Modelling of exposure.
Further development of the DREAM model.

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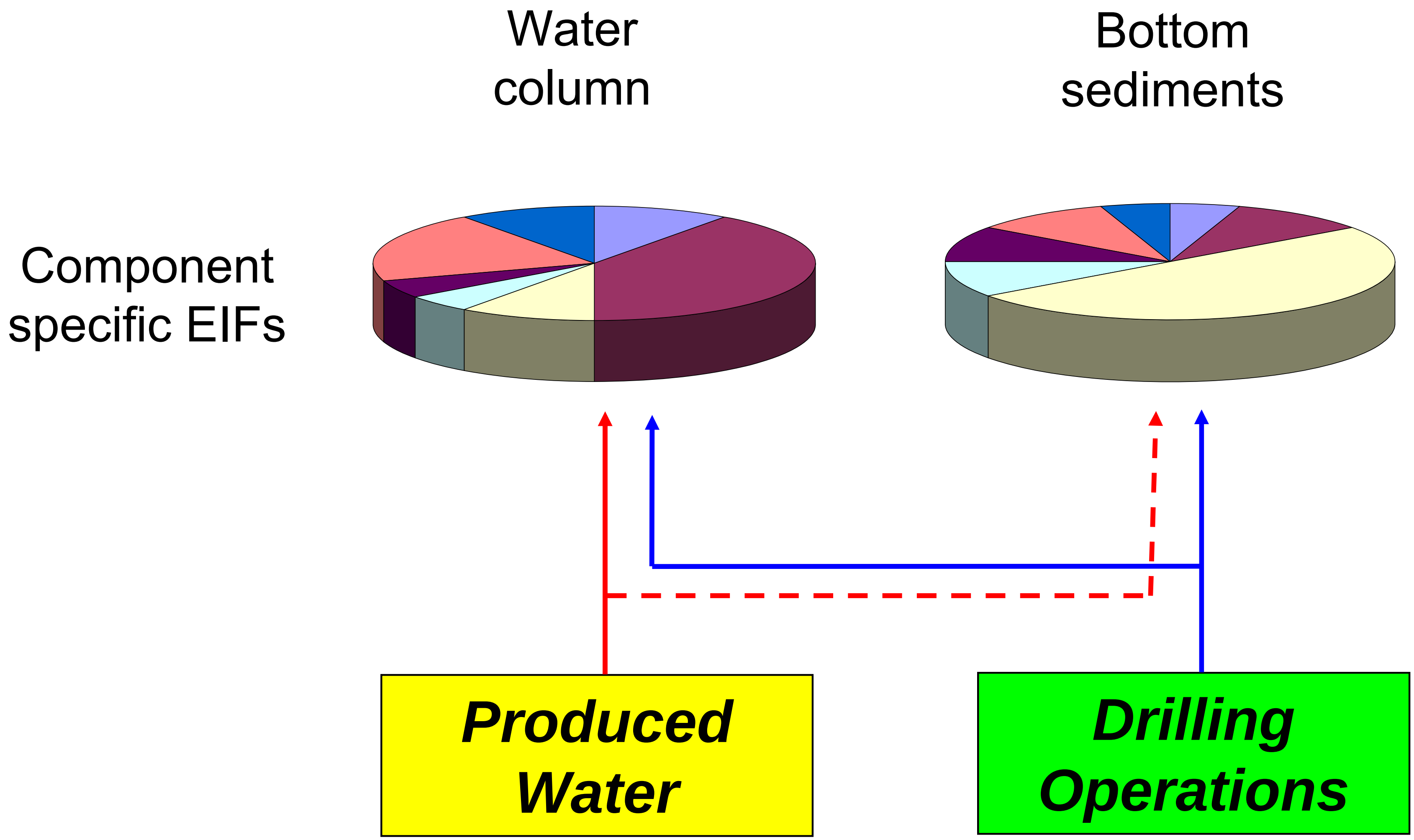
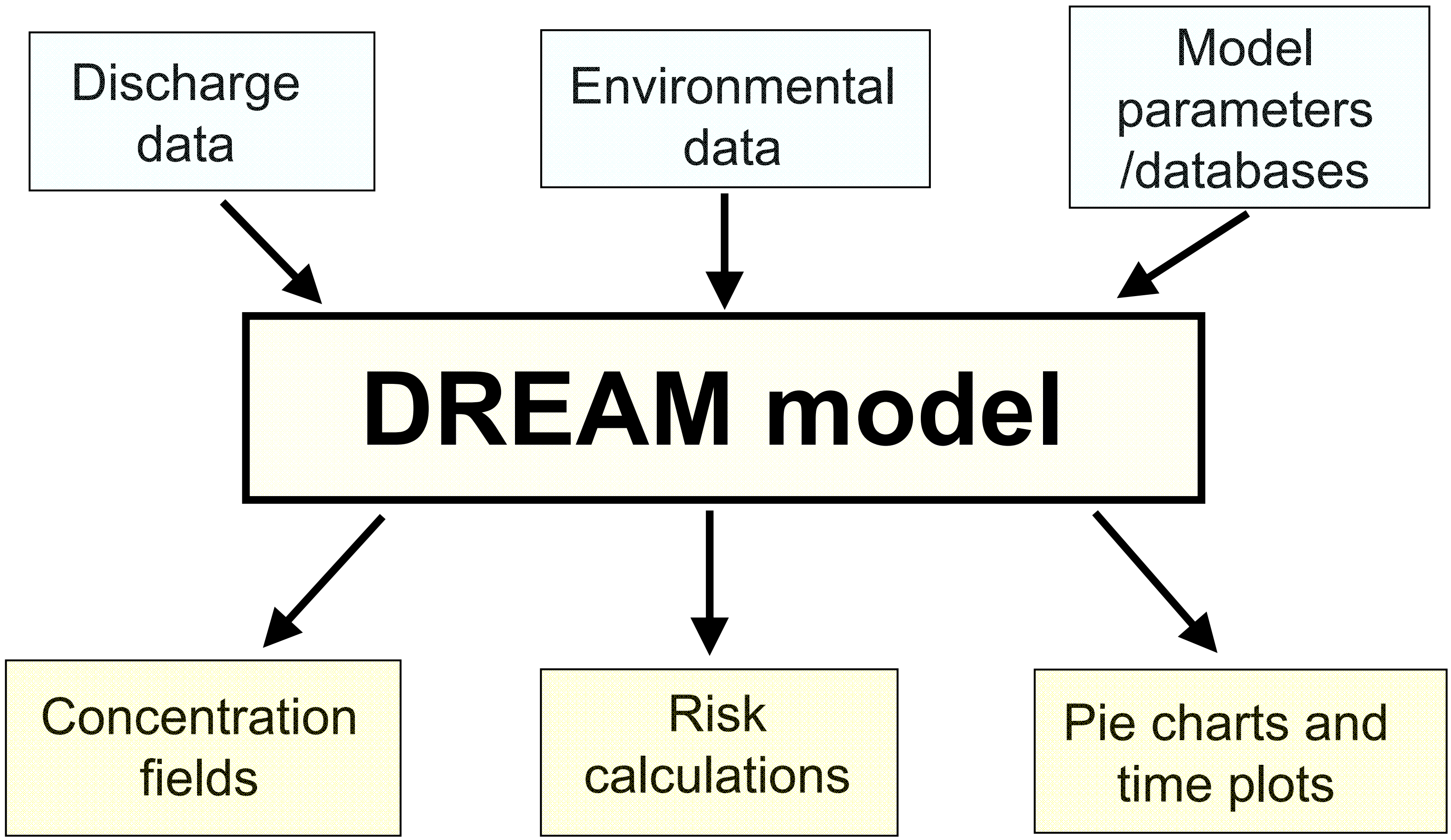
DREAM Model

- **Dose-related Risk and Effects Assessment Model**
  - Originally: Doses on biota
  - Then: Zero discharge policy
  - Response: EIF for produced water
  - Follow-up: EIF for drilling discharges

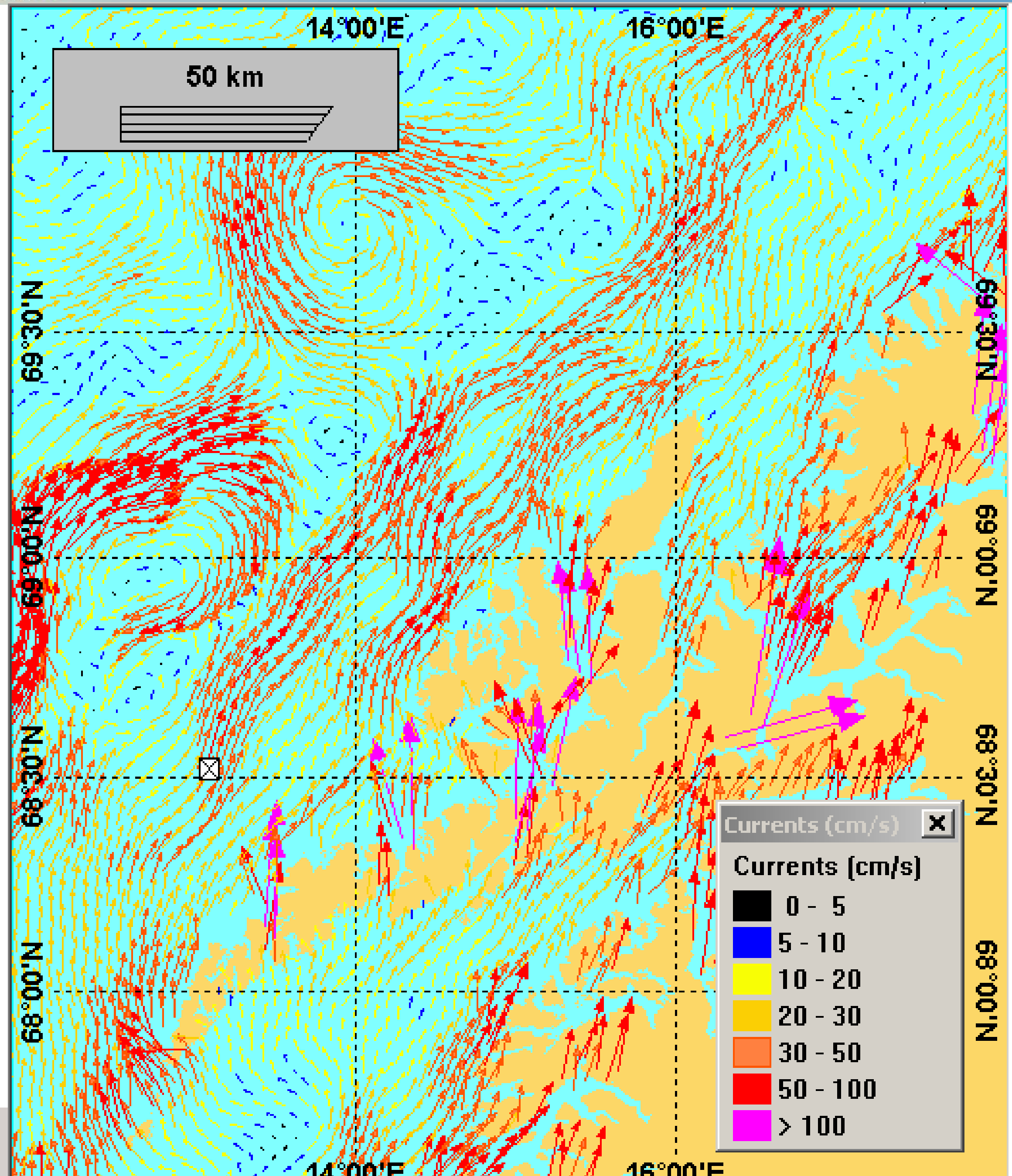
Two compartments involved:



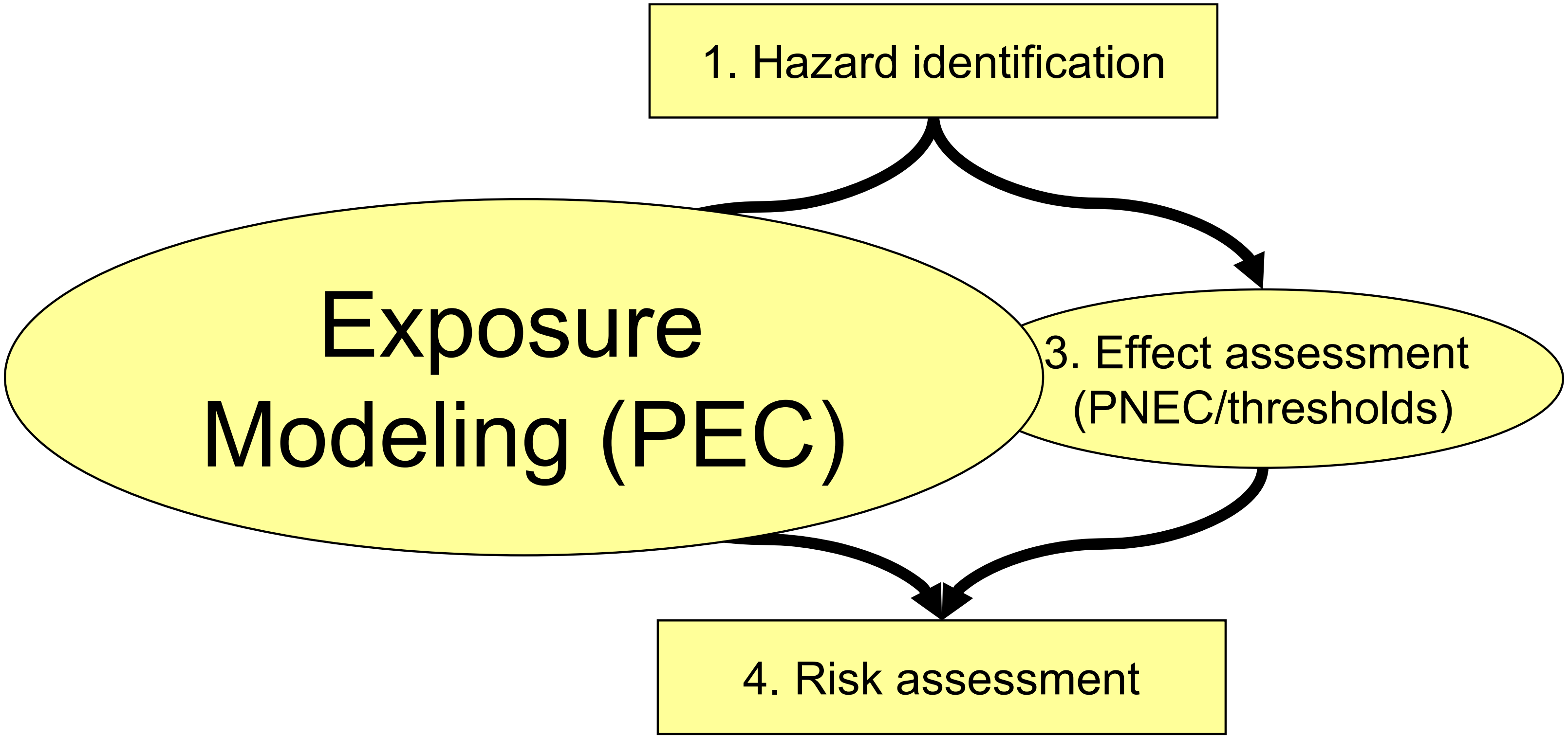
Model structure:



”Ocean currents used in the DREAM model. ”Snapshot” of the surface currents calculated with the ECOM-3D model. Geographical resolution 4 km.



Concept


1. Hazard identification
Exposure
Modeling (PEC)
3. Effect assessment
(PNEC/thresholds)
4. Risk assessment

PEC = Predicted Environmental Concentration.
Concentrations in the recipient calculated with the DREAM model. Concentrations are calculated as a function of x, y, z and time.

PNEC = Predicted No Effect Concentration (Thresholds).
The largest concentration of a product or a chemical expected to cause no measurable environmental effects. For offshore chemicals the PNEC value is determined from acute toxicity testing results values divided by an assessment factor.

EIF = Environment Impact Factor.
A measure for potential environmental risk, that is, damage on marine organisms from a discharge to sea. EIF is defined as being proportional to the water volume where PEC/PNEC > 1 (or a joint risk probability > 5 %).

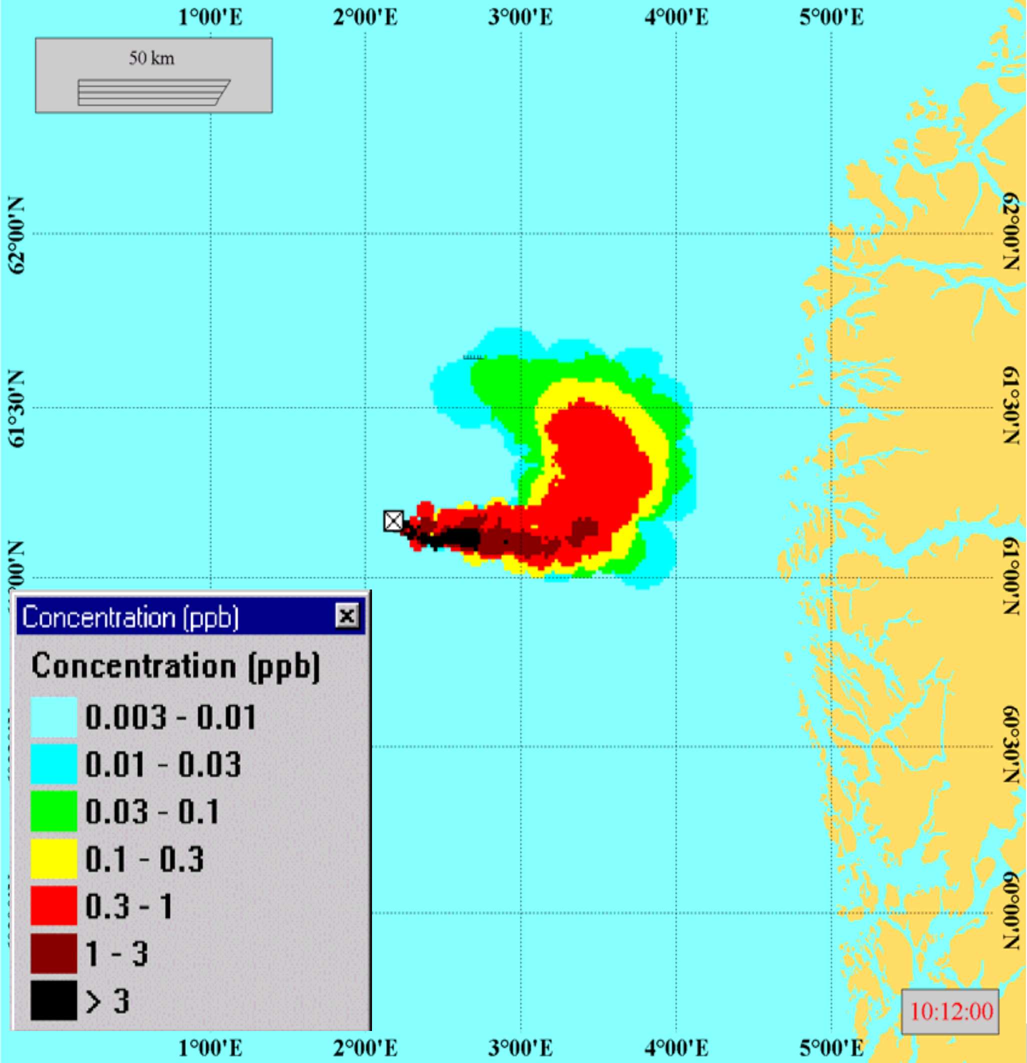
Unit EIF for water column: 100m x 100m x 10m (vol.)
Unit EIF for the sediment: 100m x 100m (area)

Calculation of produced water concentrations with the DREAM model.

3D and time variable concentration field

Parameters

- ✓Wind
- ✓Currents
- ✓Biodegradation
- ✓Evaporation
- ✓Adsorption to particulates

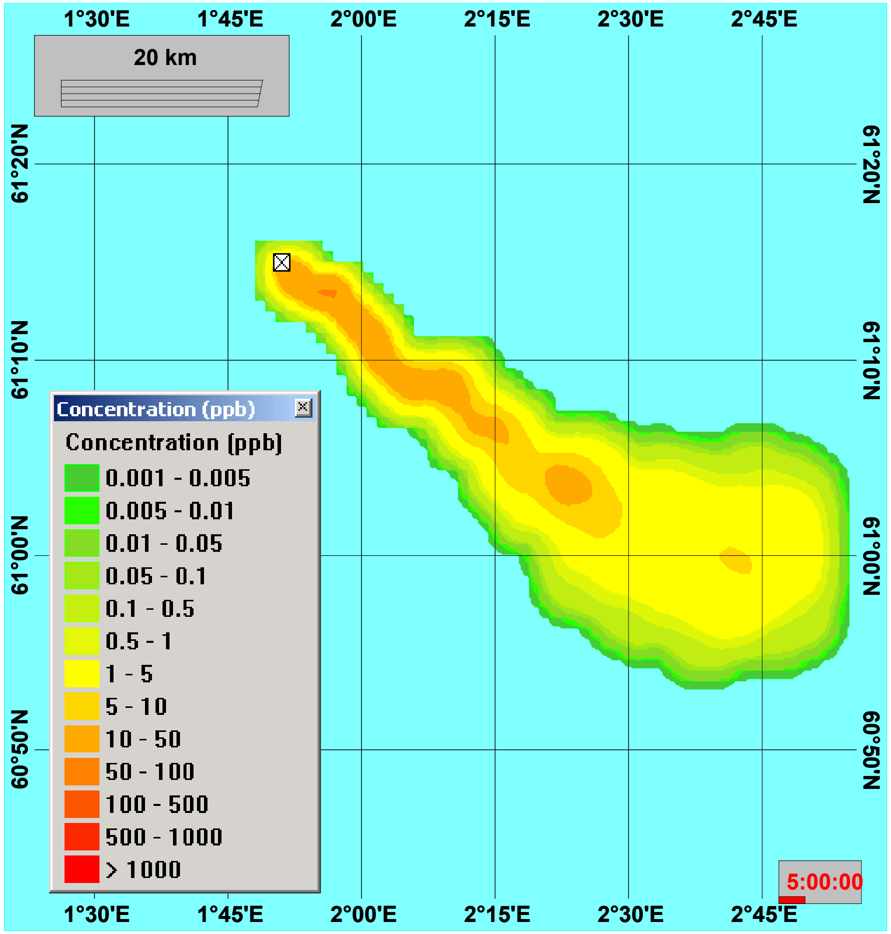


Calculation of PEC

Concentration field for discharge of produced water, calculated with the DREAM model.

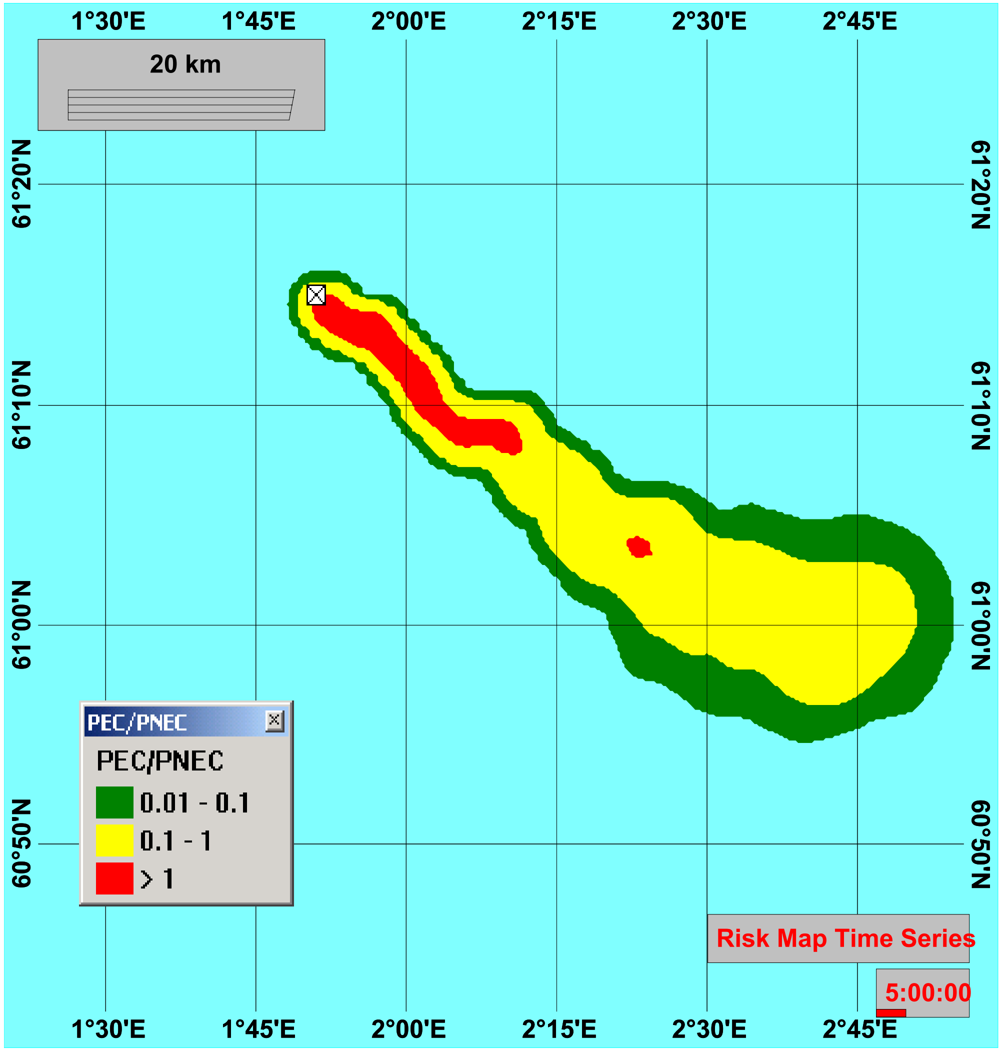
The figure shows the sum of all compounds that contribute to potential risk to the environment:

- added chemicals
- dispersed oil
- PAH's
- phenols
- heavy metals

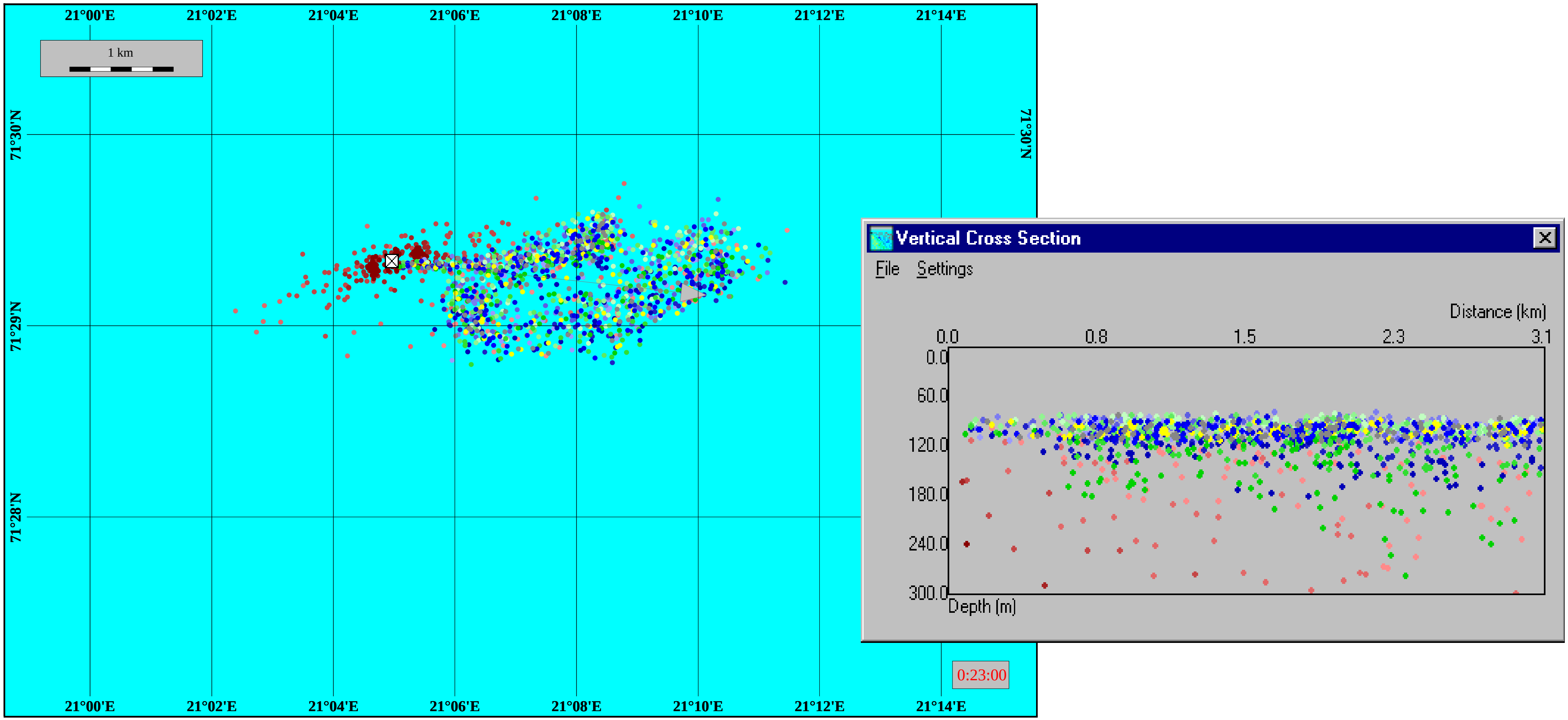


Calculation of EIF

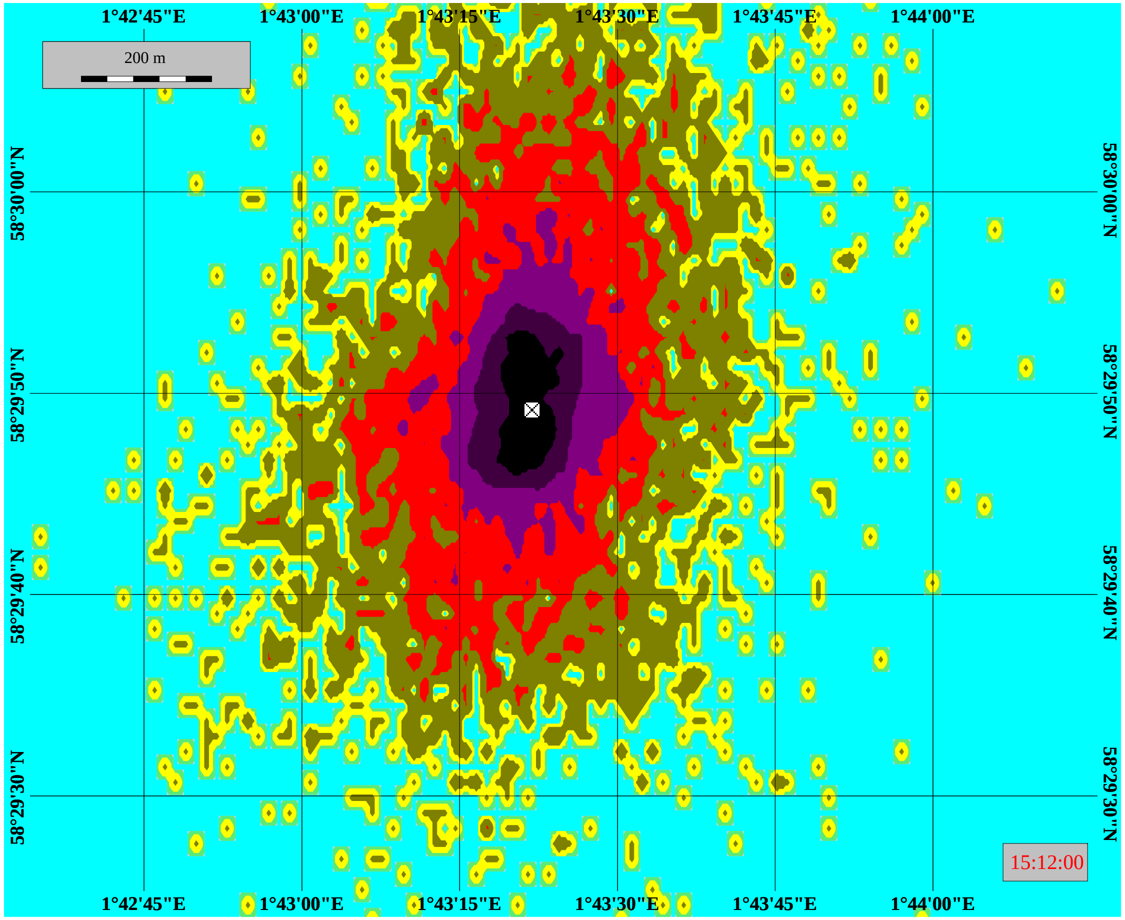
Example of the calculated risk contributions for the concentration field. Red area/volume indicates the water volume where the concentrations exceed the PNEC level, that is, PEC/PNEC > 1 (or a joint probability of potential environmental damage > 5 %) for the red area/volume.

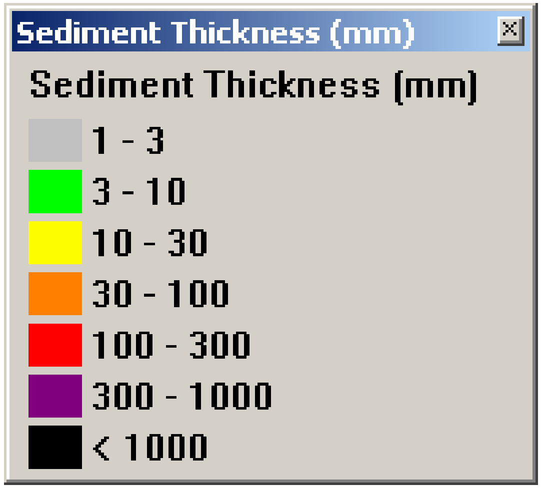


Discharge represented by particles (Lagrangian approach):

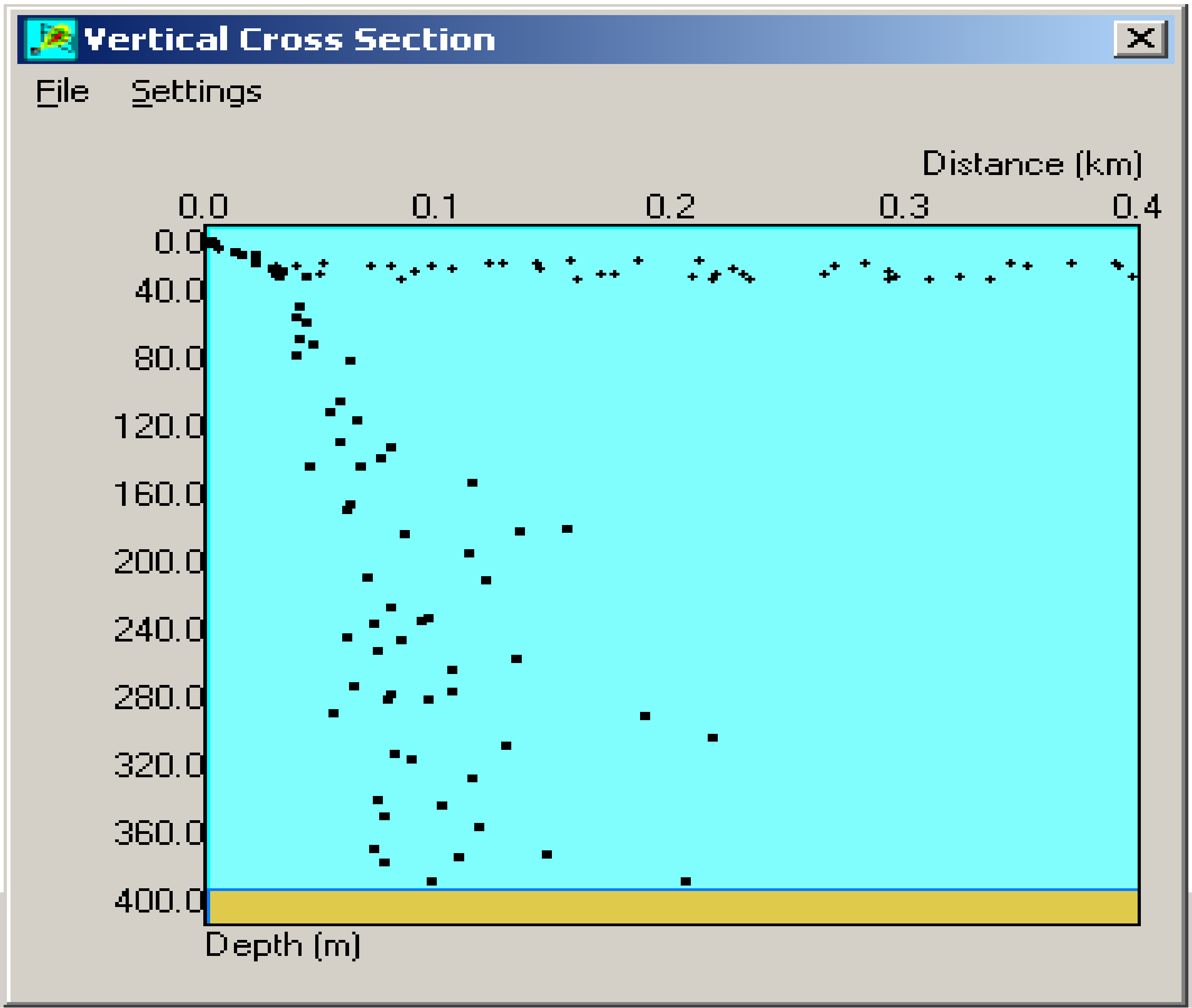


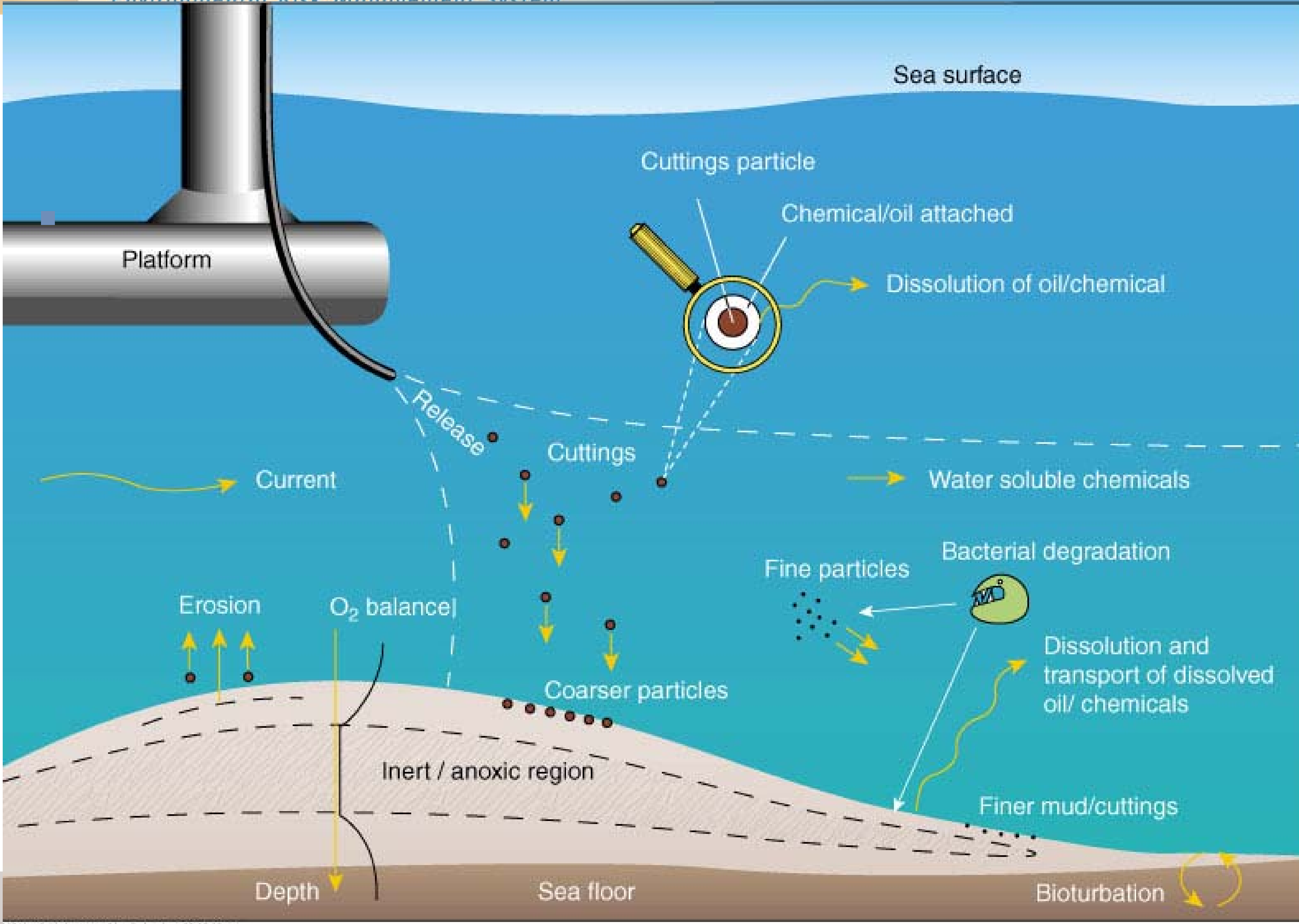
Deposition of particles on the sea floor:





DREAM: Near field plume, dissolving and non-dissolving chemicals, particle behavior:





Sea surface
Cuttings particle
Chemical/oil attached
Platform
Dissolution of oil/chemical
Release
Cuttings
Current
Water soluble chemicals
Bacterial degradation
Fine particles
Erosion
O_2 balance
Dissolution and transport of dissolved oil/ chemicals
Coarser particles
Inert / anoxic region
Finer mud/cuttings
Depth
Sea floor
Bioturbation

Concentrations in the water column:

- **Chemical stress (toxicity):**
  - Concentrations are calculated as for produced water (dilution, transport and biodegradation, basically)
  - Near field plume mixing and descent are included

- **Particles stress:**
  - Concentrations are calculated as for chemicals (no biodegradation), except that fall-out of particles are included
  - Near field plume mixing and descent are included
  - Chemicals with large partition coefficient (Pow ≥ 1000) are ”attached” to particles

Concentrations/stressors in the sediment:

- **Thickness of deposited layer** (deposition of particle matter)
- **Oxygen content** over the active bioturbation layer is calculated by means of a set of ”partial differential equations” for diffusion and consumption of pore water oxygen in the sediment
- **Average concentration of chemical compounds in added mud** is calculated over the upper 3 cm of the sediment. Toxicity is based on pore water concentrations deduced from ”equilibrium partitioning ” between pore water and sediment concentrations
- **Average change of grain size** (in terms of median grain size change) is calculated over the upper 3 cm of the sediment caused by particle deposition, mainly cuttings.

Bottom sediment fate calculations:

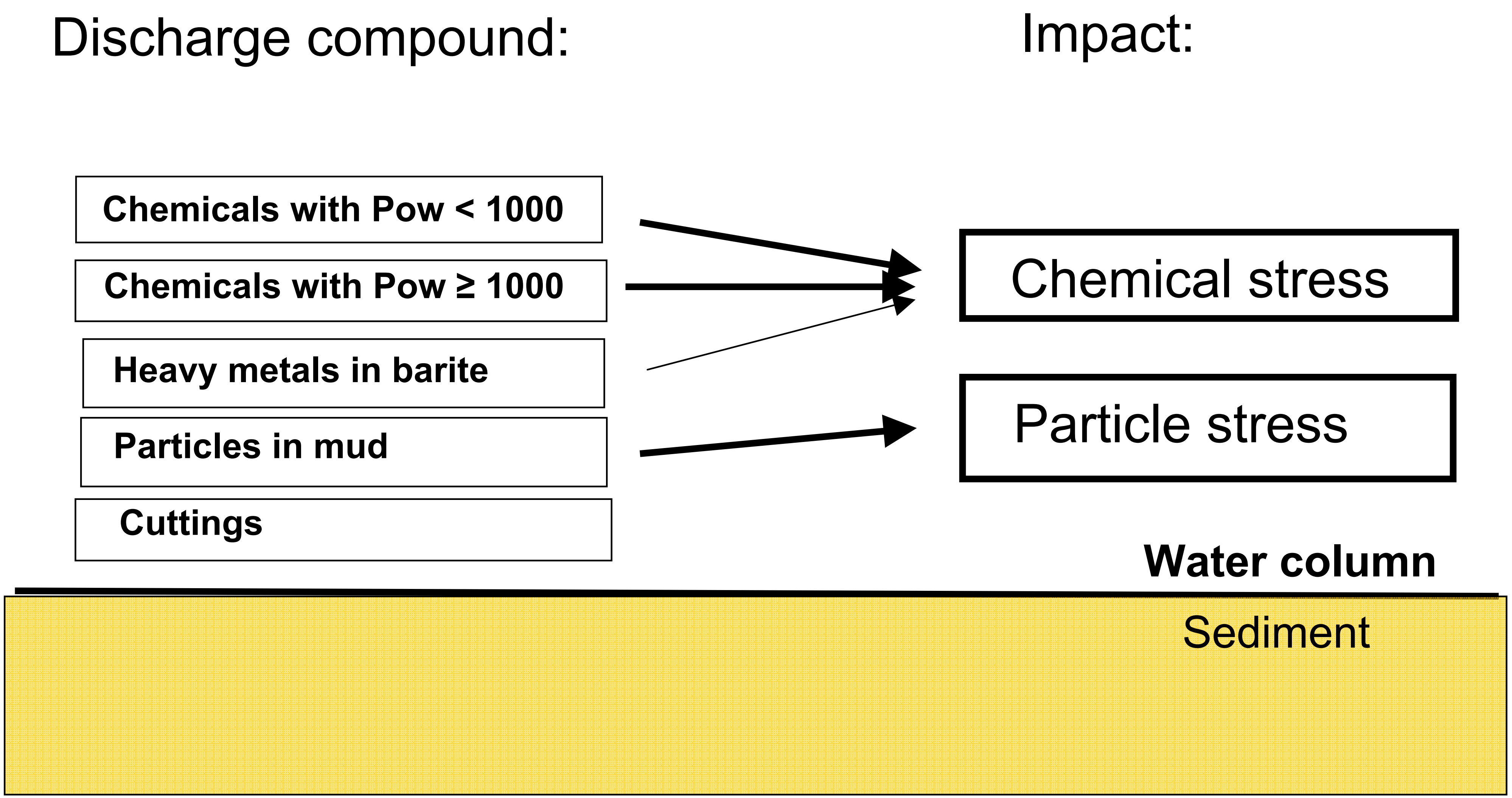
Use of the “diagenetic” equations:

$$\underbrace{\frac{\partial C}{\partial t}}_{\text{Change of property}} = \underbrace{\frac{\partial}{\partial z}\left(D \frac{\partial C}{\partial z} \right)}_{\text{Diffusion term}} \underbrace{- K_C C + Q_C}_{\text{Source/sink terms}}$$

Where ….

Z is the vertical co-ordinate
t is time
D is a diffusion coefficient
C is the property considered
K and Q are reaction constants

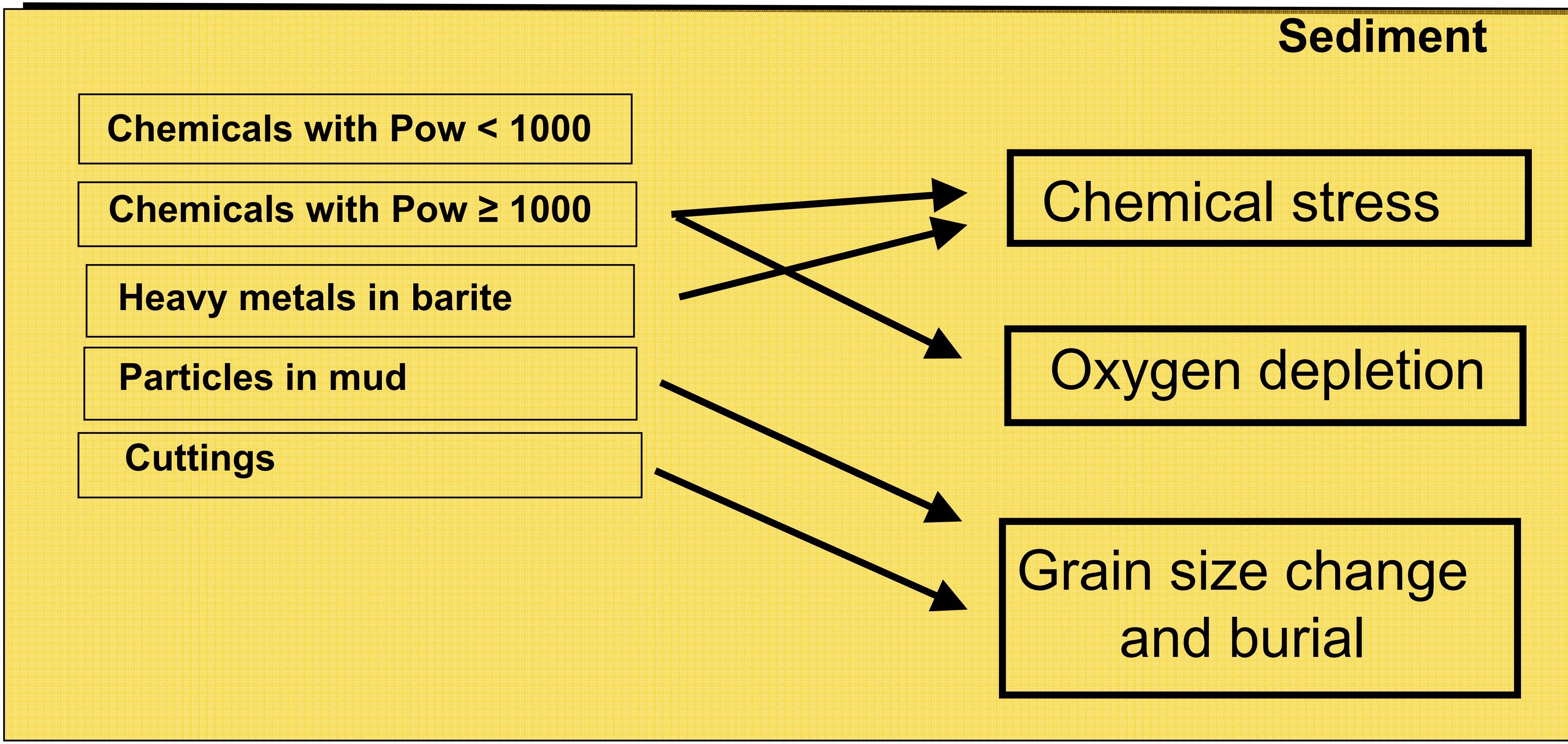
Impact on water column:



Impact on sediment:

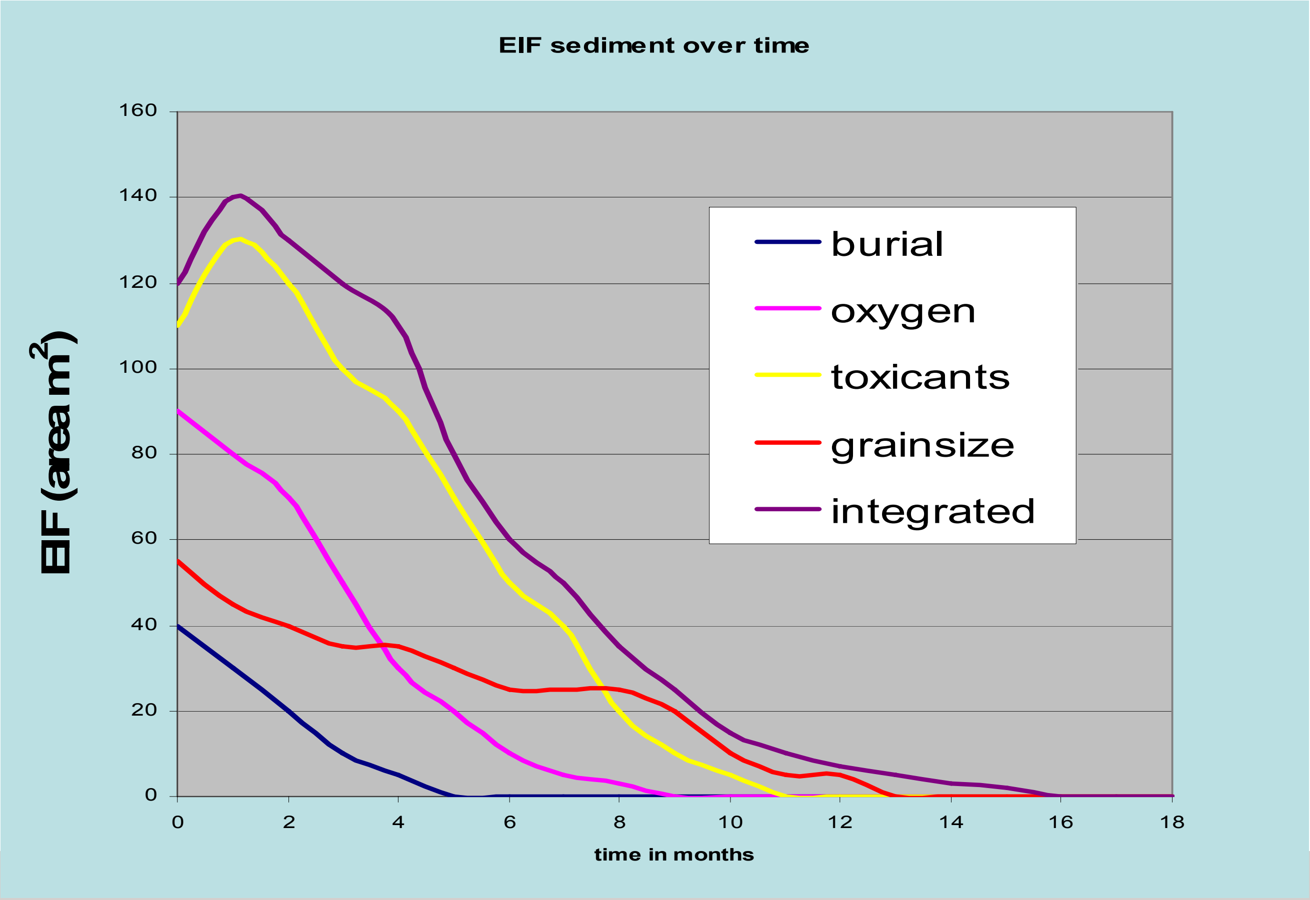
Discharge compound:

Impact: Water column

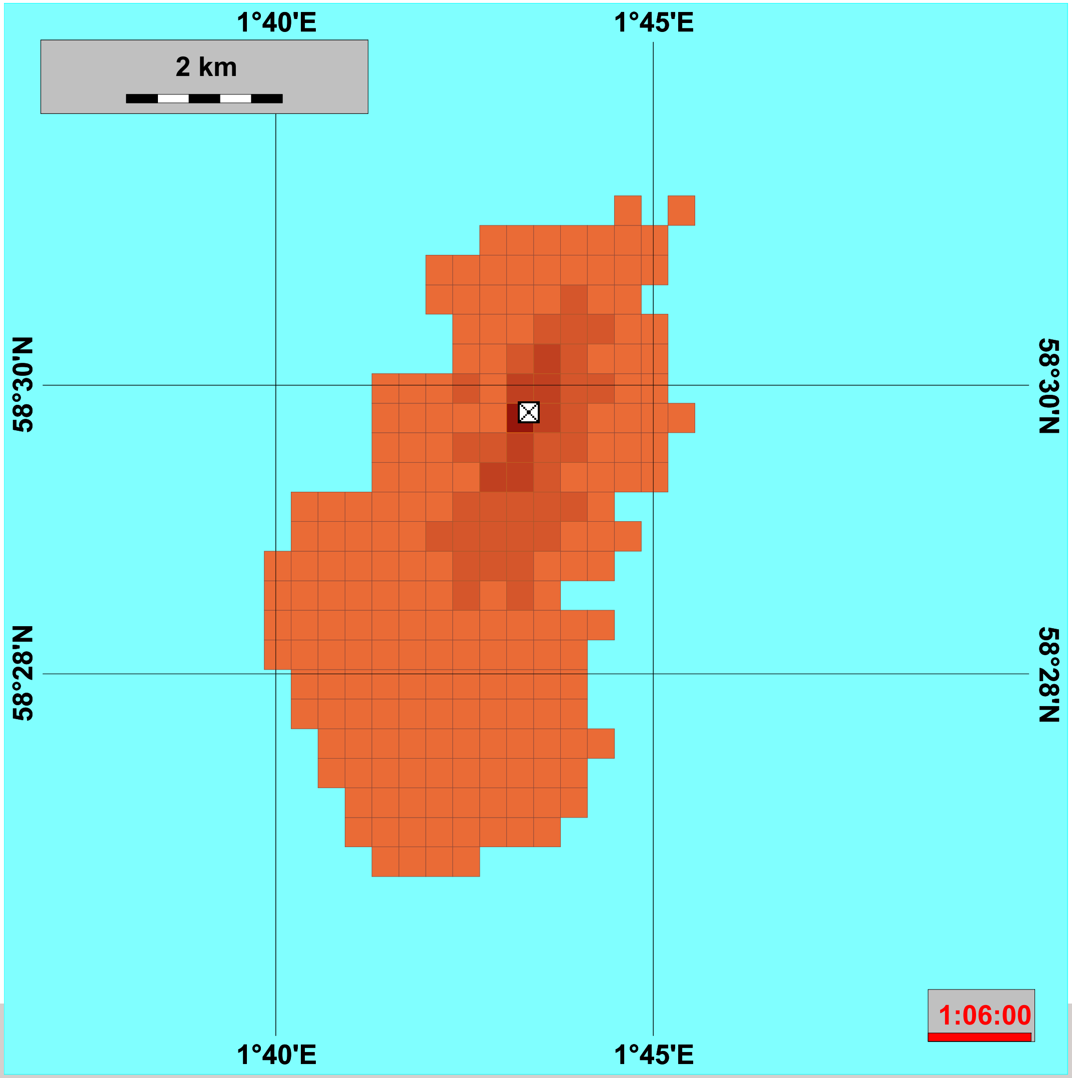


Restitution time of the sediment:

- Toxicant concentrations, oxygen changes, grain size changes and burial all change over time



Stressors (and corresponding risks) are calculated for each grid cell:



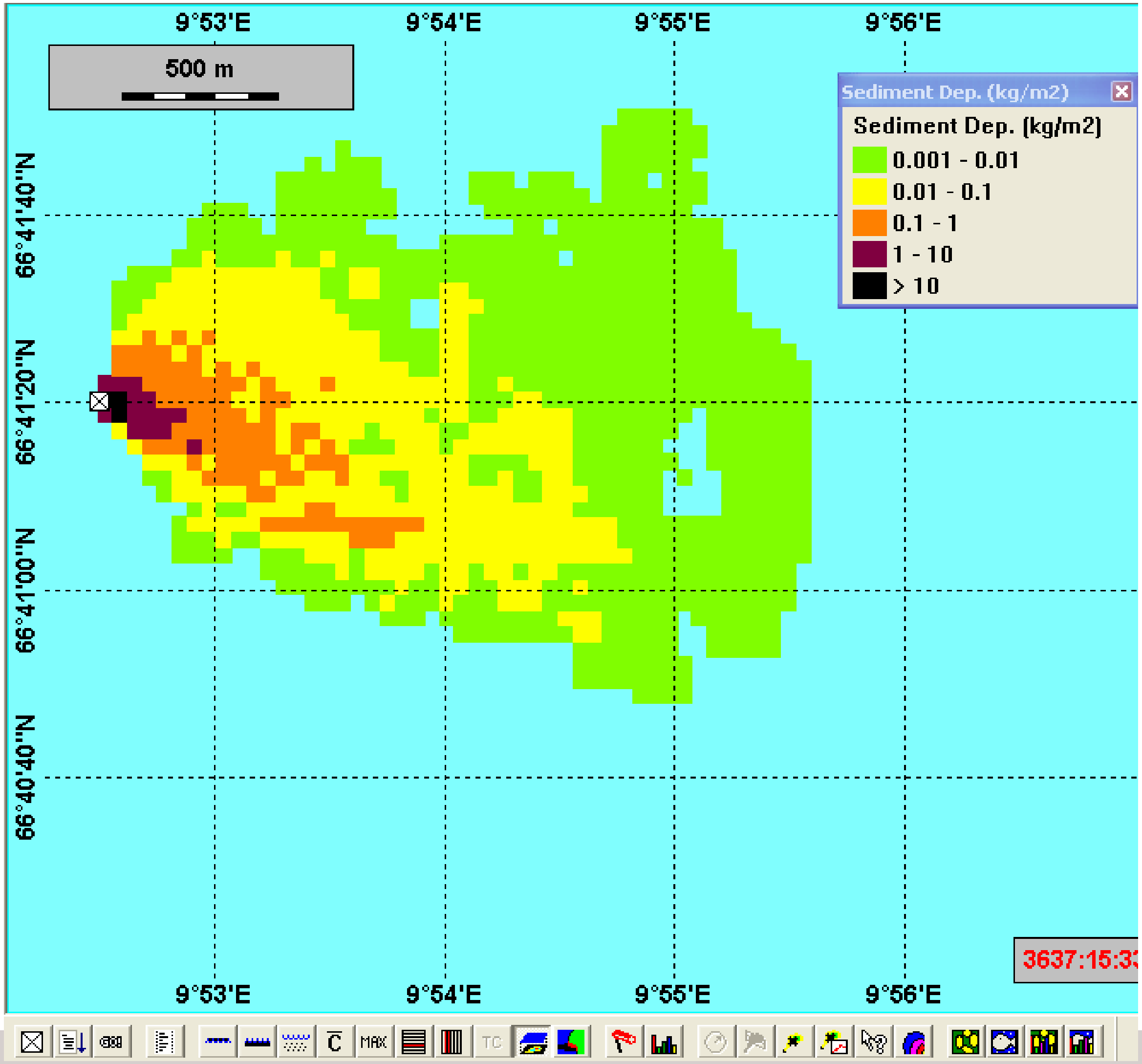
Drilling discharges included:

- **Cuttings**
- **Particles in mud (barite, bentonite, other …)**
- **Non-particle type chemicals in the mud**
- **Different types of discharges:**
  - Discharges over “shaker” and batch discharges
  - Both WBM, SBM and OBM types of mud
  - Both exploration and production drilling
  - Top hole sections and deeper well sections

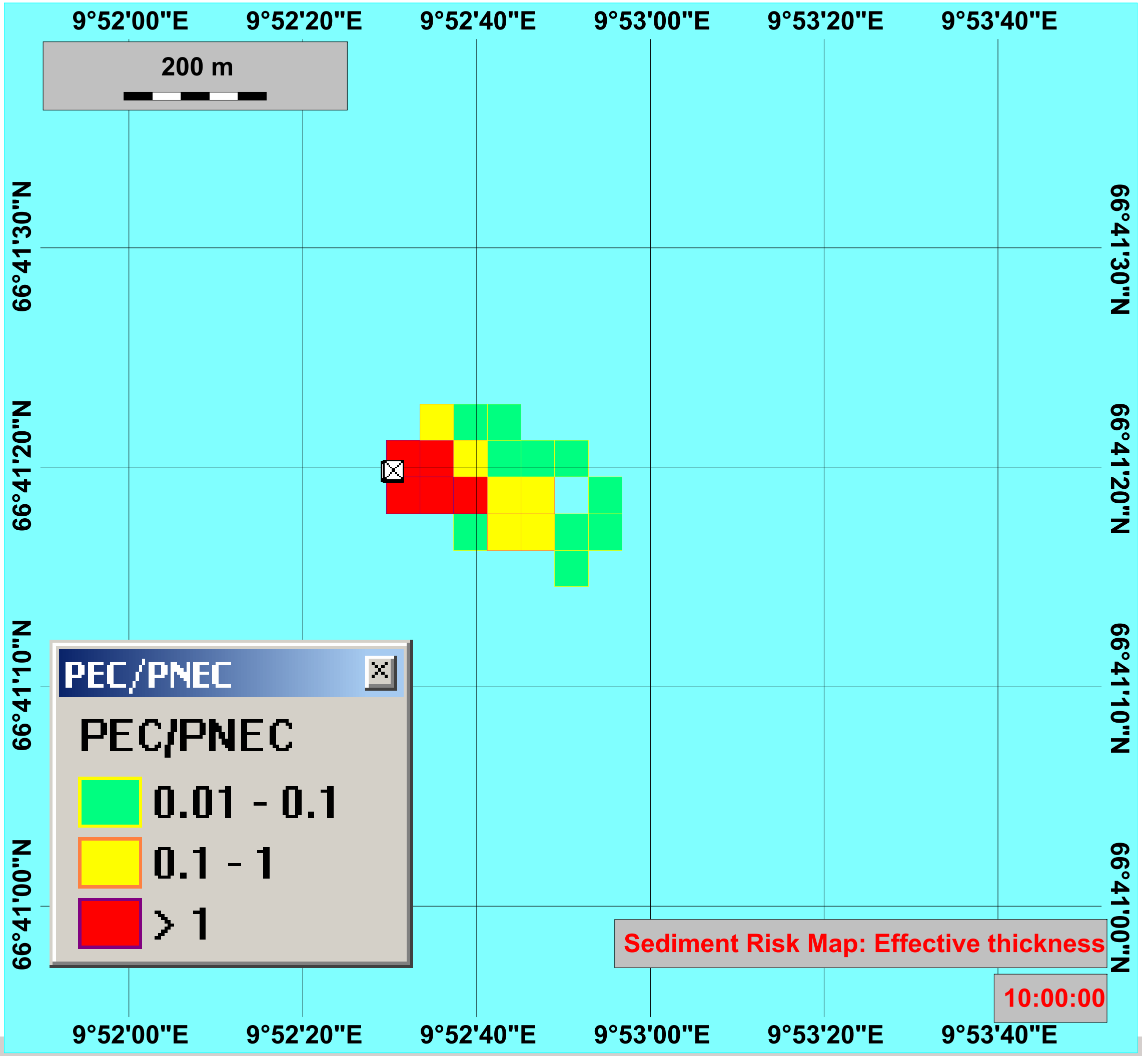
Example calculation:

- Discharges from an exploration drilling, using Water Based Mud (WBM):
  - Cuttings
  - Barite as weight material
  - Water soluble drilling fluid
  - Discharges go directly to the sea floor (upper drilling sections) and from the drilling rig (lower drilling sections)

Deposition on the sea floor:



Risks for the sediment layer due to burial. (PNEC = 6.5 mm)



Publications:

- **The use of the diagenetic equations to predict impact on sediment due to discharges of drill cuttings and mud.**
  - ✓ **Henrik Rye, Mark Reed, Ismail Durgut and May Kristin Ditlevsen, SINTEF**
  - ✓ Presented at the *International Marine Environmental Modeling Seminar*, Rio, 9 – 11 October 2006. Also submitted.

- **Development of a numerical model for calculation of exposure to toxic and non-toxic stressors in water column and sediment from drilling discharges.**
  - ✓ **Henrik Rye, Mark Reed, Tone Karin Frost (Statoil), Mathijs G.D. Smit (presently IRIS/Statoil), Ismail Durgut, Øistein Johansen and May Kristin Ditlevsen, SINTEF.**
  - ✓ Accepted for publication in the SETAC – IEAM *Integrated Environmental Assessment and Management* Journal.

Acknowledgement

The oil companies financing the ERMS program are acknowledged for financial support as well as scientific input during the program.

Contractors in the program have been: Akvaplan-niva, Battelle, MUST, RF-Akvamiljø, SINTEF, TNO and University of Oslo, with SINTEF as the co-ordinator of the program.