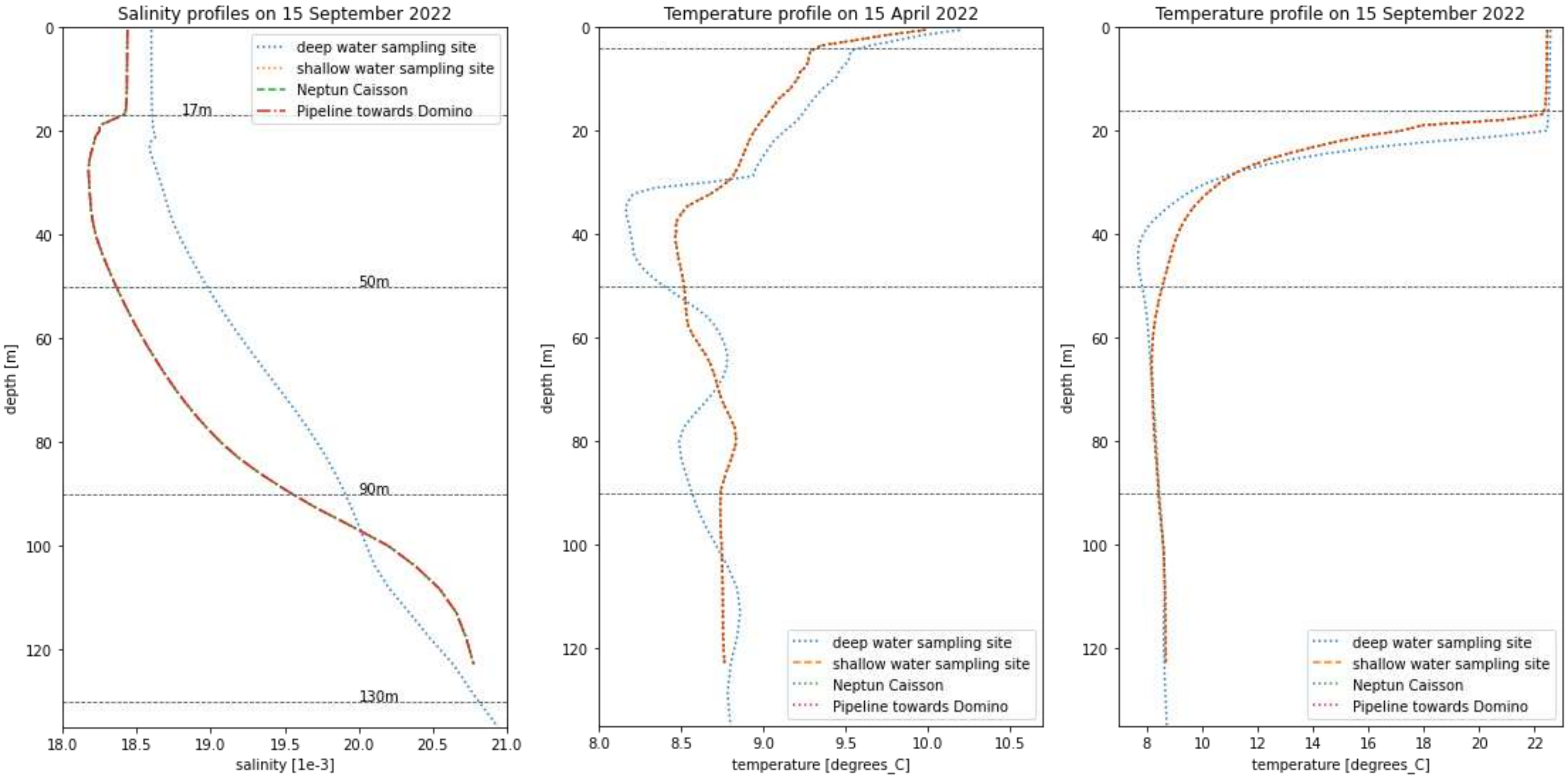
Salinity at the depth of the cooling water take out, marked locations include the caisson and pipeline discharge points as well as the water sampling sites from the report provided by OMV Petrom. The small map in the upper right corner shows the spatial extent of the downloaded data in the Black Sea.



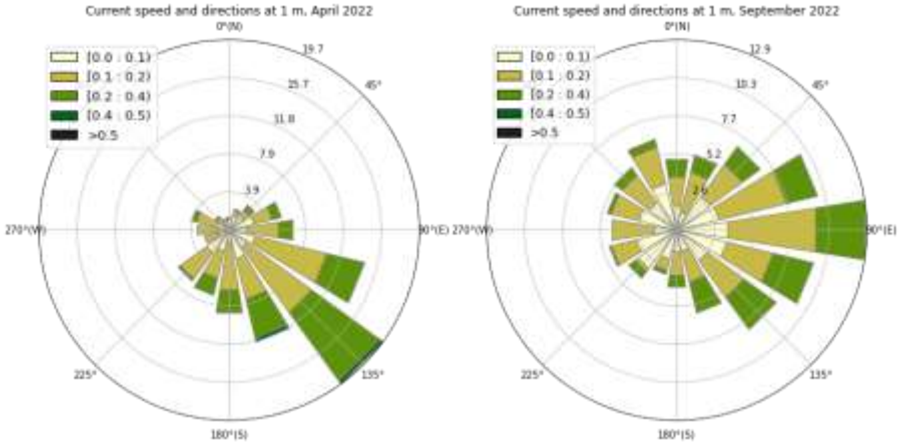
Salinity in the model data set at 51 m, ca. where the cooling water is taken from. This salinity is important for the resulting salinity of mixed cooling and produced water.

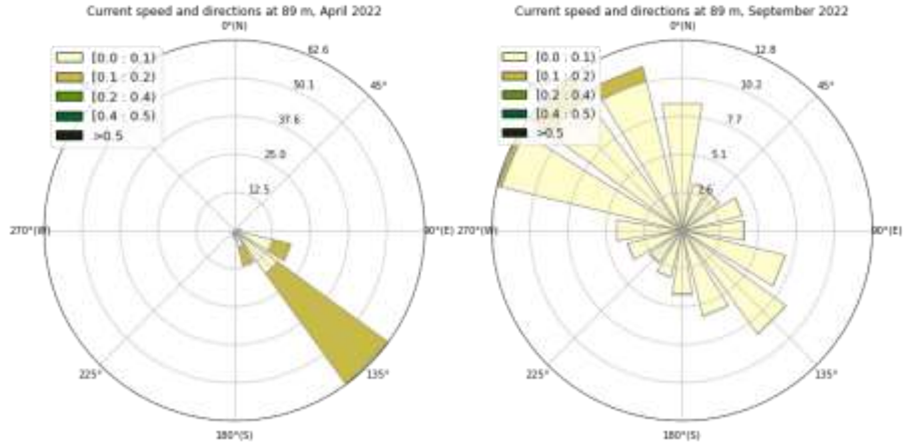


Mixed layer depth from forecast data and reanalysis in the left figure and salinity profiles from water sampling compared to model data in the right figure. Both to check the quality of the modelled data. Deviations are expected due to different periods of the data sets but the data should roughly align with each other.

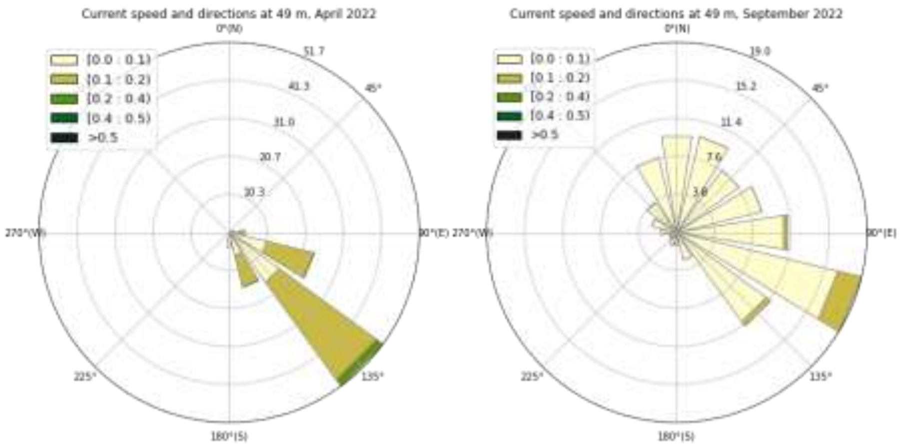


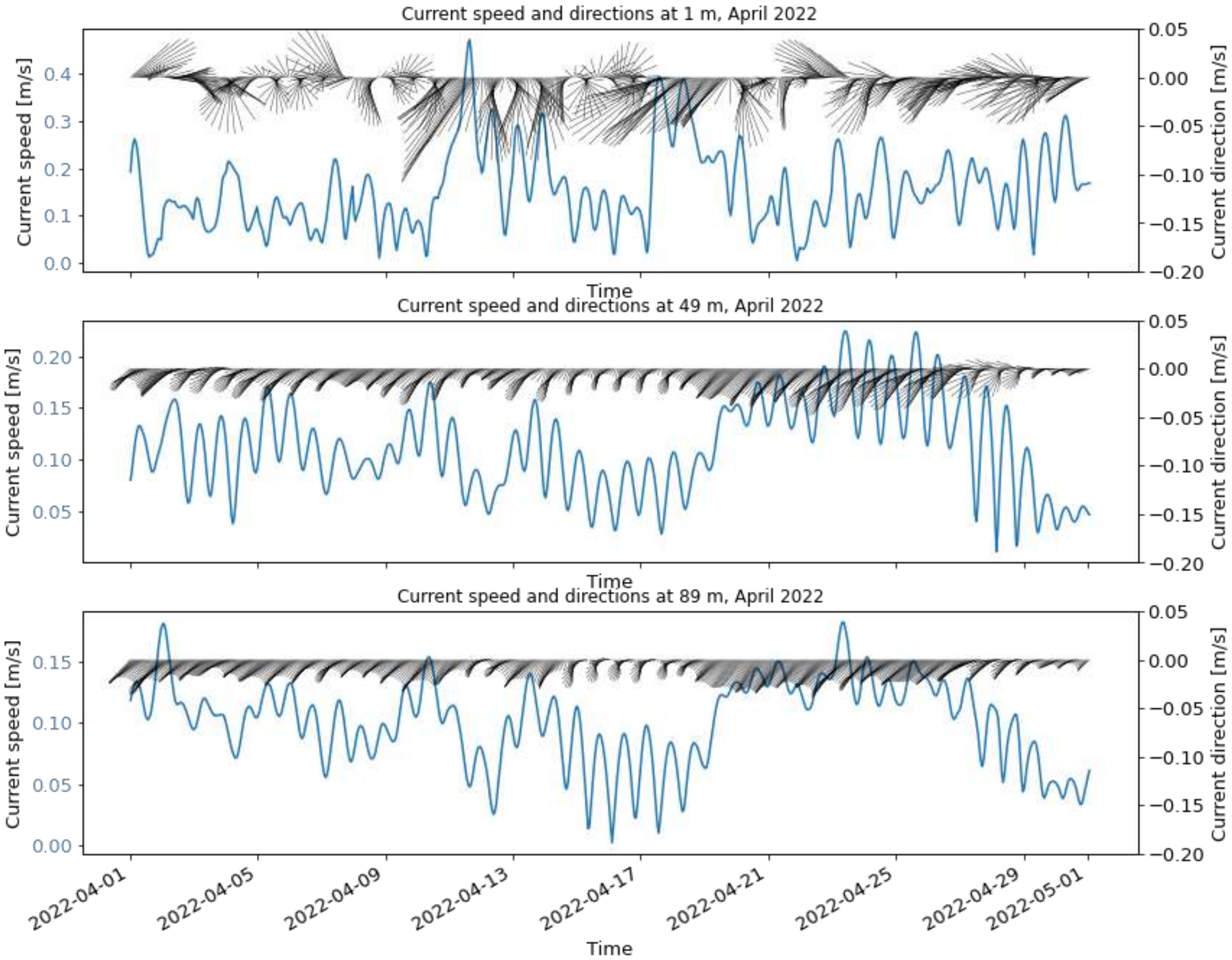
Salinity profiles from water sampling compared to model data in the left and temperature profiles in the other figures. All to check the quality of the modelled data. Deviations are expected due to different periods of the data sets but the data should roughly align with each other.





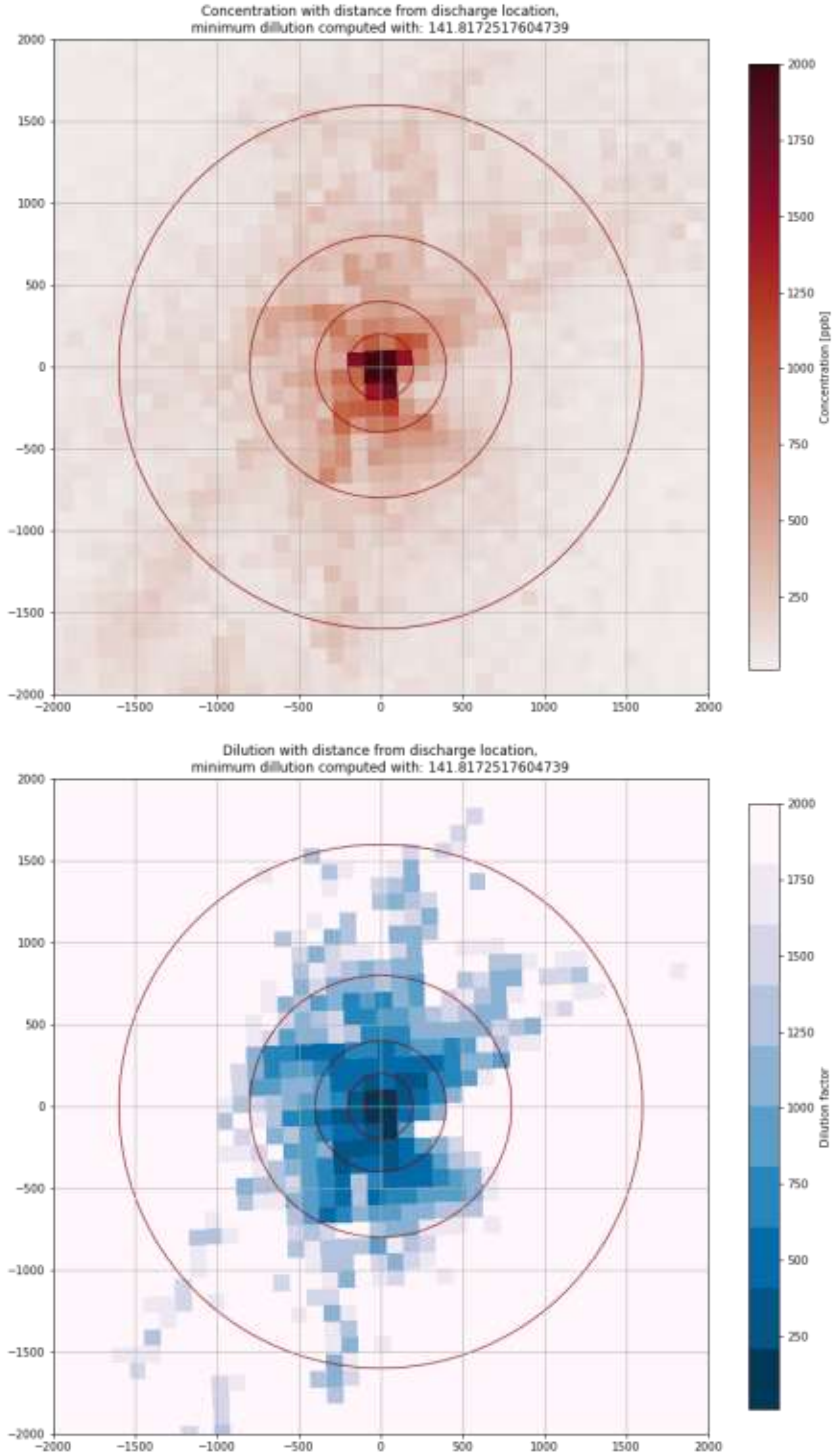
Current speed and directiona at the surface, the cooling water outtake and the discharge depth. Current speeds decline with water depth. Uniform current direction in the April data and more directional distribution in September. This usually leads to more spreading in one direction, stronger dispersion, lower concentrations and hence lower EIF.





Another sanity check of the downloaded met ocean data.Here we plotted current speed and direction together to check for regular tidal patterns which can be observed quite nicely.

Another way to look at predicted concentrations (PEC) is to compare them to the discharge concentration and compute dilution. This was not part of the study and is only included for illustration purposes.



Concentration at given distances (upper figures) and translation into dilution (lower figure). The dicharge dilutes directly in the grid cell at the discharge point (within 100m) with a factor of 141.8.

F Final ChampionX Neptun Deep Simulations

A final set of simulations was performed with updated concentrations for the production chemicals. These concentrations are based on a maximum volume of Produced Water at 6500 bwpd for Corrosion Inhibitor (injected at Domino only) and a maximum volume of PW at ca 10 000 bwpd for the other chemicals (injected at all sites). The simulation covered high and low salinity PW and even one scenario without PW and both, warm and cold season.

Discharge of Sodium Hypochlorite (SHC) was not accounted for.

				dry		Ø
	Chemical package	Salinity of PW	warm (September)	cold (April)	Discharge through caisson, downwards, depth m	Discharge through caisson, downwards, diameter mm
'Ordinary production' Produced Water discharges						
10A	ChampionX	HIGH	X		90	500
10B	ChampionX	LOW	X		90	500
10C	ChampionX	HIGH		X	90	500
10D	ChampionX	LOW		X	90	500
10E	ChampionX	-	X		90	500
10F	ChampionX	-		X	90	500
10G	ChampionX	HIGH	X		90	500
10H	ChampionX	LOW	X		90	500
10I	ChampionX	HIGH		X	90	500
10J	ChampionX	LOW		X	90	500
Well-restart simulations with intermittent discharge of MEOH for 65 hours						
11A	ChampionX	HIGH	X		90	500
11B	ChampionX	LOW	X		90	500
11C	ChampionX	HIGH		X	90	500
11D	ChampionX	LOW		X	90	500
11E	ChampionX	HIGH	X		90	500
11F	ChampionX	LOW	X		90	500
11G	ChampionX	HIGH		X	90	500
11H	ChampionX	LOW		X	90	500

F.1 Summary of results

							--------------- Main contributor to risk ---------------	
Case		Chemical	Salinity	max. EIF	time	time-avg. EIF	Corrosion inhibitor Comp-3	Corrosion inhibitor Comp-4
10A		ChampionX	HIGH	2	1	0.31	49.84	43.31
10B		ChampionX	LOW	1	1	0.16	49.85	43.31
10C		ChampionX	HIGH	0	0	0.00	0	0
10D		ChampionX	LOW	0	0	0.00	0	0
10E		ChampionX	-	21	4.5	7.84	50.59	44.33
10F		ChampionX	-	6	29.5	0.68	50.73	44.21
10G		ChampionX	HIGH	18	2	9.34	50.77	44.25
10H		ChampionX	LOW	21	6.5	7.52	50.56	44.46
10I		ChampionX	HIGH	10	29	1.82	50.8	44.25
10J		ChampionX	LOW	6	11	0.80	50.84	44.21
11A		ChampionX	HIGH	2	2	*	49.8	43.37
11B		ChampionX	LOW	2	2.5	*	49.78	43.4
11C		ChampionX	HIGH	0	0	*	0	0
11D		ChampionX	LOW	0	0	*	0	0
11E		ChampionX	HIGH	2	1	*	49.84	43.31
11F		ChampionX	LOW	1	1	*	49.85	43.31
11G		ChampionX	HIGH	0	0	*	0	0
11H		ChampionX	LOW	0	0	*	0	0

* Time-averaged EIF does not apply to these cases, as there is an intermittent change due to MEOH discharge

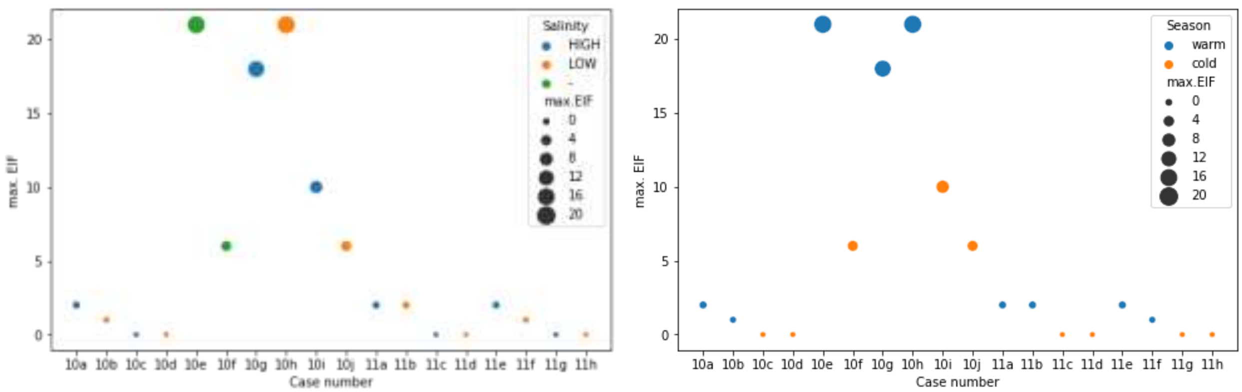


Figure F-6-22 Summary of EIF results by case number and salinity to the left, warm vs. cold season to the right

The salinity of the PW affects the resulting environmental risk very little in the studied cases and the effect is inconclusive. Warm vs. cold season in contrast has a significant effect on the result with the resulting EIF being lower in the cold season cases (April).

F.2 Detailed results from DREAM simulations and EIF computations

All case are simulated for the ChampionX chemical package, with discharge via caisson at 90m with a caisson diameter of 0.5m.

F.2.1 Operational discharge, minimum concentrations

The scenario setups are based on the following concentrations (minimum dosage) and maximum effluents at Domino and Pelican:

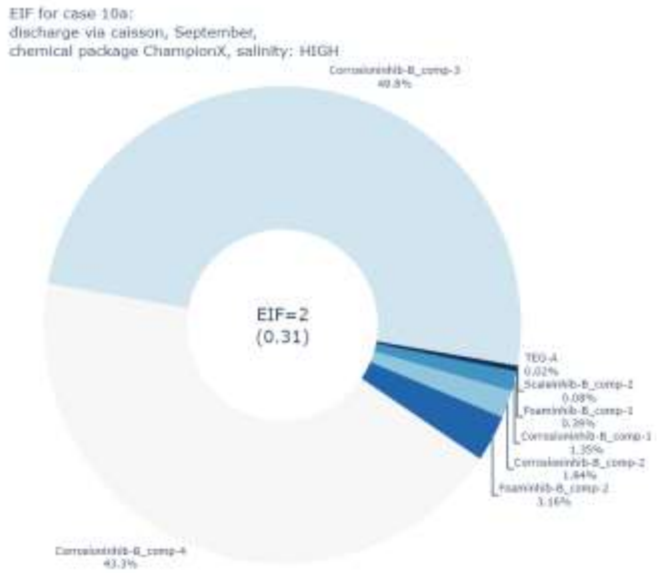
	Profile CHAMPOINXMINPWTEGCOOLINGNOSHC			
Case #	10A	10B	10C	10D
Season	warm (September)		cold (April)	
PW Salinity	High	Low	High	Low
Scenario	Min: PW, TEG, cooling, No SHC	Min: PW, TEG, cooling, No SHC	Min: PW, TEG, cooling, No SHC	Min: PW, TEG, cooling, No SHC
Chemical concentrations ppm:				
Corrosion Inhibitor	50	50	50	50
Component 1	1.2	1.2	1.2	1.2
Component 2	11.24	11.24	11.24	11.24
Component 3	2.2	2.2	2.2	2.2
Component 4	9.76	9.76	9.76	9.76
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	15	15	15	15
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	4.5	4.5	4.5	4.5
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	10	10	10	10
Component 1	4	4	4	4
Component 2	0	0	0	0
Methanol	NO	NO	NO	NO
SHC	NO	NO	NO	NO
TEG ppm	332	332	332	332
Effluents m^3/h				
Domino PW m3/h (used for Corrosion Inhibitor)	43.06	43.06	43.06	43.06
Pelican PW m3/h (used for all others)	64.45	64.45	64.45	64.45
TEG	0.57	0.57	0.57	0.57
Cooling water	317.3	317.3	317.3	317.3
159 m3 MEOH over 65 hours	NO	NO	NO	NO
241 m3 MEOH over 65 hours	NO	NO	NO	NO

This results in mixing of PW, cooling water and water from the TEG stream and a 'dilution' of the chemicals in these streams, Sodium Hypochlorite is not accounted for as expected discharge concentrations are within the allowed limits.

Mixing				
Total release volume	382.32	382.32	382.32	382.32
special case: corrosion inhibitor:	9176	9176	9176	9176
Total release volume	360.93	360.93	360.93	360.93
PW dilution by cooling water and TEG water	5.93	5.93	5.93	5.93
TEG dilution by PW and cooling water	670.74	670.74	670.74	670.74
special case: corrosion inhibitor:				
PW dilution by cooling water and TEG water	8.38	8.38	8.38	8.38
Chemicals' dilution by cooling water and TEG water	-	-	-	-
TEG dilution by cooling water	-	-	-	-
special case: corrosion inhibitor:				
Chemicals' dilution by cooling water and TEG water	-	-	-	-
PW dilution by TEG water, cooling water and methanol	-	-	-	-
TEG dilution by PW, cooling water and methanol	-	-	-	-
MEOH dilution by PW, TEG water and cooling water	-	-	-	-
special case: corrosion inhibitor:				
PW dilution by TEG water, cooling water and methanol	-	-	-	-
Resulting chemical concentrations ppm in discharge:				
Corrosion Inhibitor	*5.97*	*5.97*	*5.97*	*5.97*
Component 1	3.0542	3.0542	3.0542	3.0542
Component 2	0.1432	0.1432	0.1432	0.1432
Component 3	1.3410	1.3410	1.3410	1.3410
Component 4	0.2625	0.2625	0.2625	0.2625
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	*2.5286*	*2.5286*	*2.5286*	*2.5286*
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	0.5057	0.5057	0.5057	0.5057
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	*1.6858*	*1.6858*	*1.6858*	*1.6858*
Component 1	1.0115	1.0115	1.0115	1.0115
Component 2	0.6743	0.6743	0.6743	0.6743
Methanol	NO	NO	NO	NO
SHC	NO	NO	NO	NO
TEG ppm	0.4950	0.4950	0.4950	0.4950
Case #	10A	10B	10C	10D
Resulting salinities	September		April	
PW high salinity	28	28	28	28
PW low salinity	6.787	6.787	6.787	6.787
salinity of cooling water (sea water at 50 m) ppt	18.45	18.45	18.62	18.62
salinity of PW, cooling water & TEG, high salinity PW	20.06		20.20	
salinity of PW, cooling water & TEG, low salinity PW		16.48		16.63
Temperatures				
temperature total volume (PW+TEG+cooling water)	22.32	22.32	22.32	22.32
Computed EIF max (time-averaged)	2 (0.31)	1 (0.16)	0 (0)	0 (0)

F.2.1.1 Case 10A: warm season, high salinity PW, September

The resulting maximum EIF is computed with 2 with a time averaged EIF of 0.31. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



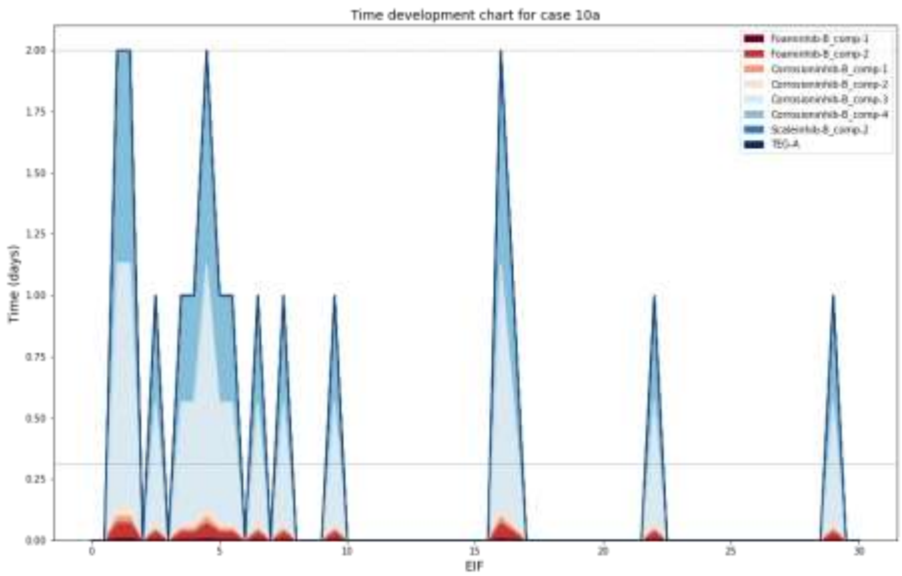


Figure F-6-23 EIF pie chart and time development for case 10a.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

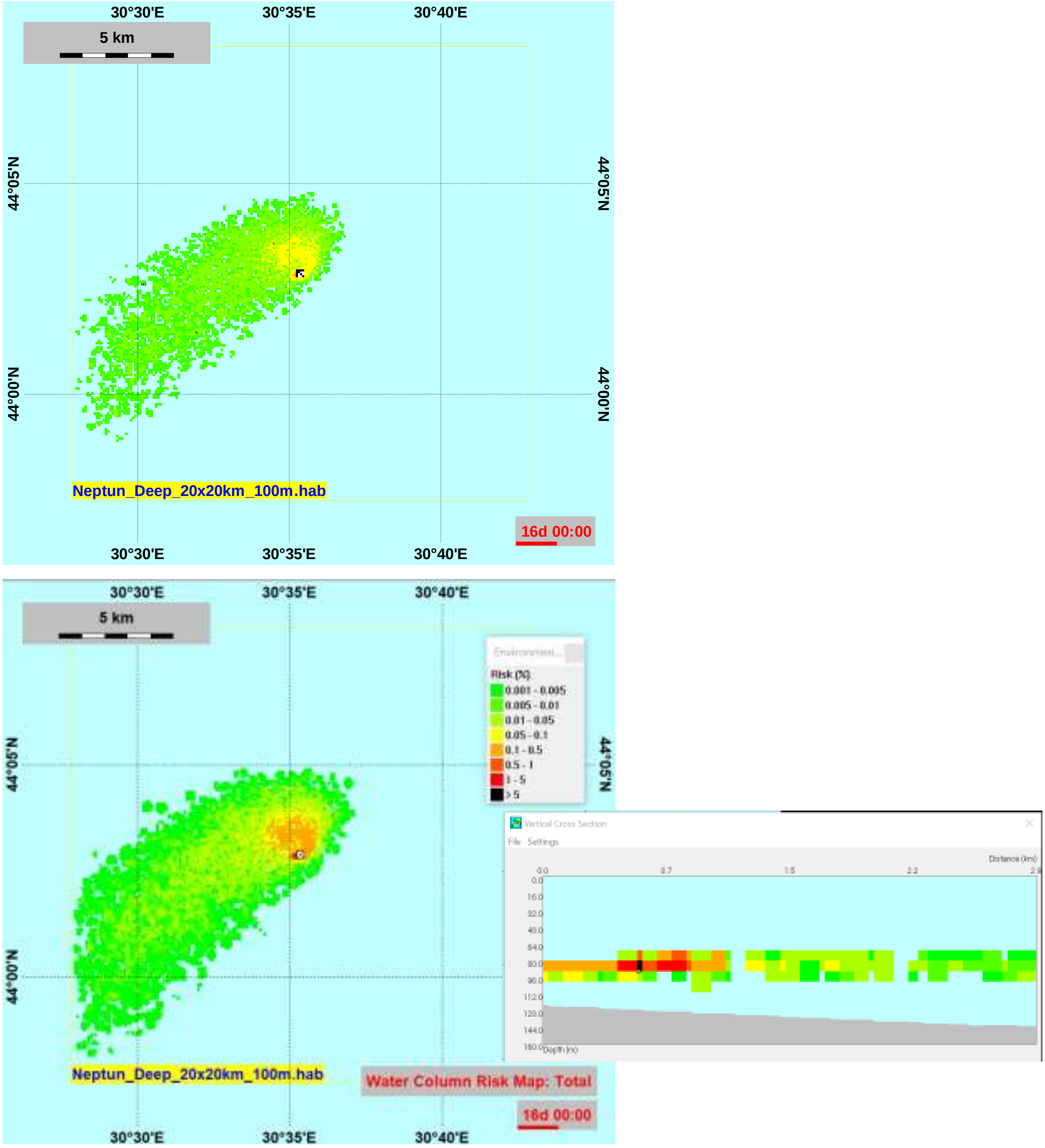
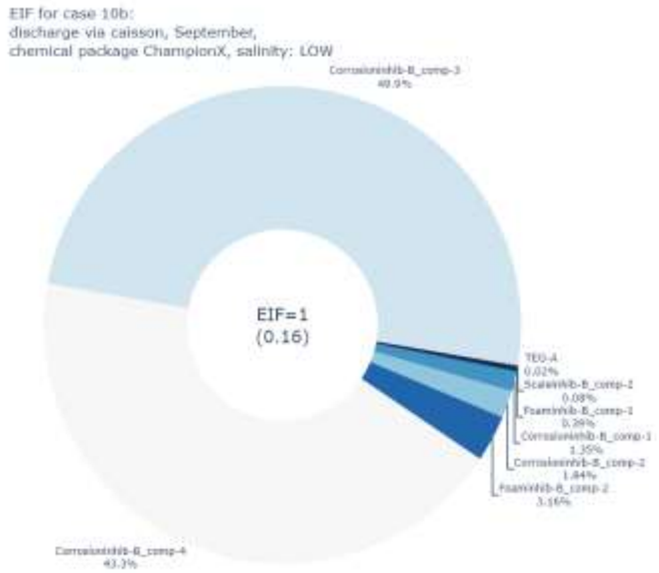


Figure F-6-24 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.1.2 Case 10B: warm season, low salinity PW, September

The resulting maximum EIF is computed with 1 with a time averaged EIF of 0.16. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



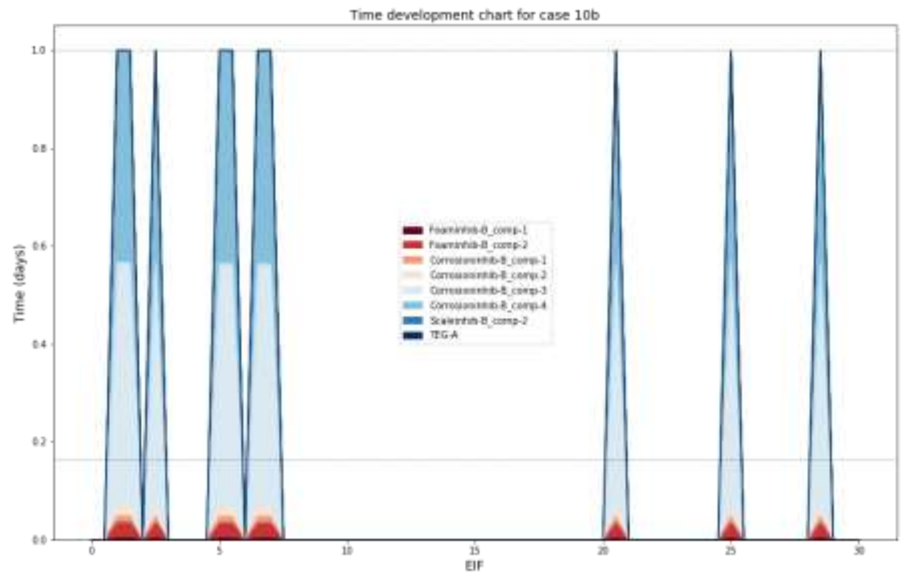


Figure F-6-25 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

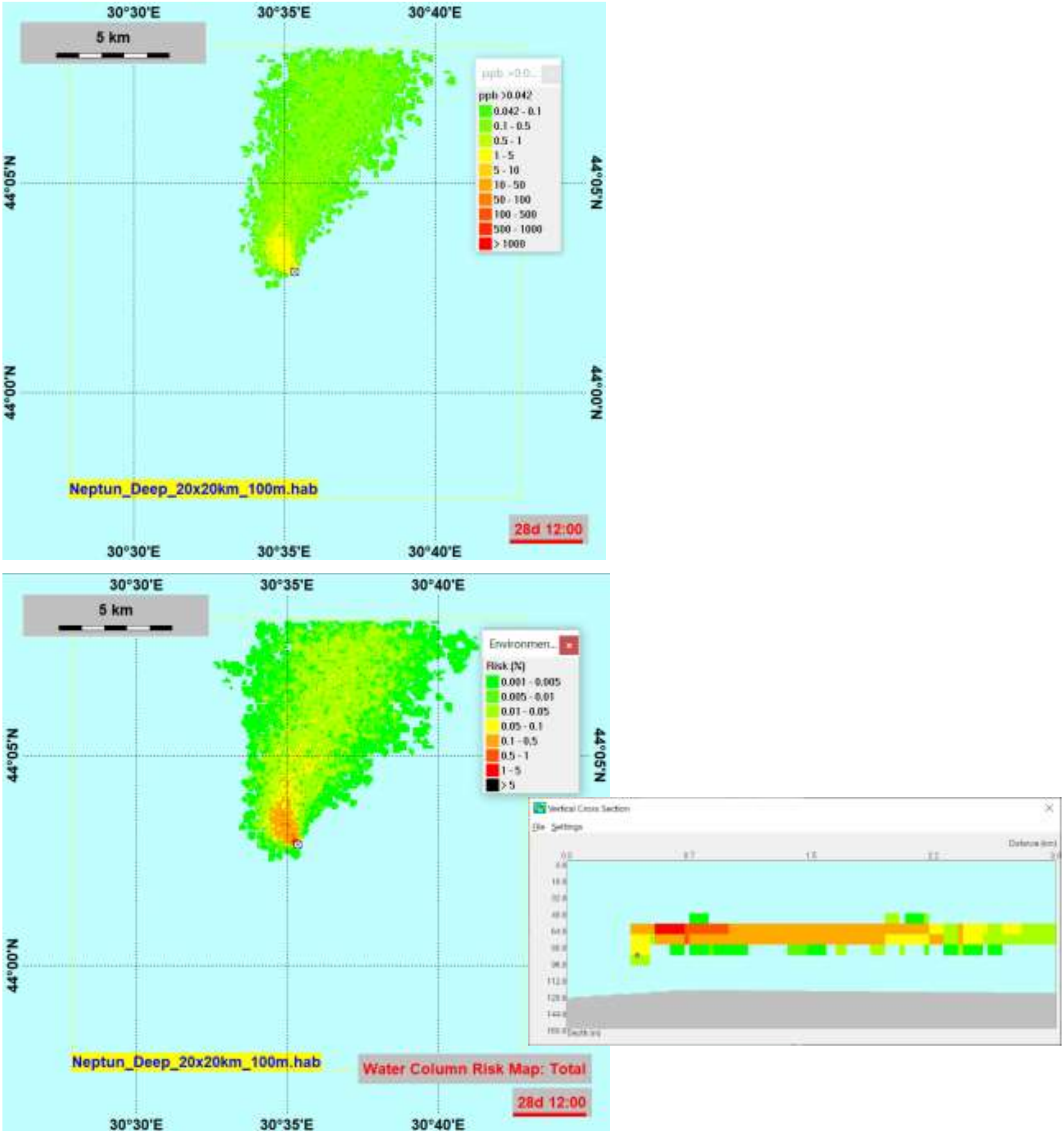


Figure F-6-26 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.1.3 Case 10C: cold season, high salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

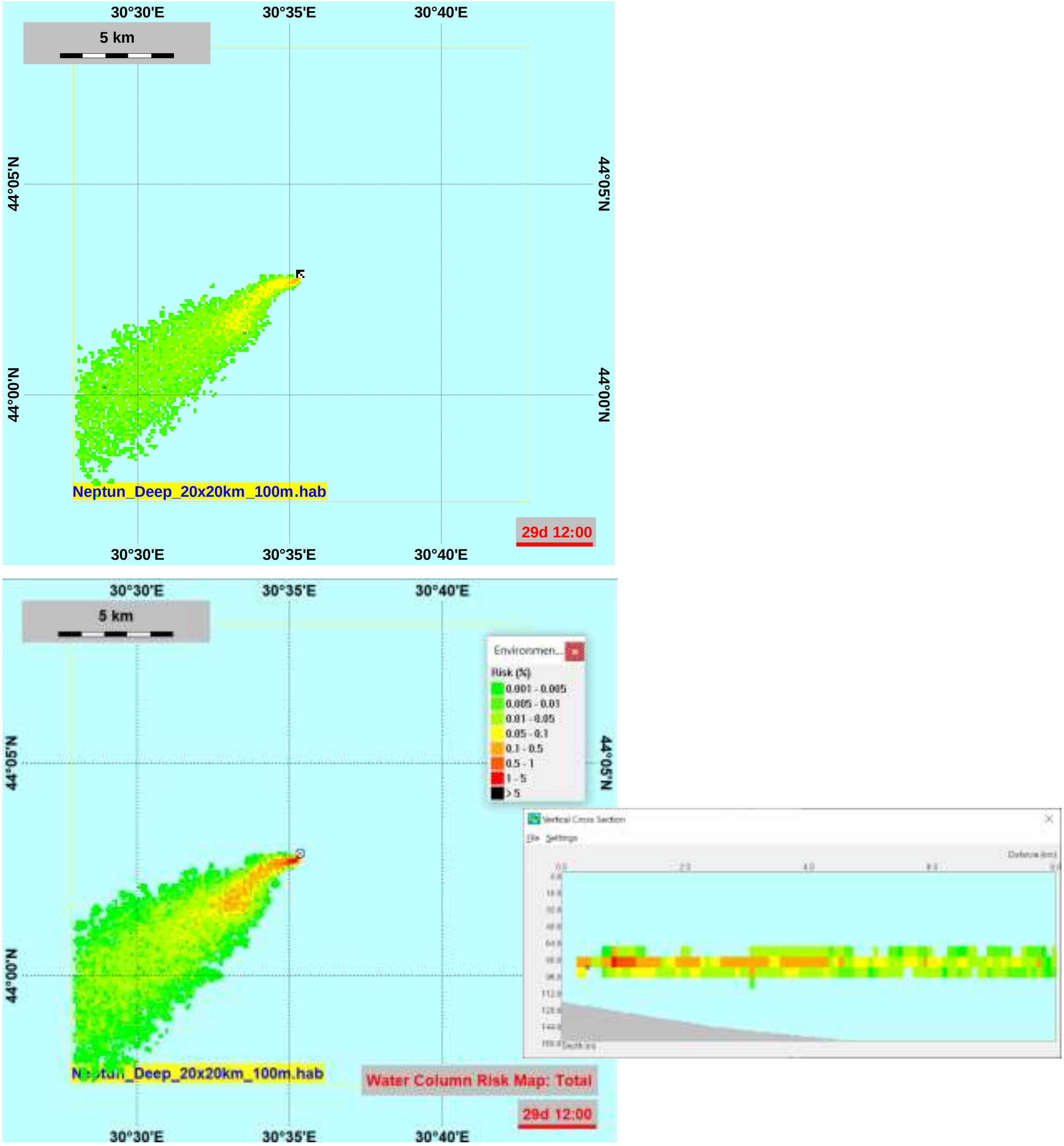


Figure F-6-27 Water column concentrations and resulting environmental risk at the end of the simulation.

F.2.1.4 Case 10D: cold season, low salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

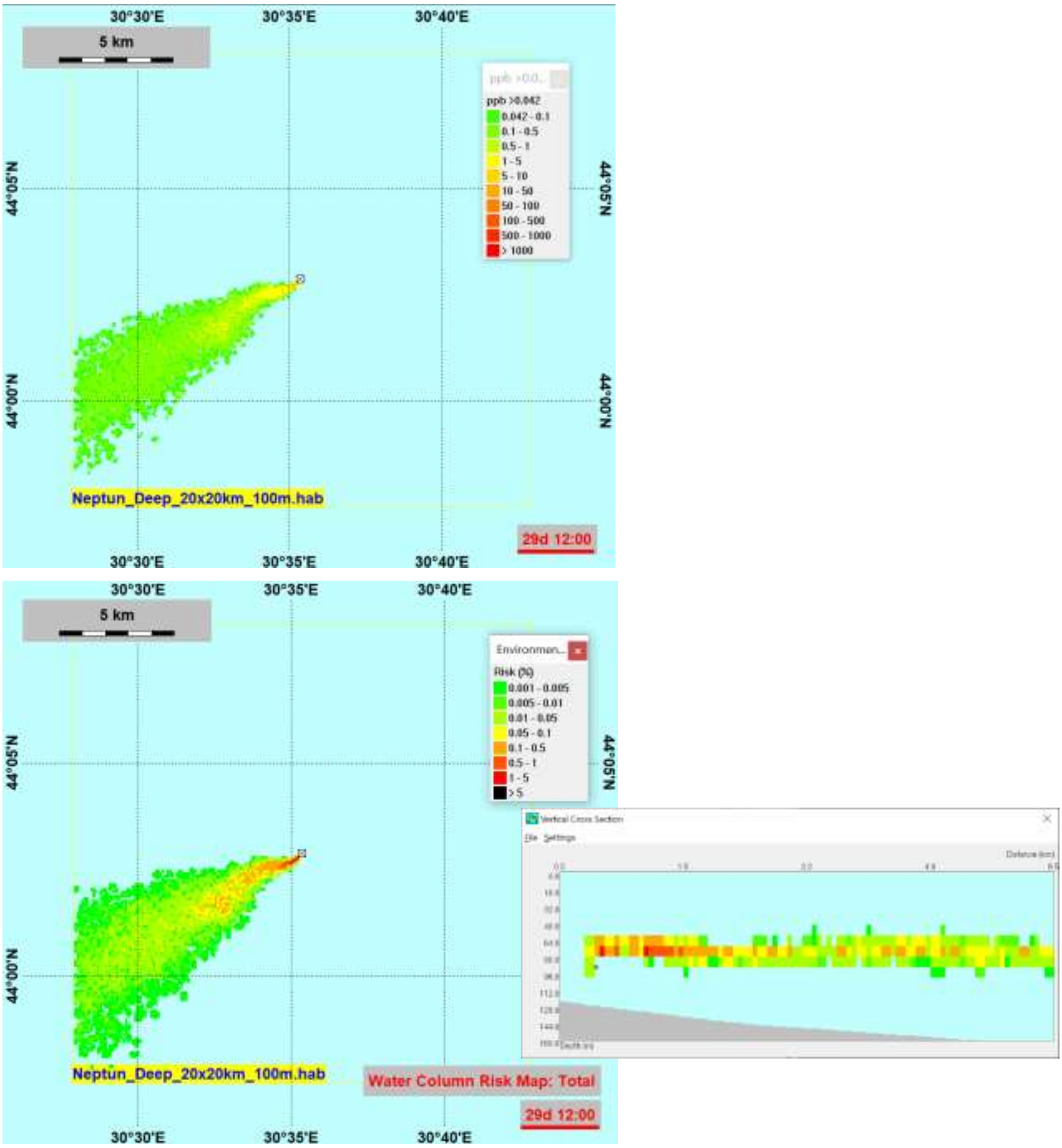


Figure F-6-28 Water column concentrations and resulting environmental risk at the at the end of the simulation.

F.2.2 Operational discharge, maximum concentrations

The next two scenario setups are based on the following concentrations (maximum dosage) and no PW effluent in the discharge, concentrations are still based on maximum PW rates at Domino and Pelican :

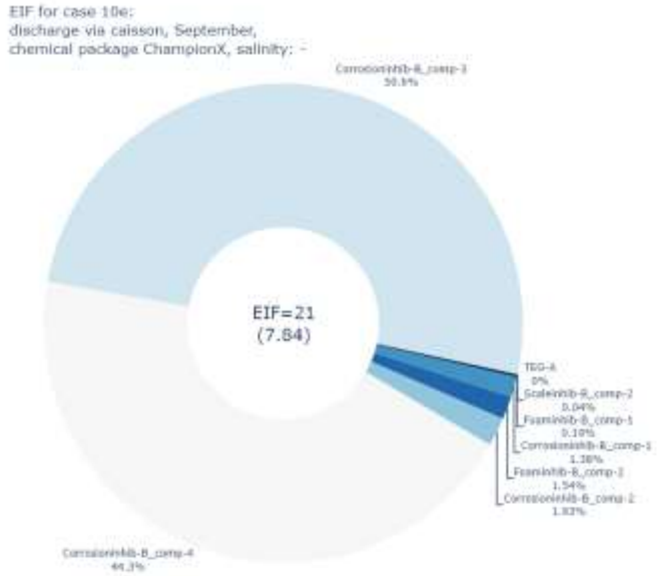
	CHAMPIONXMAXNOPWTEGCOOLINGNOSHC	
Case #	10E	10F
Season	warm	cold
PW Salinity	n/a	n/a
Scenario	Max: no PW, TEG, cooling, no SHC	Max: no PW, TEG, cooling, no SHC
Chemical concentrations ppm:		
Corrosion Inhibitor	200	200
Component 1	4.8	4.8
Component 2	44.96	44.96
Component 3	8.8	8.8
Component 4	39.04	39.04
Component 5	PLONOR	PLONOR
Scale inhibitor	30	30
Component 1	PLONOR	PLONOR
Component 2	9	9
Component 3	PLONOR	PLONOR
Component 4	PLONOR	PLONOR
Anti Foam	20	20
Component 1	8	8
Component 2	0	0
Methanol	NO	NO
SHC	NO	NO
TEG ppm	332	332
Effluents m³/h		
Domino PW m3/h (used for Corrosion Inhibitor)	NO	NO
Pelican PW m3/h (used for all others)	NO	NO
TEG	0.57	0.57
Cooling water	317.3	317.3
159 m3 MEOH over 65 hours	NO	NO
241 m3 MEOH over 65 hours	NO	NO

This results in mixing of cooling water and water from the TEG stream and a 'dilution' of the chemicals in these streams, Sodium Hypochlorite is not accounted for as expected discharge concentrations are within the allowed limits.

Mixing		
Total release volume	317.87	317.87
special case: corrosion inhibitor:	7629	7629
Total release volume	317.87	317.87
PW dilution by cooling water and TEG water	-	-
TEG dilution by PW and cooling water	-	-
special case: corrosion inhibitor:		
PW dilution by cooling water and TEG water	-	-
Chemicals' dilution by cooling water and TEG water	4.93	4.93
TEG dilution by cooling water	557.67	557.67
special case: corrosion inhibitor:		
Chemicals' dilution by cooling water and TEG water	7.38	7.38
PW dilution by TEG water, cooling water and methanol	-	-
TEG dilution by PW, cooling water and methanol	-	-
MEOH dilution by PW, TEG water and cooling water	-	-
special case: corrosion inhibitor:		
PW dilution by TEG water, cooling water and methanol	-	-
Resulting chemical concentrations ppm in discharge:		
Corrosion Inhibitor	*27.09*	*27.09*
Component 1	13.8715	13.8715
Component 2	0.6502	0.6502
Component 3	6.0905	6.0905
Component 4	1.1921	1.1921
Component 5	PLONOR	PLONOR
Scale inhibitor	*6.0827*	*6.0827*
Component 1	PLONOR	PLONOR
Component 2	1.2165	1.2165
Component 3	PLONOR	PLONOR
Component 4	PLONOR	PLONOR
Anti Foam	*4.0551*	*4.0551*
Component 1	2.4331	2.4331
Component 2	1.6220	1.6220
Methanol	NO	NO
SHC	NO	NO
TEG ppm	0.5953	0.5953
Case #	10E	10F
Resulting salinities	September	April
PW high salinity	28	28
PW low salinity	6.787	6.787
salinity of cooling water (sea water at 50 m) ppt	18.45	18.62
salinity of PW, cooling water & TEG, high salinity PW		
salinity of PW, cooling water & TEG, low salinity PW		
Temperatures		
temperature total volume (PW+TEG+cooling water)	22.32	22.32
Computed EIF max (time-averaged)	21 (7.8)	6 (0.68)

F.2.2.1 Case 10E: no PW, September

The resulting maximum EIF is computed with 21 with a time averaged EIF of 7.84. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



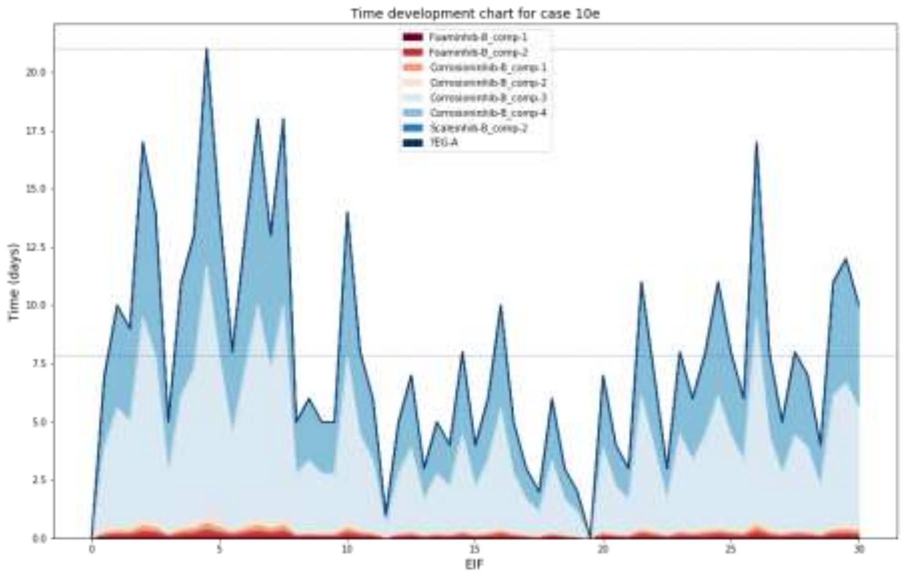


Figure F-6-29 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

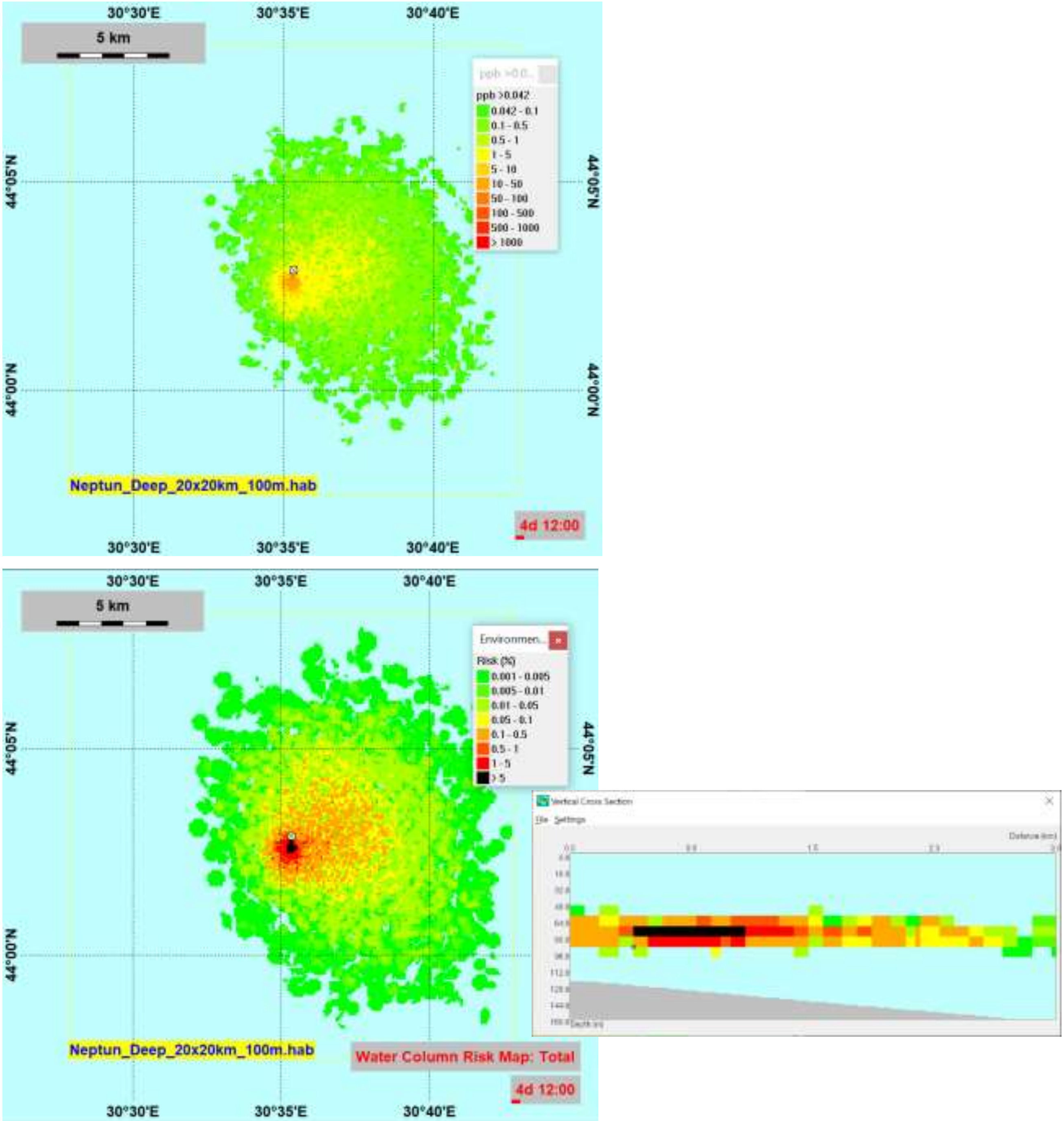
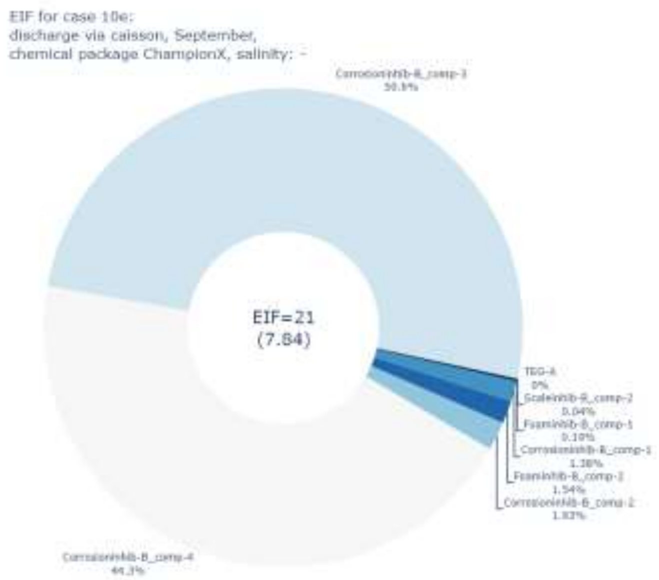


Figure F-6-30 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.2.2 Case 10F: no PW, April

The resulting maximum EIF is computed with 21 with a time averaged EIF of 7.84. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



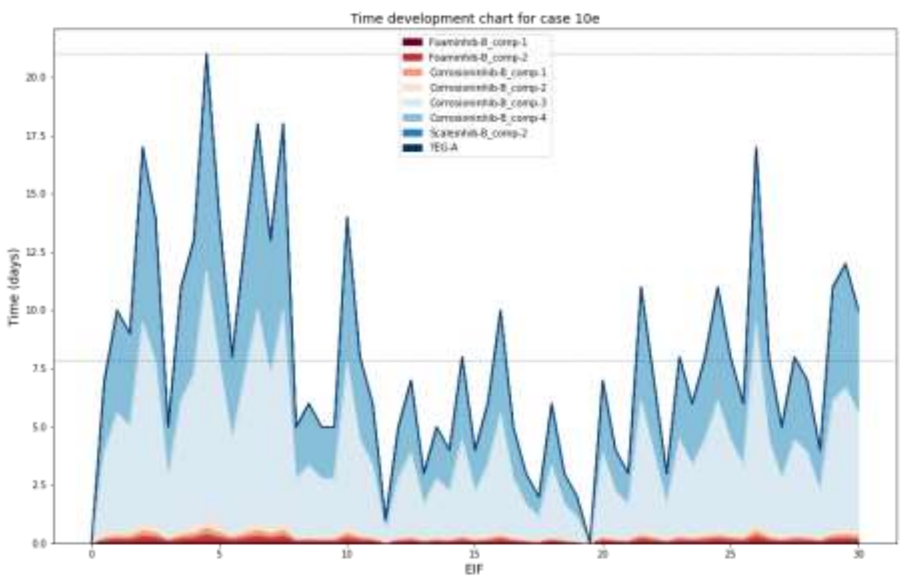


Figure F-6-31 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

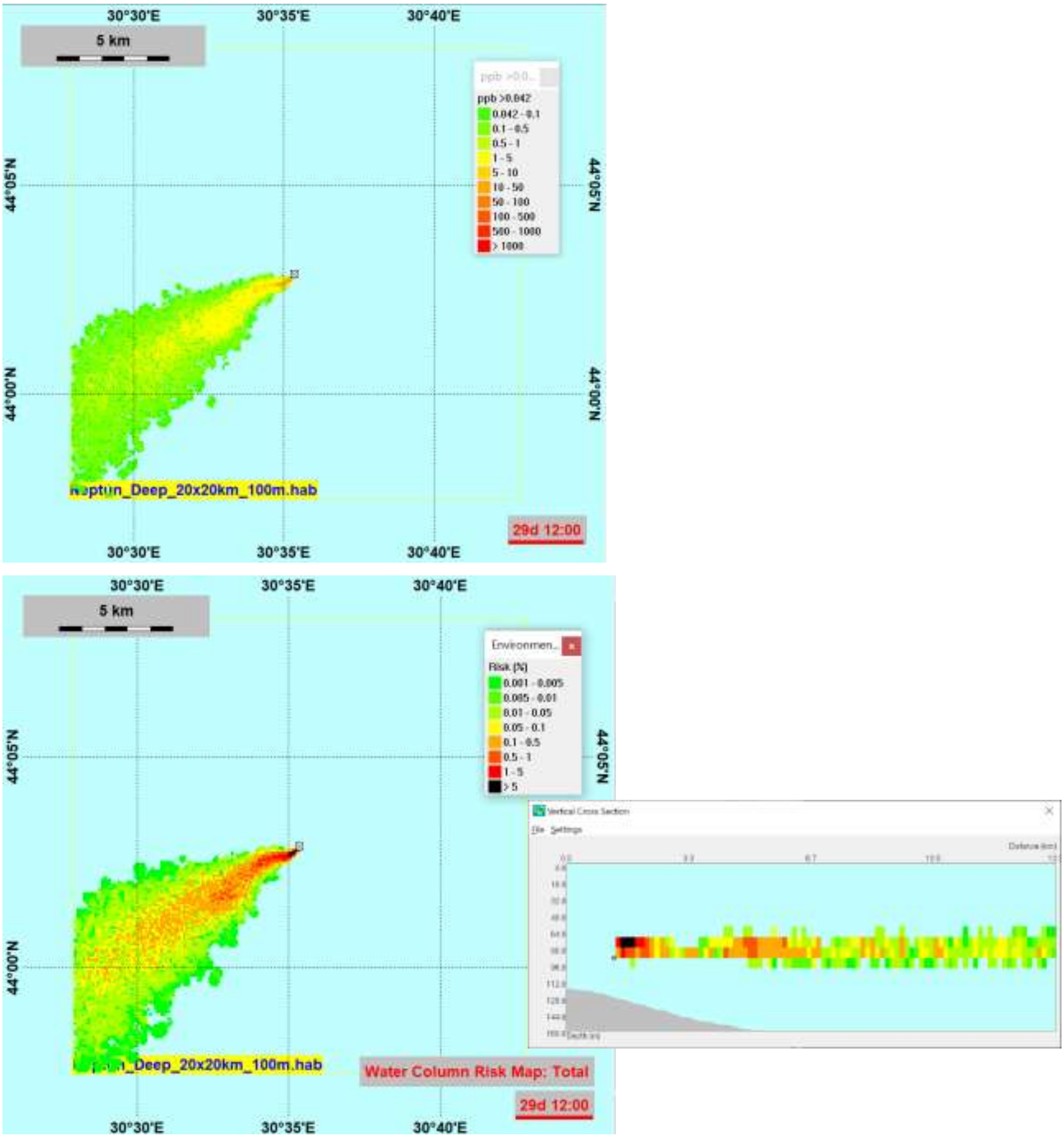


Figure F-6-32 Water column concentrations and resulting environmental risk at the time of maximum EIF.

The following scenarios include PW and are based on the following concentrations (maximum dosage) and maximum effluents at Domino and Pelican:

	Profile CHAMPIONXMAXPWTEGCOOLINGNOSHC			
Case #	10G	10H	10I	10J
Season	warm		cold	
PW Salinity	High	Low	High	Low
Scenario	Max: PW, TEG, cooling, no SHC	Max: PW, TEG, cooling, no SHC	Max: PW, TEG, cooling, no SHC	Max: PW, TEG, cooling, no SHC
Chemical concentrations ppm:				
Corrosion Inhibitor	200	200	200	200
Component 1	4.8	4.8	4.8	4.8
Component 2	44.96	44.96	44.96	44.96
Component 3	8.8	8.8	8.8	8.8
Component 4	39.04	39.04	39.04	39.04
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	30	30	30	30
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	9	9	9	9
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	20	20	20	20
Component 1	8	8	8	8
Component 2	0	0	0	0
Methanol	NO	NO	NO	NO
SHC	NO	NO	NO	NO
TEG ppm	332	332	332	332
Effluents m^3/h				
Domino PW m3/h (used for Corrosion Inhibitor)	43.06	43.06	43.06	43.06
Pelican PW m3/h (used for all others)	64.45	64.45	64.45	64.45
TEG	0.57	0.57	0.57	0.57
Cooling water	317.3	317.3	317.3	317.3
159 m3 MEOH over 65 hours	NO	NO	NO	NO
241 m3 MEOH over 65 hours	NO	NO	NO	NO

This results in mixing of PW, cooling water and water from the TEG stream and a 'dilution' of the chemicals in these streams, Sodium Hypochlorite is not accounted for as expected discharge concentrations are within the allowed limits.

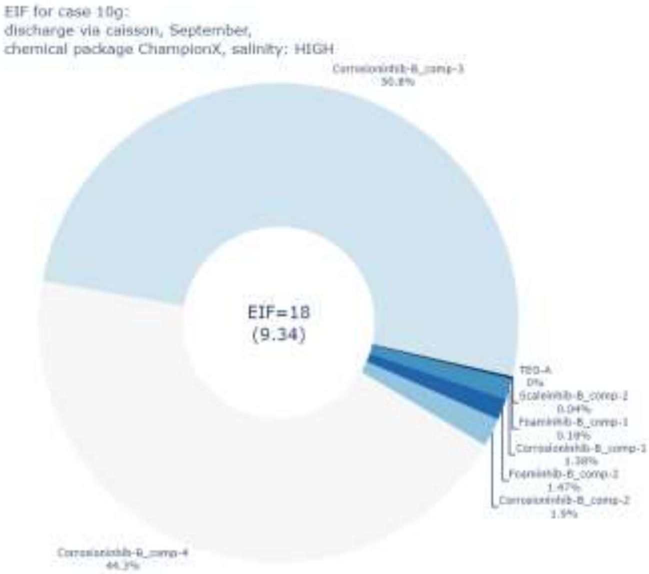
Mixing				
Total release volume	382.32	382.32	382.32	382.32
special case: corrosion inhibitor:	9176	9176	9176	9176
Total release volume	360.93	360.93	360.93	360.93
PW dilution by cooling water and TEG water	5.93	5.93	5.93	5.93
TEG dilution by PW and cooling water	670.74	670.74	670.74	670.74
special case: corrosion inhibitor:				
PW dilution by cooling water and TEG water	8.38	8.38	8.38	8.38
Chemicals' dilution by cooling water and TEG water	-	-	-	-
TEG dilution by cooling water	-	-	-	-
special case: corrosion inhibitor:				
Chemicals' dilution by cooling water and TEG water	-	-	-	-
PW dilution by TEG water, cooling water and methanol	-	-	-	-
TEG dilution by PW, cooling water and methanol	-	-	-	-
MEOH dilution by PW, TEG water and cooling water	-	-	-	-
special case: corrosion inhibitor:				
PW dilution by TEG water, cooling water and methanol	-	-	-	-

Resulting chemical concentrations ppm in discharge:				
Corrosion Inhibitor	*23.86*	*23.86*	*23.86*	*23.86*
Component 1	12.2166	12.2166	12.2166	12.2166
Component 2	0.5727	0.5727	0.5727	0.5727
Component 3	5.3639	5.3639	5.3639	5.3639
Component 4	1.0499	1.0499	1.0499	1.0499
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	*5.0573*	*5.0573*	*5.0573*	*5.0573*
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	1.0115	1.0115	1.0115	1.0115
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	*3.3715*	*3.3715*	*3.3715*	*3.3715*
Component 1	2.0229	2.0229	2.0229	2.0229
Component 2	1.3486	1.3486	1.3486	1.3486
Methanol	NO	NO	NO	NO
SHC	NO	NO	NO	NO
TEG ppm	0.4950	0.4950	0.4950	0.4950

Case #	10G	10H	10I	10J
Resulting salinities	September	September	April	April
PW high salinity	28	28	28	28
PW low salinity	6.787	6.787	6.787	6.787
salinity of cooling water (sea water at 50 m) ppt	18.45	18.45	18.62	18.62
salinity of PW, cooling water & TEG, high salinity PW	20.06		20.20	
salinity of PW, cooling water & TEG, low salinity PW		16.48		16.63
Temperatures				
temperature total volume (PW+TEG+cooling water)	22.32	22.32	22.32	22.32
Computed EIF max (time-averaged)	18 (9.3)	21 (7.5)	10 (1.8)	6 (0.8)

F.2.2.3 Case 10G: warm season, high salinity PW, September

The resulting maximum EIF is computed with 18 with a time averaged EIF of 9.34. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



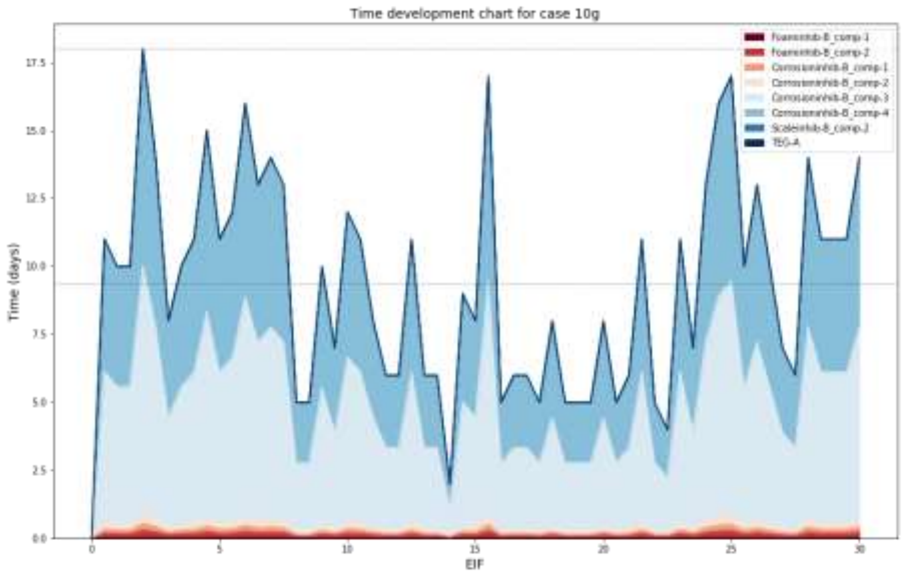


Figure F-6-33 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

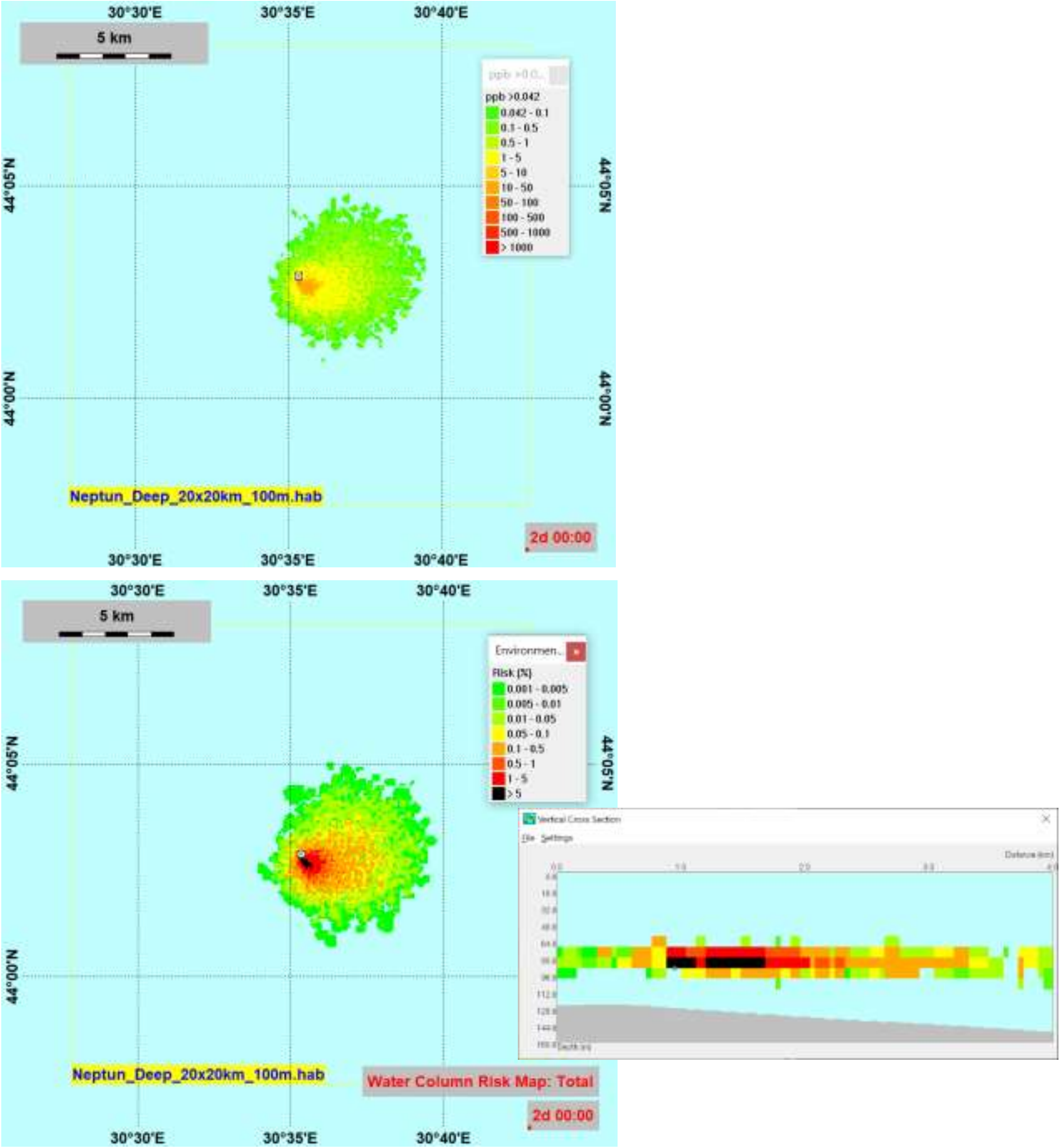
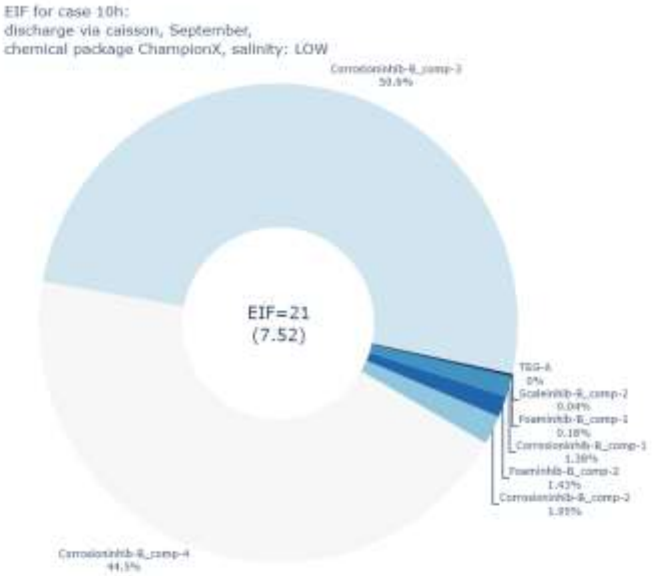


Figure F-6-34 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.2.4 Case 10H: warm season, low salinity PW, September

The resulting maximum EIF is computed with 21 with a time averaged EIF of 7.52. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



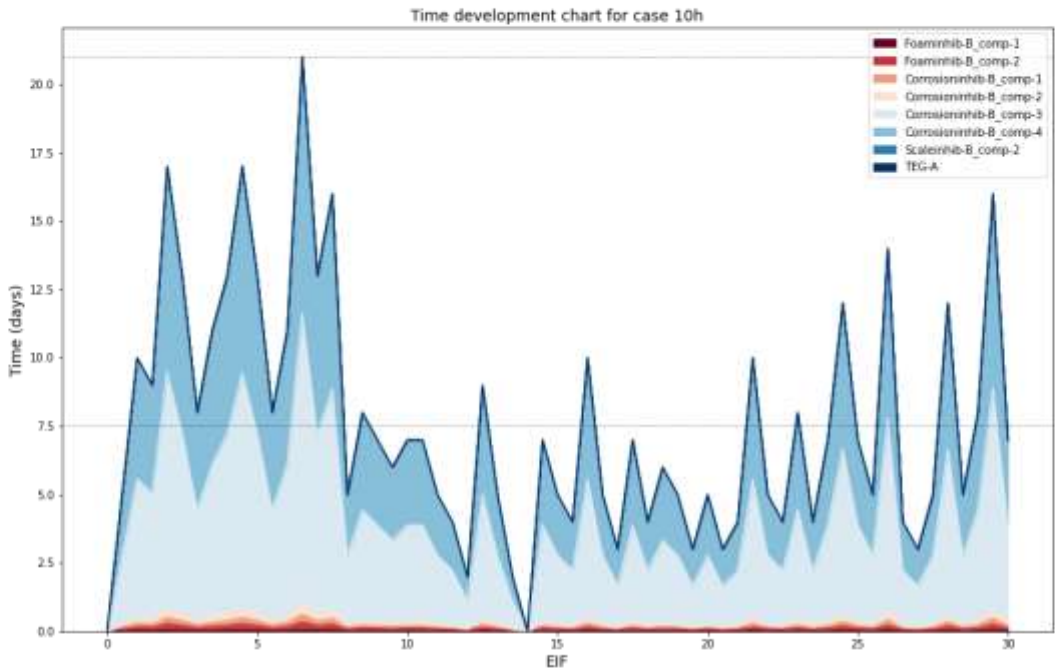


Figure F-6-35 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

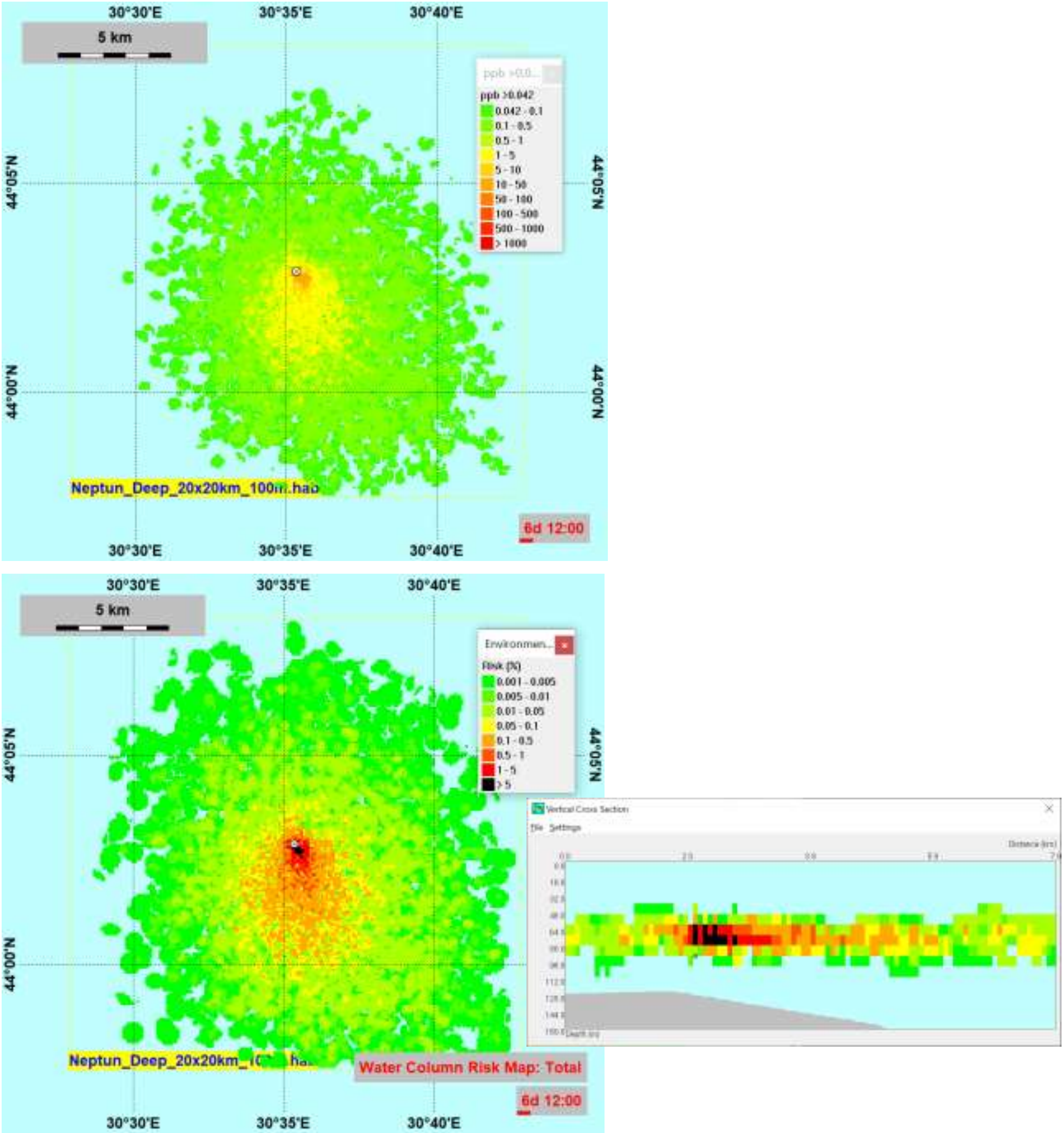


Figure F-6-36 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.2.5 Case 10I: cold season, high salinity PW, April

The resulting maximum EIF is computed with 10 with a time averaged EIF of 1.82. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.

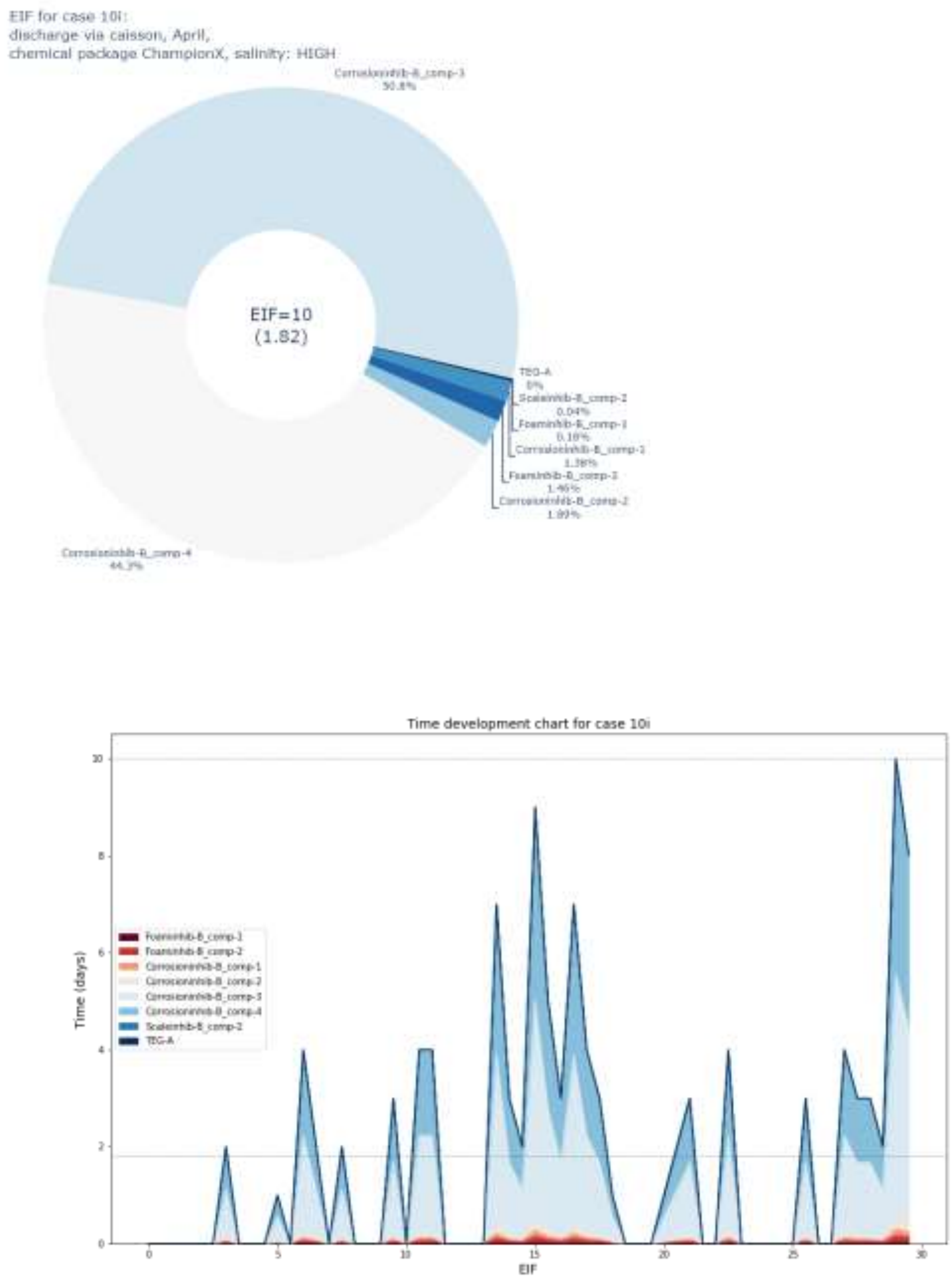


Figure F-6-37 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

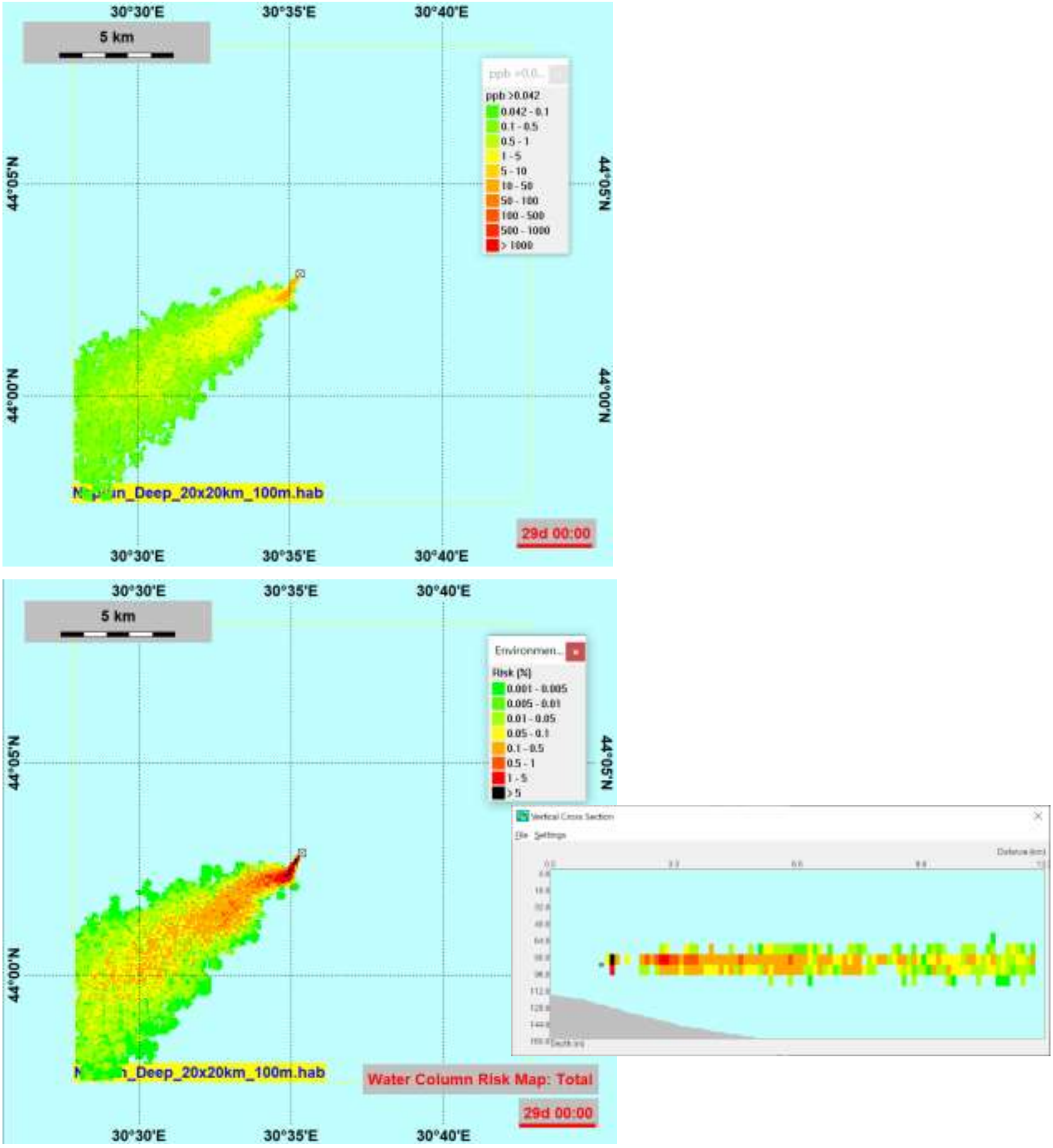
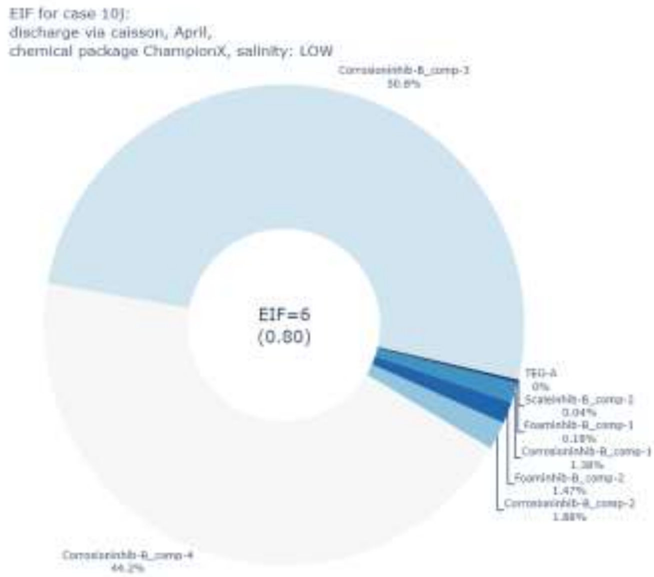


Figure F-6-38 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.2.6 Case 10J: cold season, low salinity PW, April

The resulting maximum EIF is computed with 6 with a time averaged EIF of 0.8. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



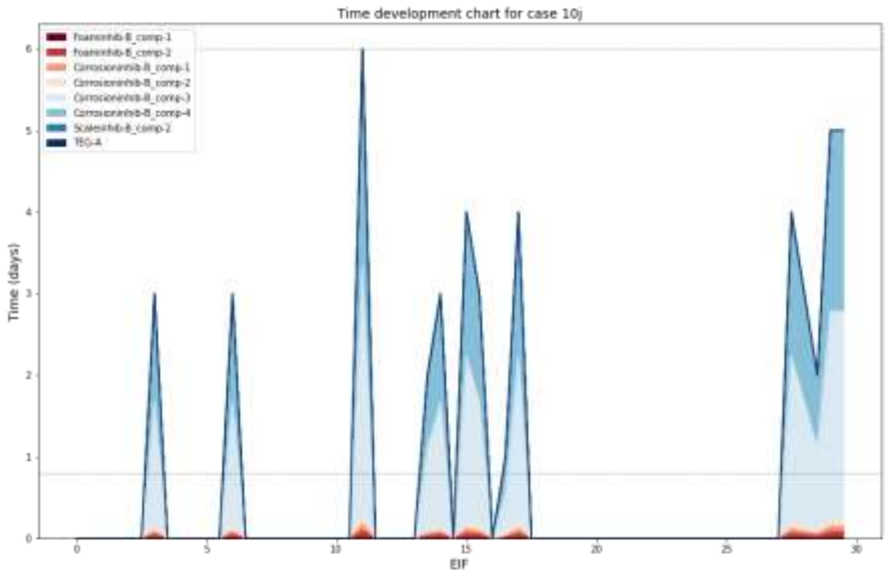


Figure F-6-39 EIF pie chart and time development.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

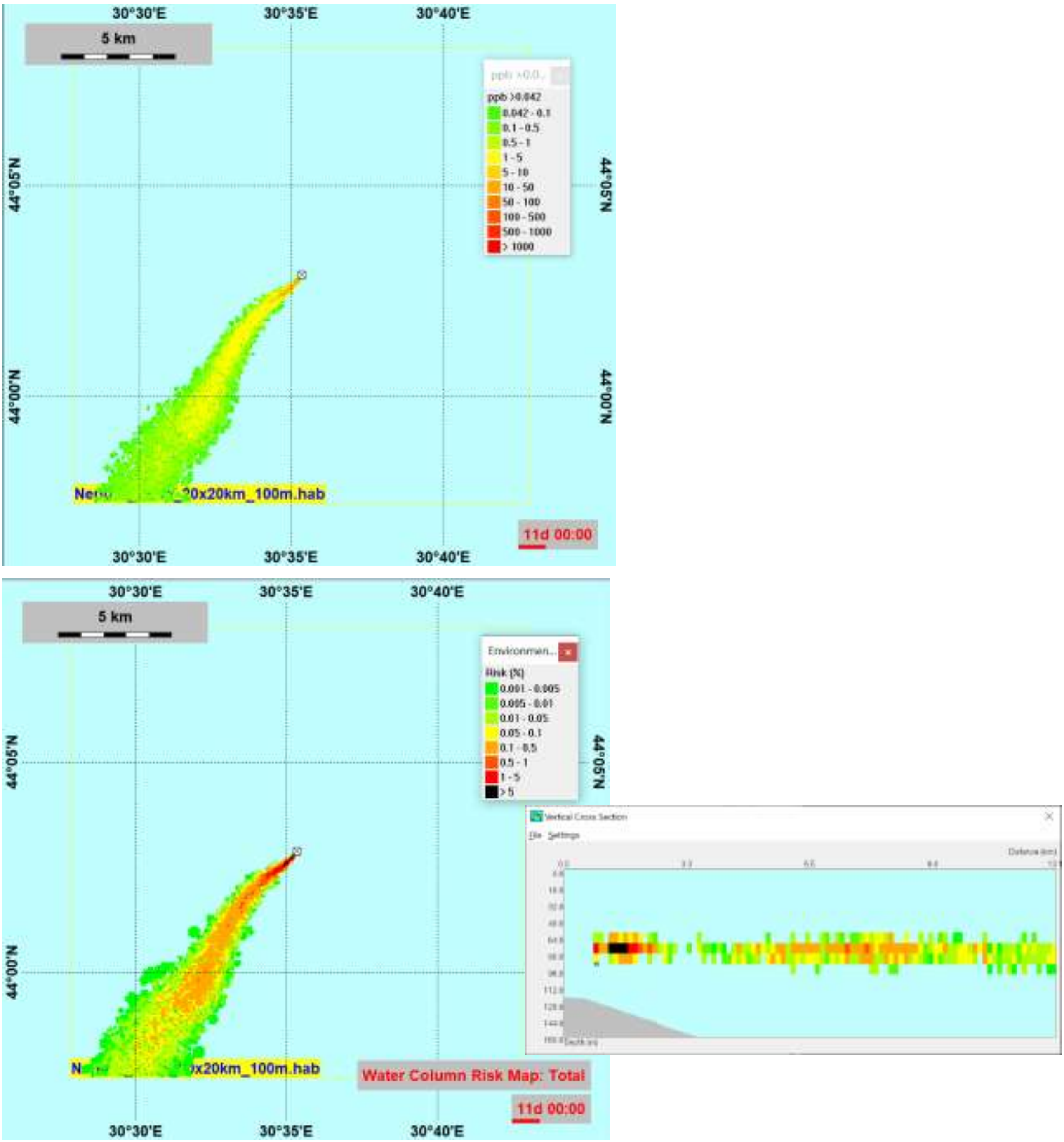


Figure F-6-40 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.3 Well-restart scenarios, intermittent MEOH discharge, low MEOH rate

The scenario setups are based on the following concentrations (minimum dosage) and maximum effluents at Domino and Pelican, as well as intermittent discharge of MEOH at lower rate of 159m^3 over 65 hours:

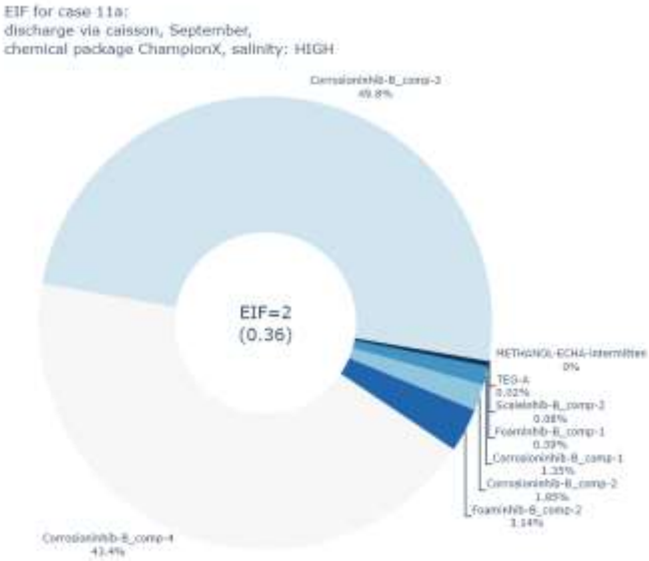
	Profile CHAMPOINXMINPWTEGCOOLINGNOSHC CHAMPIONXMEOHMINPWTEGCOOLINGNOSHC CHAMPOINXMINPWTEGCOOLINGNOSHC			
Case #	11A	11B	11C	11D
Season	warm		cold	
PW Salinity	High	Low	High	Low
Scenario	Min MEOH: PW, TEG, cooling, No SHC	Min MEOH: PW, TEG, cooling, No SHC	Min MEOH: PW, TEG, cooling, No SHC	Min MEOH: PW, TEG, cooling, No SHC
Chemical concentrations ppm:				
Corrosion Inhibitor	50	50	50	50
Component 1	1.2	1.2	1.2	1.2
Component 2	11.24	11.24	11.24	11.24
Component 3	2.2	2.2	2.2	2.2
Component 4	9.76	9.76	9.76	9.76
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	15	15	15	15
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	4.5	4.5	4.5	4.5
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	10	10	10	10
Component 1	4	4	4	4
Component 2	0	0	0	0
Methanol	1,000,000.00	1,000,000.00	1,000,000.00	1,000,000.00
SHC	NO	NO	NO	NO
TEG ppm	332	332	332	332
Effluents m^3/h				
Domino PW m3/h (used for Corrosion Inhibitor)	43.06	43.06	43.06	43.06
Pelican PW m3/h (used for all others)	64.45	64.45	64.45	64.45
TEG	0.57	0.57	0.57	0.57
Cooling water	317.3	317.3	317.3	317.3
159 m3 MEOH over 65 hours	2.45	2.45	2.45	2.45
241 m3 MEOH over 65 hours	NO	NO	NO	NO

This results in mixing of PW, cooling water, water from the TEG stream and MEOH and a 'dilution' of the chemicals in these streams, Sodium Hypochlorite is not accounted for as expected discharge concentrations are within the allowed limits.

Mixing				
Total release volume	384.77	384.77	384.77	384.77
special case: corrosion inhibitor:	9234	9234	9234	9234
Total release volume	363.38	363.38	363.38	363.38
PW dilution by cooling water and TEG water	-	-	-	-
TEG dilution by PW and cooling water	-	-	-	-
special case: corrosion inhibitor:				
PW dilution by cooling water and TEG water	-	-	-	-
Chemicals' dilution by cooling water and TEG water	-	-	-	-
TEG dilution by cooling water				
special case: corrosion inhibitor:				
Chemicals' dilution by cooling water and TEG water	-	-	-	-
PW dilution by TEG water, cooling water and methanol	5.97	5.97	5.97	5.97
TEG dilution by PW, cooling water and methanol	675.03	675.03	675.03	675.03
MEOH dilution by PW, TEG water and cooling water	157.29	157.29	157.29	157.29
special case: corrosion inhibitor:				
PW dilution by TEG water, cooling water and methanol	8.44	8.44	8.44	8.44
Resulting chemical concentrations ppm in discharge:				
Corrosion Inhibitor	*5.92*	*5.92*	*5.92*	*5.92*
Component 1	3.0336	3.0336	3.0336	3.0336
Component 2	0.1422	0.1422	0.1422	0.1422
Component 3	1.3319	1.3319	1.3319	1.3319
Component 4	0.2607	0.2607	0.2607	0.2607
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	*2.5126*	*2.5126*	*2.5126*	*2.5126*
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	0.5025	0.5025	0.5025	0.5025
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	*1.6750*	*1.6750*	*1.6750*	*1.6750*
Component 1	1.0050	1.0050	1.0050	1.0050
Component 2	0.6700	0.6700	0.6700	0.6700
Methanol	6357.5079	6357.5079	6357.5079	6357.5079
SHC	NO	NO	NO	NO
TEG ppm	0.4918	0.4918	0.4918	0.4918
Case #	11A	11B	11C	11D
Resulting salinities	September		April	
PW high salinity	28	28	28	28
PW low salinity	6.787	6.787	6.787	6.787
salinity of cooling water (sea water at 50 m) ppt	18.45	18.45	18.62	18.62
salinity of PW, cooling water & TEG, high salinity PW	19.93		20.07	
salinity of PW, cooling water & TEG, low salinity PW		16.38		16.52
Temperatures				
temperature total volume (PW+TEG+cooling water)	22.32	22.32	22.32	22.32
Computed EIF max (time-averaged)	2 (0.36)	2 (0.25)	0 (0)	0 (0)
	The time-averaged EIF does not really apply here, since we do not have a regular ongoing release but an intermittend additional one.			

F.2.3.1 Case 11A: warm season, high salinity PW, September

The resulting maximum EIF is computed with 2 with a time averaged EIF of 0.36*. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



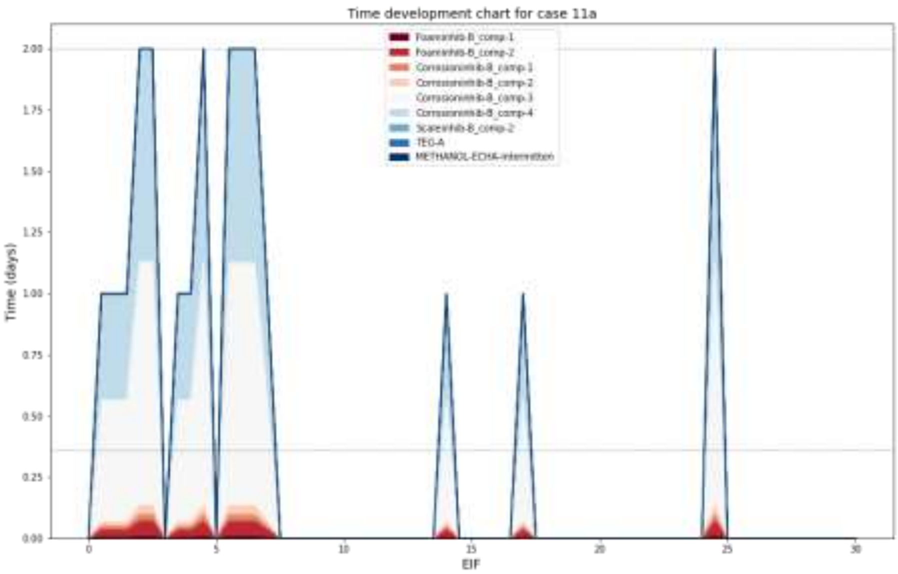


Figure F-6-41 EIF pie chart and time development.

*Time-averaging the EIF does not really make sense here as there is an intermittent discharge in addition to PW.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

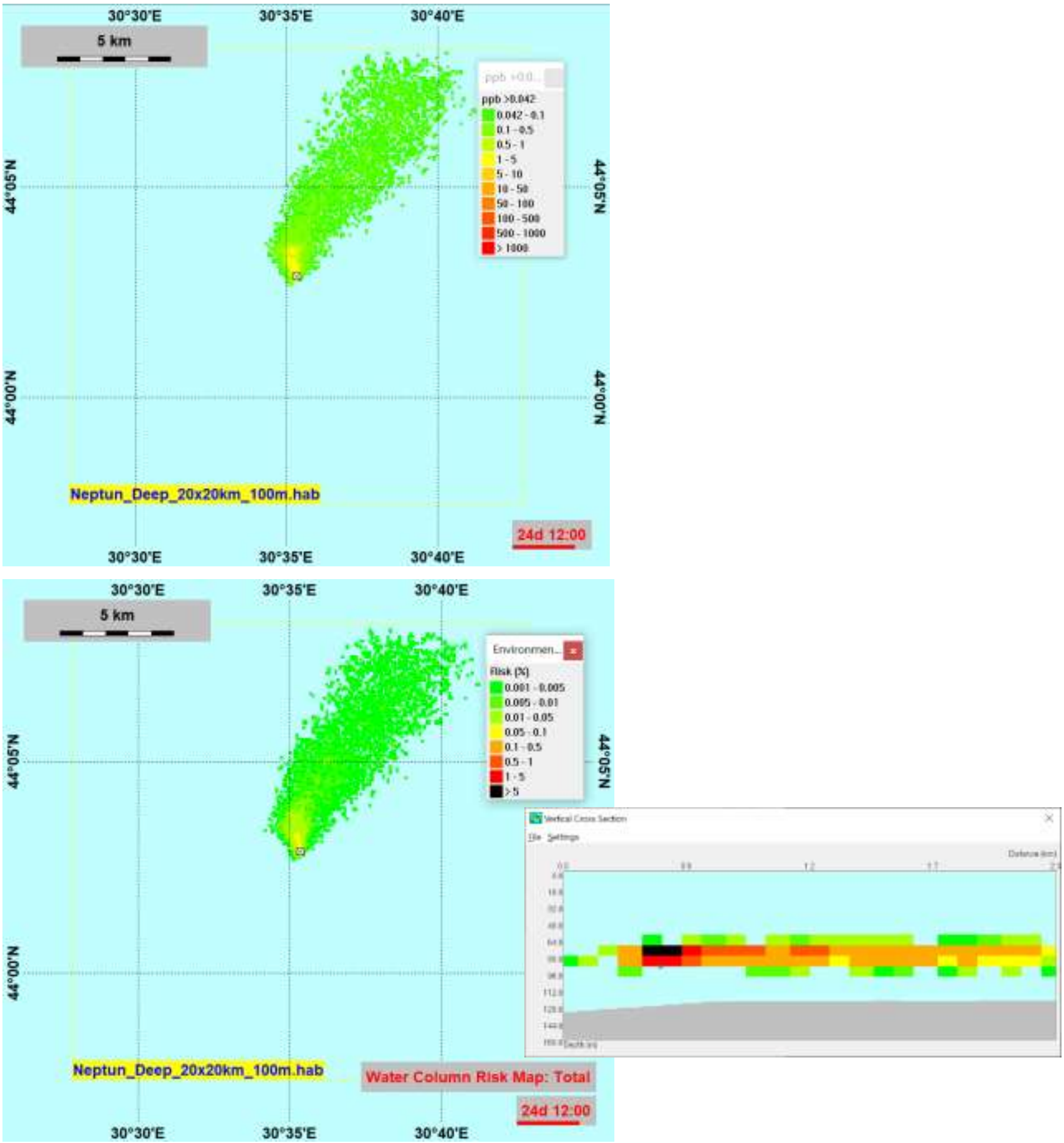


Figure F-6-42 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.3.2 Case 11B: warm season, low salinity PW, September

The resulting maximum EIF is computed with 2 with a time averaged EIF of 0.25*. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.

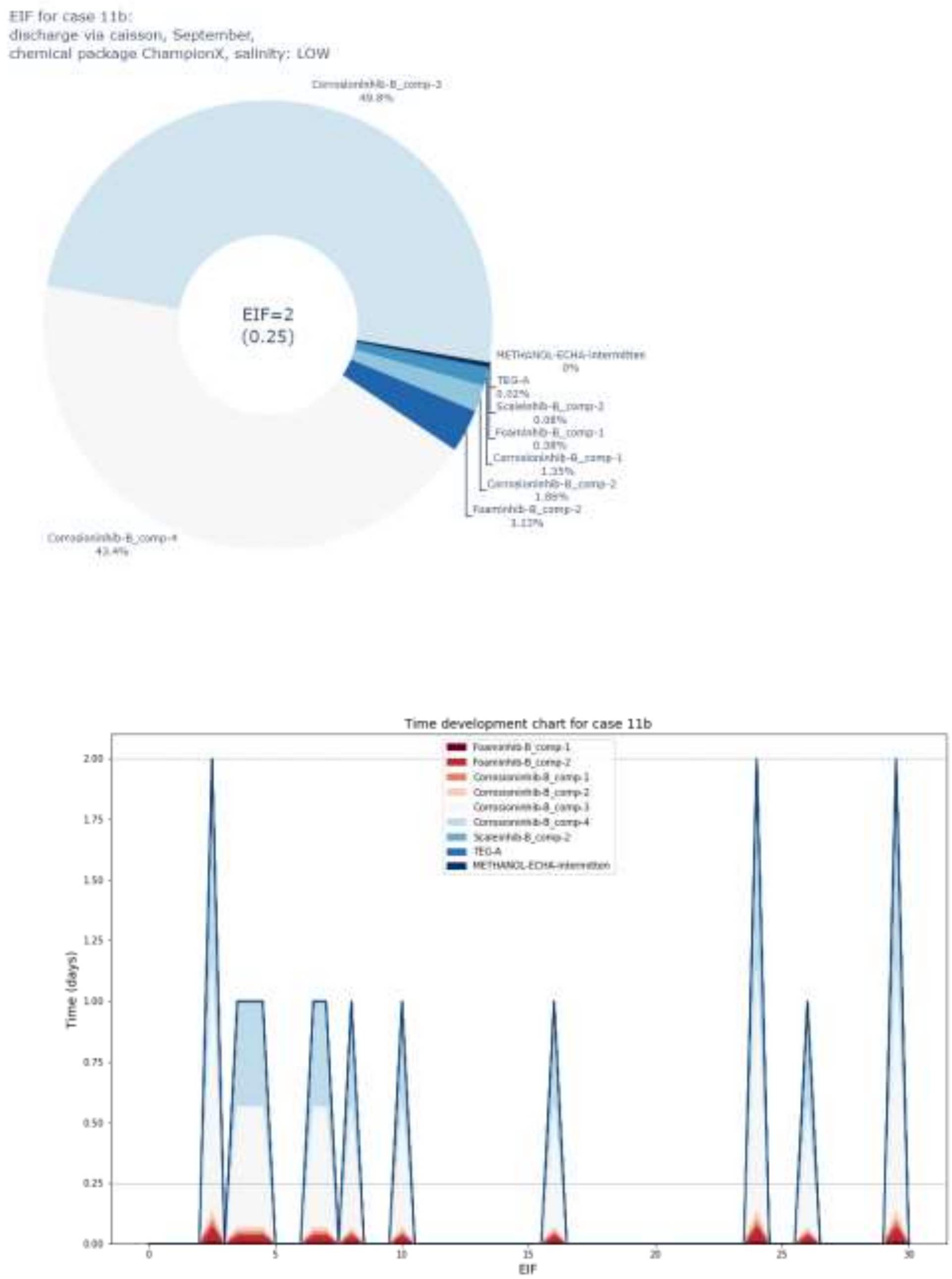


Figure F-6-43 EIF pie chart and time development.

*Time-averaging the EIF does not really make sense here as there is an intermittent discharge in addition to PW.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

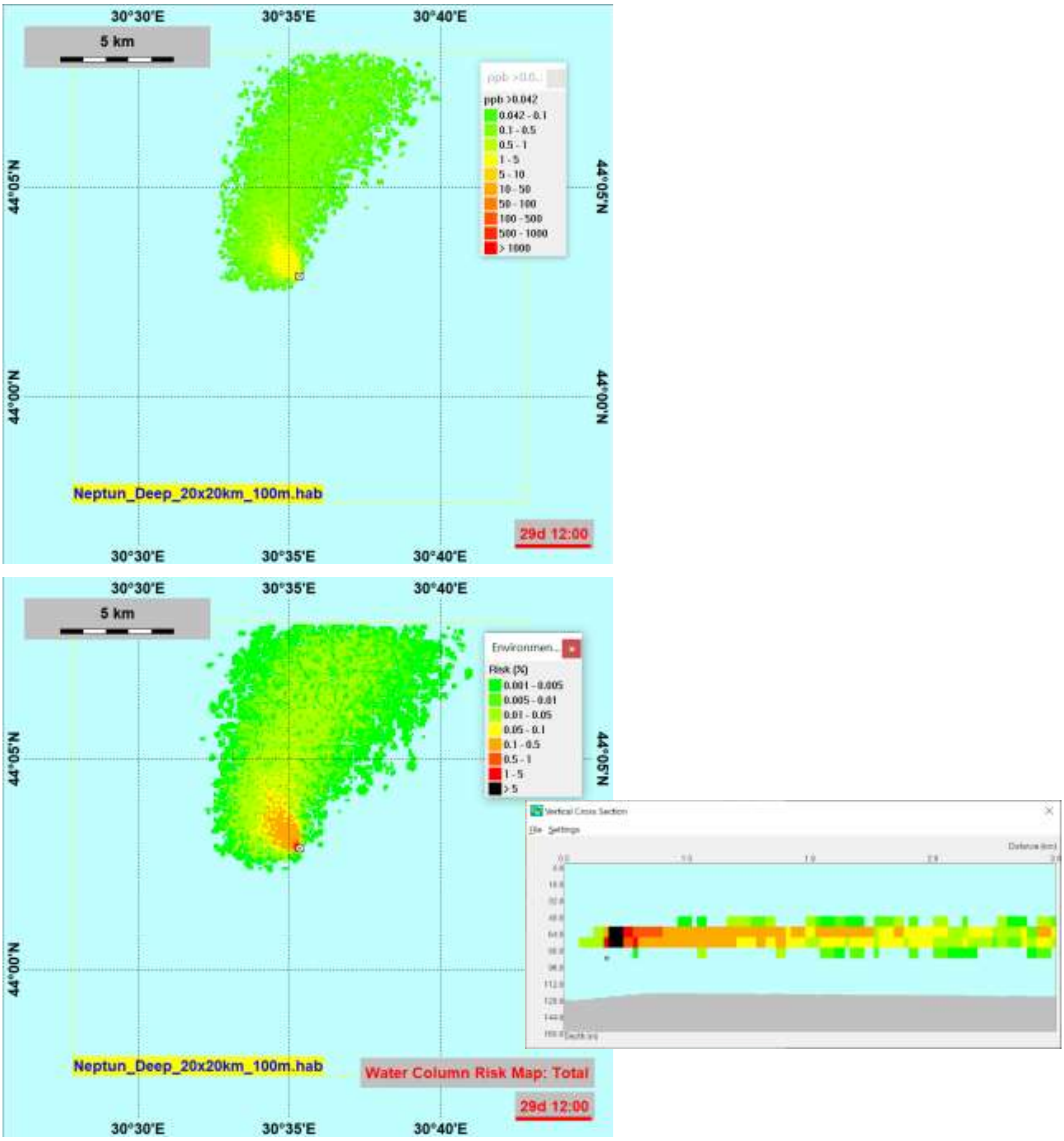


Figure F-6-44 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.3.3 Case 11C: cold season, high salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

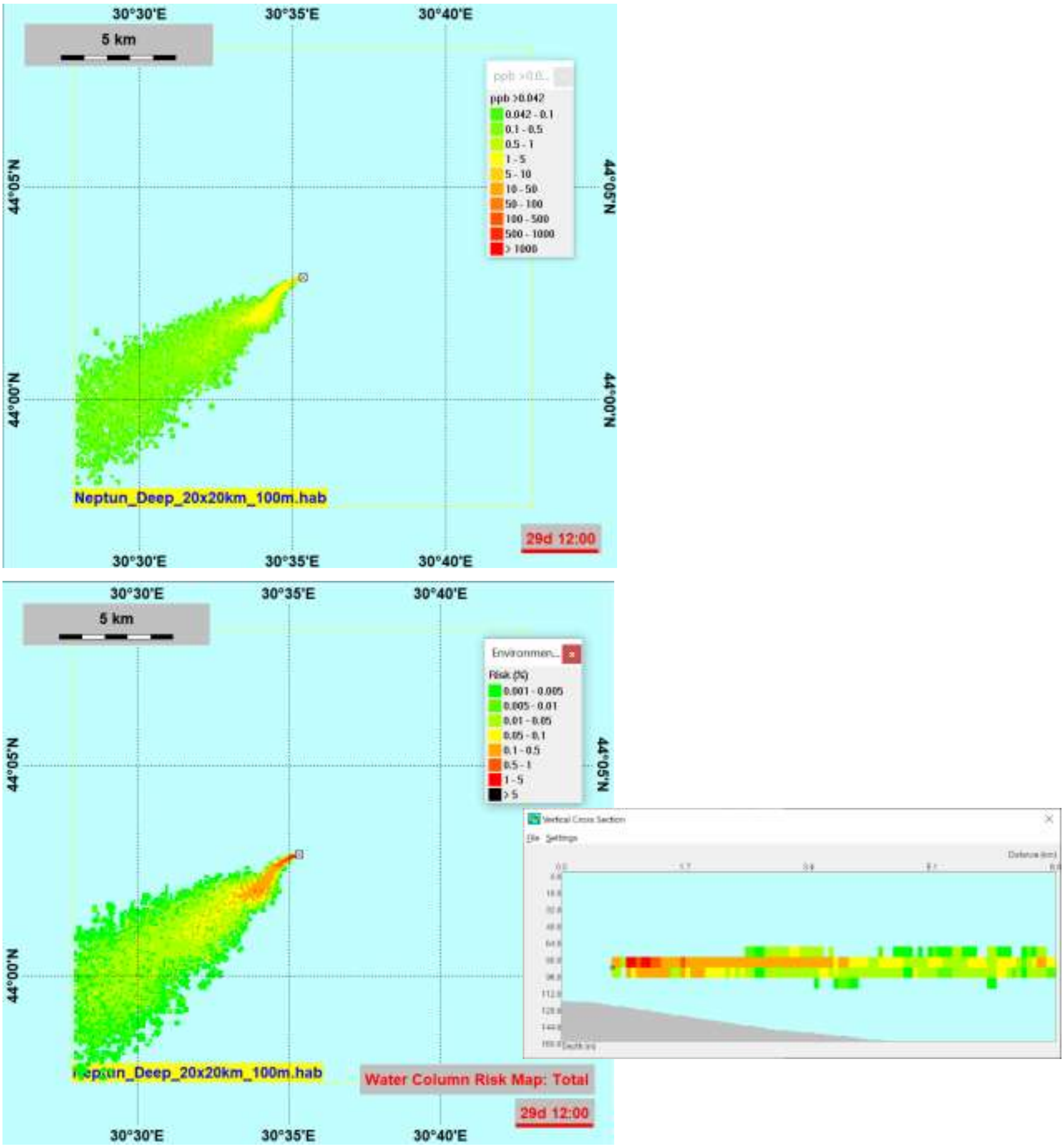


Figure F-6-45 Water column concentrations and resulting environmental risk at the end of the simulation.

F.2.3.4 Case 11D: cold season, low salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

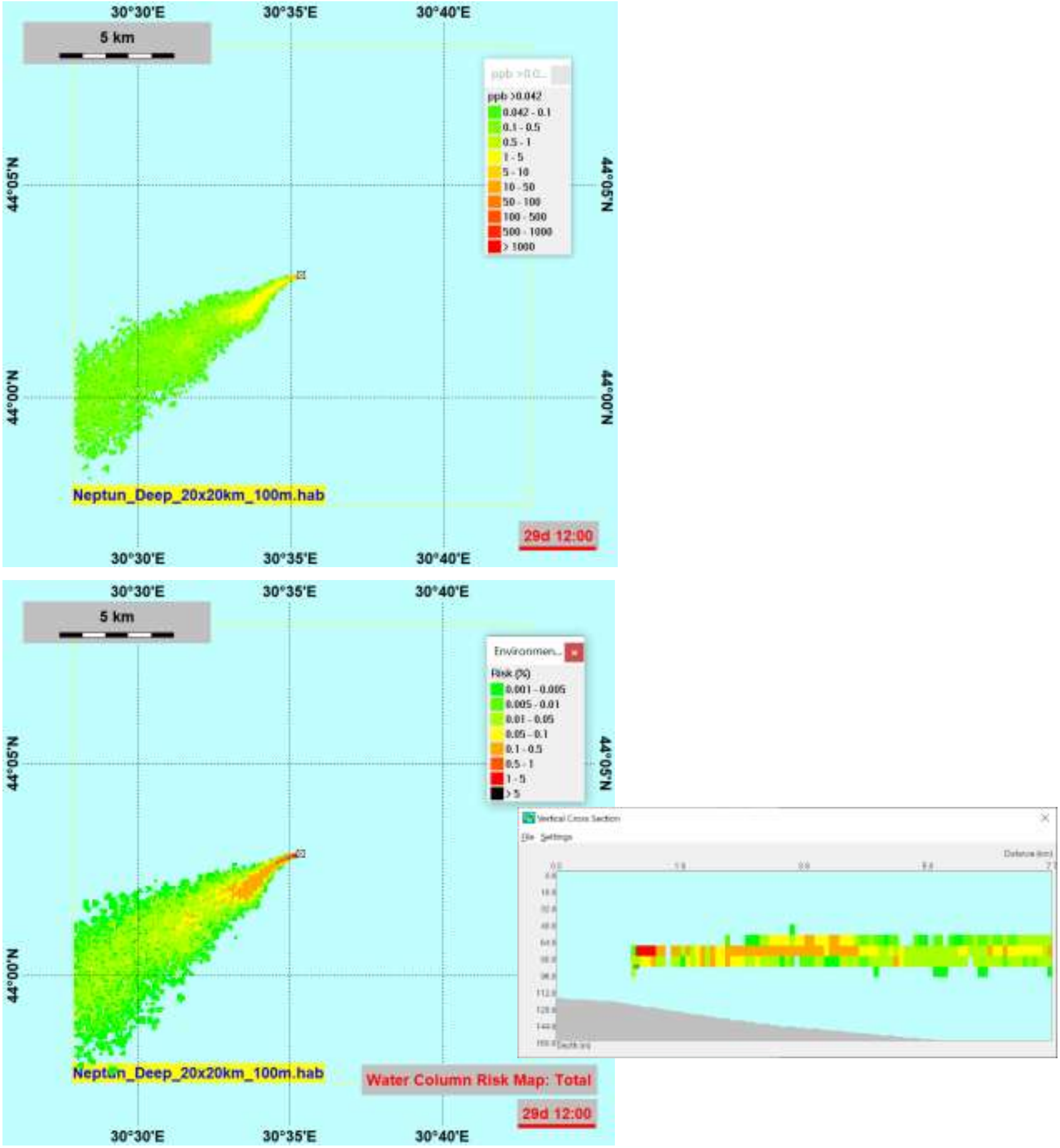


Figure F-6-46 Water column concentrations and resulting environmental risk at the end of the simulation.

F.2.4 Well-restart scenarios, intermittent MEOH discharge, high MEOH rate

The scenario setups are based on the following concentrations (minimum dosage) and maximum effluents at Domino and Pelican, as well as intermittent discharge of MEOH at higher rate of XXXm^3 over 65 hours:

	Profile CHAMPOINXMINPWTEGCOOLINGNOSHC CHAMPIONXMEOHAXPWTEGCOOLINGNOSHC CHAMPOINXMINPWTEGCOOLINGNOSHC			
Case #	11E	11F	11G	11H
Season	warm		cold	
PW Salinity	High	Low	High	Low
Scenario	Max MEOH: PW, TEG, cooling, No SHC	Max MEOH: PW, TEG, cooling, No SHC	Max MEOH: PW, TEG, cooling, No SHC	Max MEOH: PW, TEG, cooling, No SHC
Chemical concentrations ppm:				
Corrosion Inhibitor	50	50	50	50
Component 1	1.2	1.2	1.2	1.2
Component 2	11.24	11.24	11.24	11.24
Component 3	2.2	2.2	2.2	2.2
Component 4	9.76	9.76	9.76	9.76
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	15	15	15	15
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	4.5	4.5	4.5	4.5
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	10	10	10	10
Component 1	4	4	4	4
Component 2	0	0	0	0
Methanol	1,000,000.00	1,000,000.00	1,000,000.00	1,000,000.00
SHC	NO	NO	NO	NO
TEG ppm	332	332	332	332
Effluents m^3/h				
Domino PW m3/h (used for Corrosion Inhibitor)	43.06	43.06	43.06	43.06
Pelican PW m3/h (used for all others)	64.45	64.45	64.45	64.45
TEG	0.57	0.57	0.57	0.57
Cooling water	317.3	317.3	317.3	317.3
159 m3 MEOH over 65 hours	NO	NO	NO	NO
241 m3 MEOH over 65 hours	3.71	3.71	3.71	3.71

This results in mixing of PW, cooling water, water from the TEG stream and MEOH and a 'dilution' of the chemicals in these streams, Sodium Hypochlorite is not accounted for as expected discharge concentrations are within the allowed limits.

Mixing

Total release volume	386.03	386.03	386.03	386.03
special case: corrosion inhibitor:	9265	9265	9265	9265
Total release volume	364.64	364.64	364.64	364.64
PW dilution by cooling water and TEG water	-	-	-	-
TEG dilution by PW and cooling water	-	-	-	-
special case: corrosion inhibitor:				
PW dilution by cooling water and TEG water	-	-	-	-
Chemicals' dilution by cooling water and TEG water	-	-	-	-
TEG dilution by cooling water				
special case: corrosion inhibitor:				
Chemicals' dilution by cooling water and TEG water	-	-	-	-
PW dilution by TEG water, cooling water and methanol	5.99	5.99	5.99	5.99
TEG dilution by PW, cooling water and methanol	677.24	677.24	677.24	677.24
MEOH dilution by PW, TEG water and cooling water	104.12	104.12	104.12	104.12
special case: corrosion inhibitor:				
PW dilution by TEG water, cooling water and methanol	8.47	8.47	8.47	8.47

Resulting chemical concentrations ppm in discharge:

Corrosion Inhibitor	*5.90*	*5.90*	*5.90*	*5.90*
Component 1	3.0231	3.0231	3.0231	3.0231
Component 2	0.1417	0.1417	0.1417	0.1417
Component 3	1.3273	1.3273	1.3273	1.3273
Component 4	0.2598	0.2598	0.2598	0.2598
Component 5	PLONOR	PLONOR	PLONOR	PLONOR
Scale inhibitor	*2.5044*	*2.5044*	*2.5044*	*2.5044*
Component 1	PLONOR	PLONOR	PLONOR	PLONOR
Component 2	0.5009	0.5009	0.5009	0.5009
Component 3	PLONOR	PLONOR	PLONOR	PLONOR
Component 4	PLONOR	PLONOR	PLONOR	PLONOR
Anti Foam	*1.6696*	*1.6696*	*1.6696*	*1.6696*
Component 1	1.0017	1.0017	1.0017	1.0017
Component 2	0.6678	0.6678	0.6678	0.6678
Methanol	9604.7314	9604.7314	9604.7314	9604.7314
SHC	NO	NO	NO	NO
TEG ppm	0.4902	0.4902	0.4902	0.4902

Case #	11E	11F	11G	11H
Resulting salinities	September		April	
PW high salinity	28	28	28	28
PW low salinity	6.787	6.787	6.787	6.787
salinity of cooling water (sea water at 50 m) ppt	18.45	18.45	18.62	18.62
salinity of PW, cooling water & TEG, high salinity PW	19.87	19.87	20.01	20.01
salinity of PW, cooling water & TEG, low salinity PW	16.33	16.33	16.47	16.47

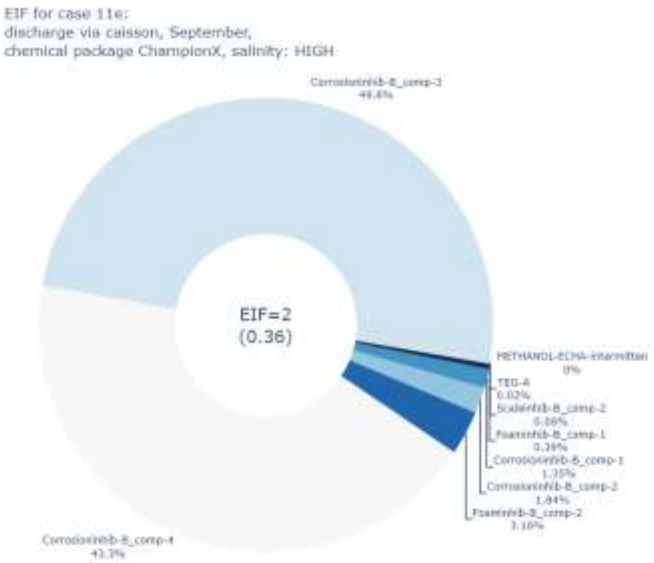
Temperatures				
temperature total volume (PW+TEG+cooling water)	22.32	22.32	22.32	22.32

Computed EIF max (time-averaged)	2 (0.36)	1 (0.16)	0 (0)	0 (0)

The time-averaged EIF does not really apply here, since we do not have a regular ongoing release but an intermittend additional one.

F.2.4.1 Case 11E: warm season, high salinity PW, September

The resulting maximum EIF is computed with 2 with a time averaged EIF of 0.36*. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



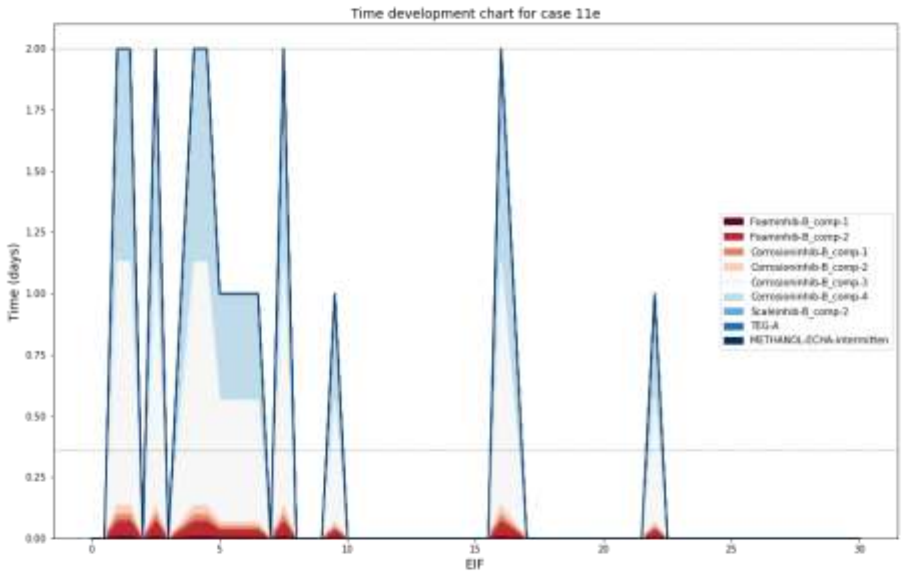


Figure F-6-47 EIF pie chart and time development.

*Time-averaging the EIF does not really make sense here as there is an intermittent discharge in addition to PW.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

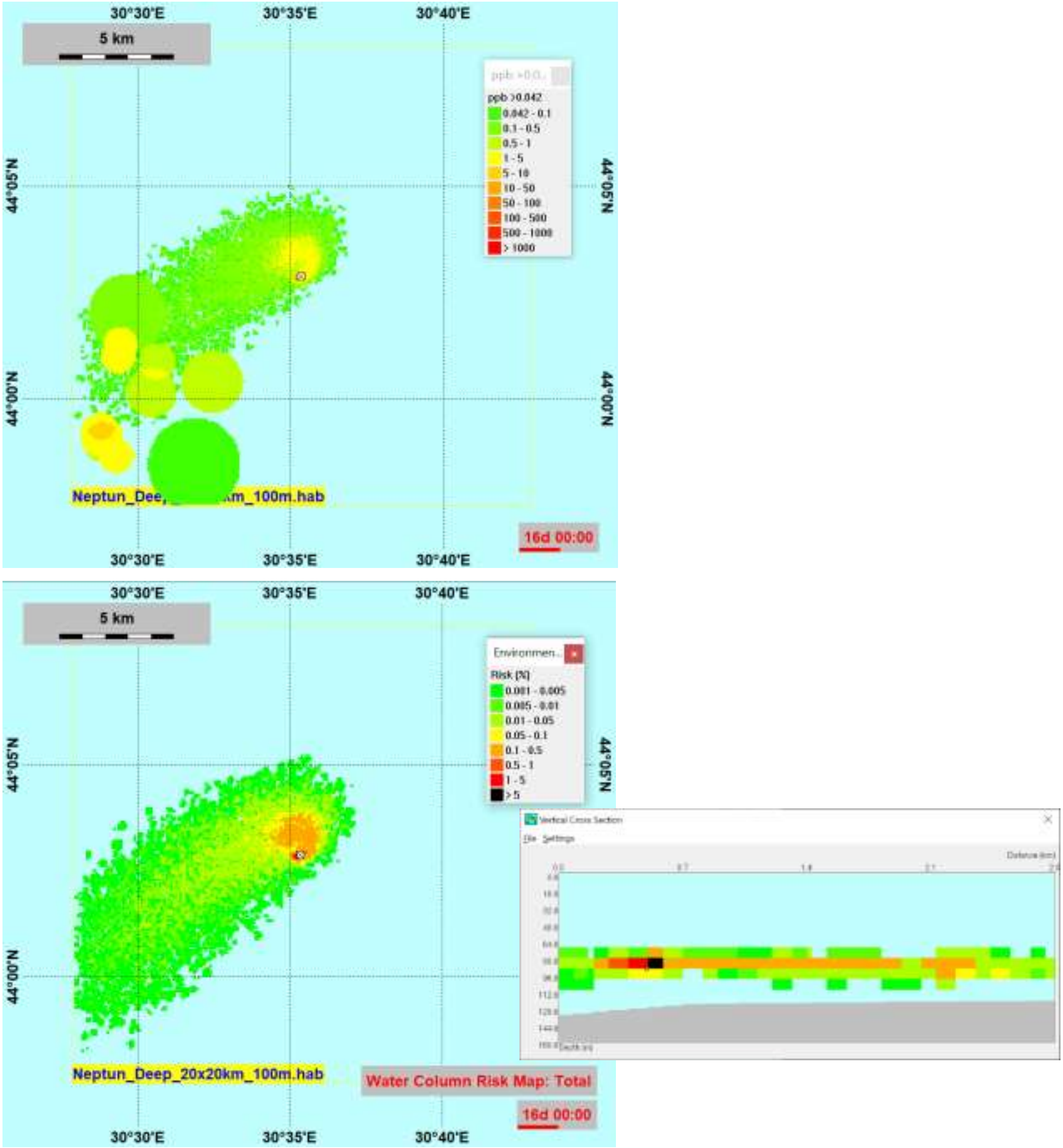
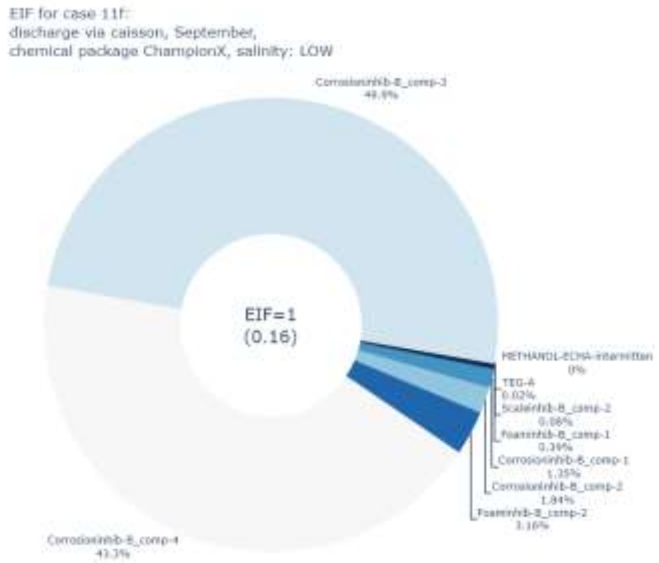


Figure F-6-48 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.4.2 Case 11F: warm season, low salinity PW, September

The resulting maximum EIF is computed with 1 with a time averaged EIF of 0.16*. Time development and pie chart for contribution to the maximum EIF by the single chemical components are shown below.



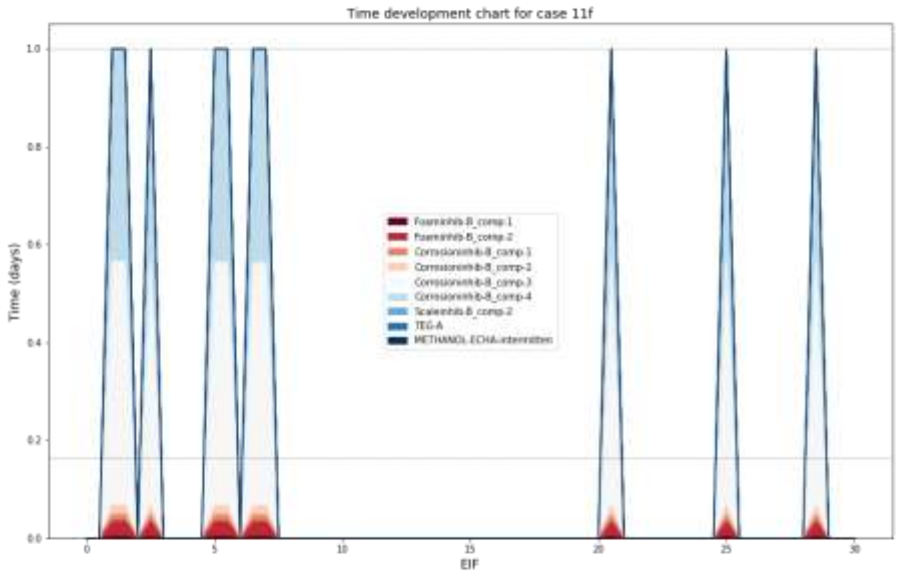


Figure F-6-49 EIF pie chart and time development.

*Time-averaging the EIF does not really make sense here as there is an intermittent discharge in addition to PW.

Maximum water column concentrations and resulting environmental risk at the time of maximum EIF are shown in the snapshots below:

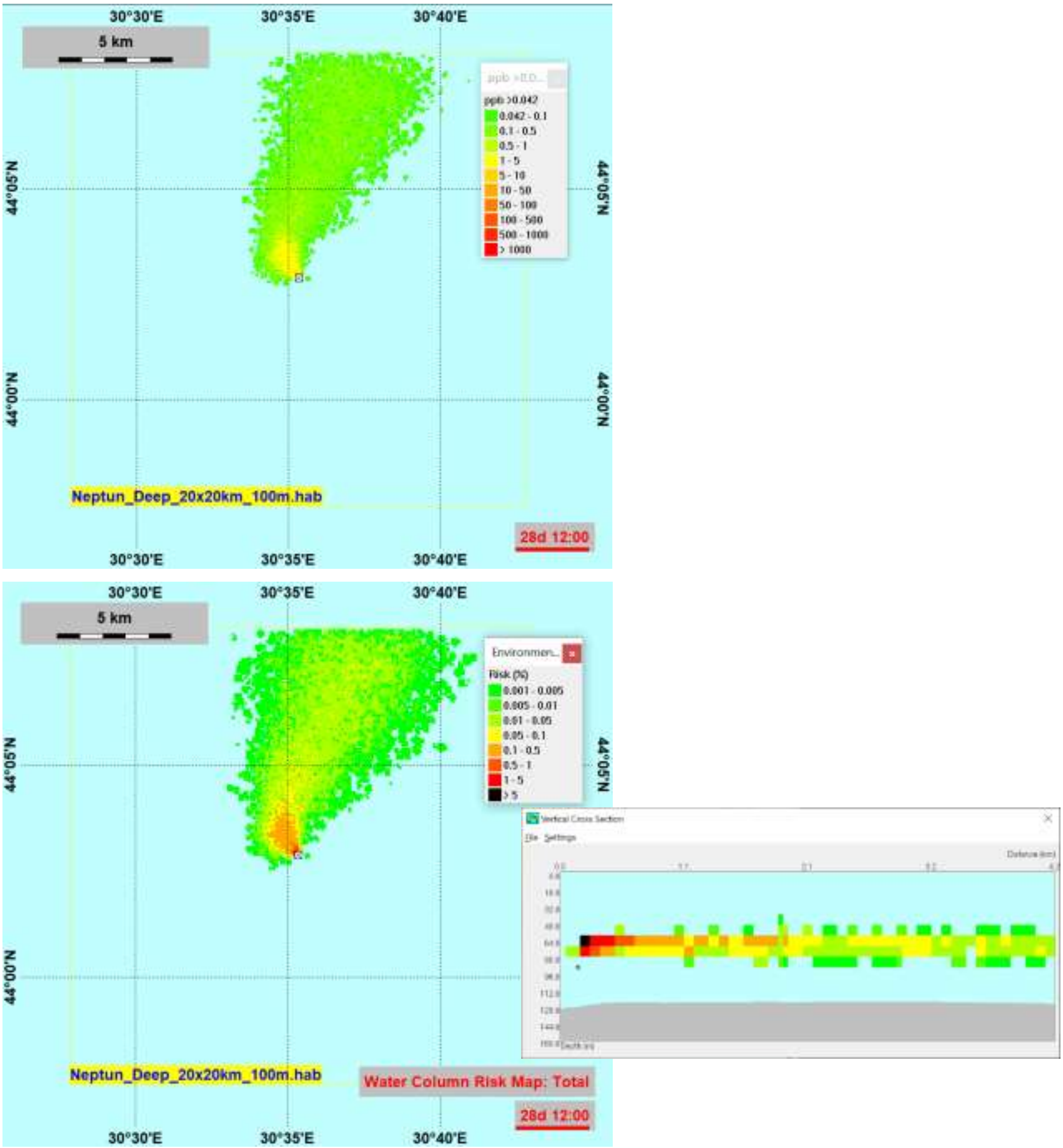


Figure F-6-50 Water column concentrations and resulting environmental risk at the time of maximum EIF.

F.2.4.3 Case 11G: cold season, high salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

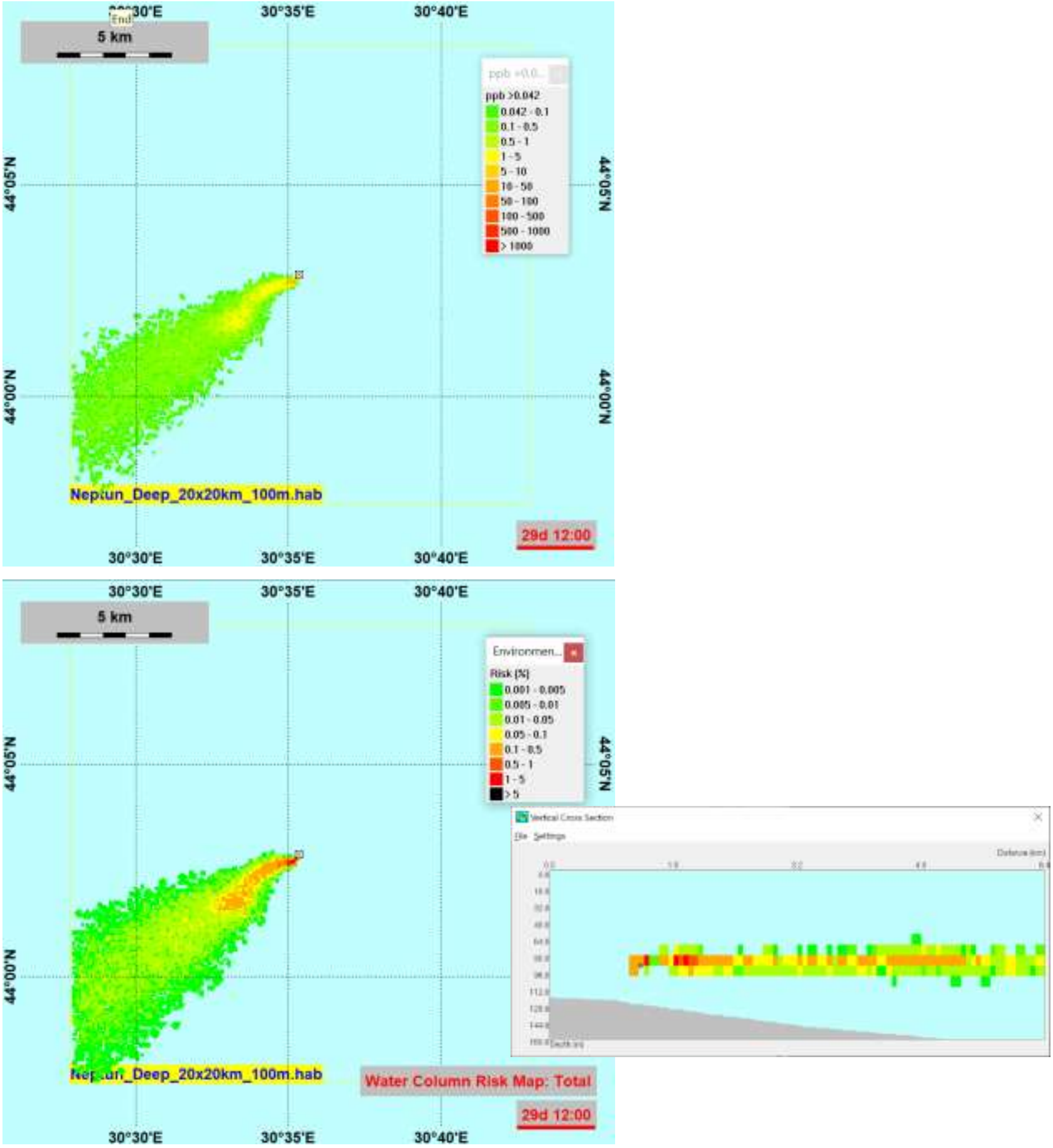


Figure F-6-51 Water column concentrations and resulting environmental risk at the end of the simulation.

F.2.4.4 Case 11H: cold season, low salinity PW, April

The resulting maximum EIF is computed with 0.

Maximum water column concentrations and resulting environmental risk at the end of the simulation are shown in the snapshots below:

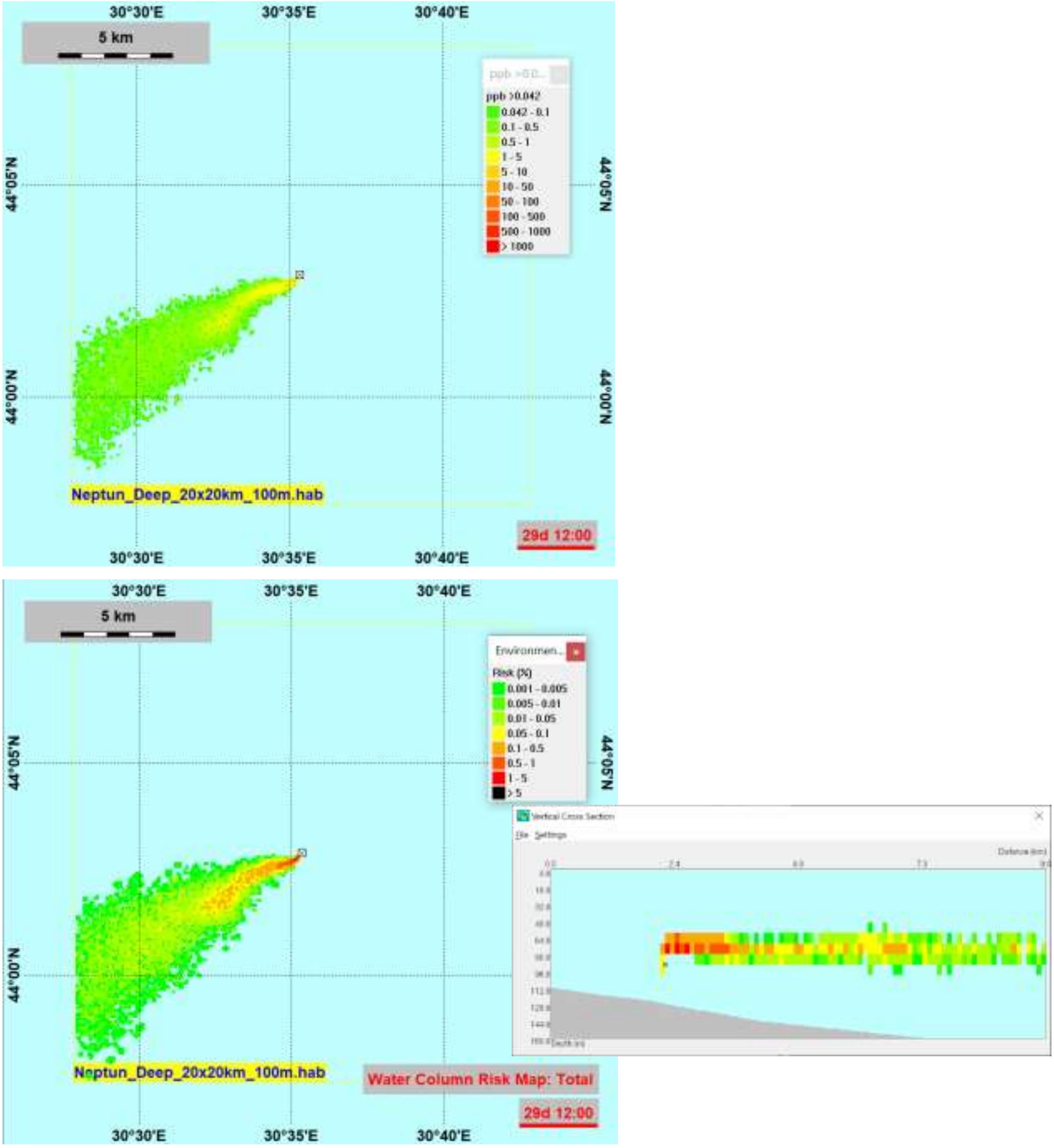


Figure F-6-52 Water column concentrations and resulting environmental risk at the end of the simulation.

F.3 Interpretation & Conclusion

SINTEF has performed DREAM simulations for a range of >60 different scenarios for PW discharges at the Neptun Deep development. The scenarios were used to employ the OSPAR risk-based approach to PW discharges and included:

1. Scenarios to assess the optimal discharge depth and diameter of the Neptun caisson to arrive at preferred behaviour of the discharge in the water columns and minimal environmental risk expressed through the EIF. These scenarios resulted in a discharge design with a caisson outlet at 90m depth and a 0.5m diameter, see Chapter 4.1.
2. Scenarios to compare the two proposed chemical packages from ChampionX and Schlumberger for corrosion inhibitor, scale inhibitor and foam inhibitor. The scenarios showed a clear better environmental performance of the ChampionX package, see Chapter 5.1.
3. Scenarios to compare discharges from the caisson with discharges through a pipeline, which resulted in favour of the caisson, see Chapter 5.5.
4. Scenarios for dilution of the PW in the discharge which performed unfavourable in comparison to direct discharge with dilution by cooling water only.

Additionally, scenarios included the comparison between colder and warmer months as well as high and low salinity PW and scenarios that accounted for intermittent discharges from well restart scenarios.

The latest set of simulation is based on the most realistic and expected concentrations for the production chemicals and reported in Appendix F, the EIF results are summarised in the image below, showing EIF results for the warmer months (represented by September) in blue and EIF results for the colder months (represented by April) in orange. The size of the dots is proportional to the computed EIF.

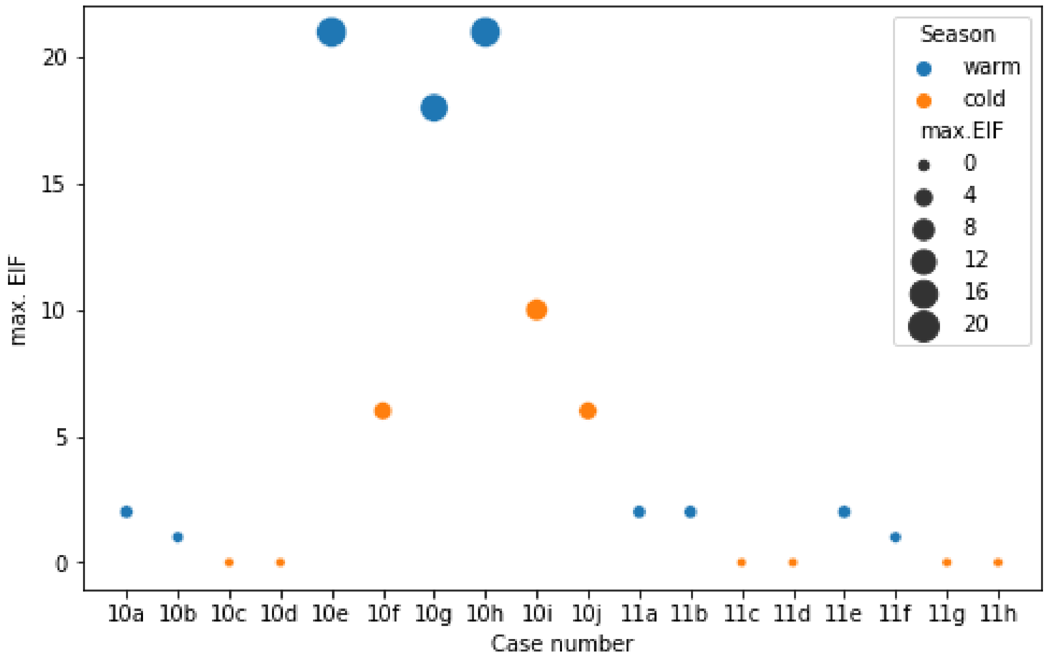


Figure F-6-53 Summary of latest results as reported in this Chapter.

The results show that EIF are relatively low with maximum EIF of 21 for maximum discharge concentrations in cases 10f, 10g, and 10h, see Chapter E.1 for comparison to other fields / studies. The scenarios confirm the favourable properties of the ChampionX chemical package. EIF results are based on HOCNF toxicity data and the employed PNECS are derived from LC50 values and a safety factor of 1000.

Intermittent discharges of MEOH at the studies rates do not influence environmental risk and EIF. MEOH is considered PLONOR and only included in environmental risk assessment when not discharged intermittent or in very high volumes.

In conclusion, the chemical components from the corrosion inhibitor might pose environmental risk to a small water volume around the discharge when discharged in the warmer months. This is based on conservative PNECS based on LC50 values and a safety factor of 1000. At the highest studied dosages, EIF are still around 20, i.e. no environmental risk beyond some 100m from the discharge point for all studied cases.