STATUS AND CHALLENGES IN RISK ASSESSMENT - THE DREAM MODEL

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Abstract

In general, environmental risk and effect assessment of discharges to the oceans are based on data from acute toxic, static tests. Various safety factors are applied to compensate for differences with more realistic exposure regimes and sub-lethal effects which may occur at lower concentrations or doses.

The objective of the DREAM project is to develop a general environmental risk analysis methodology which allows for time-varying sub-lethal exposures of marine biota to discharge plumes which may be composed of mixtures of chemicals. Users are anticipated to be industry and government agencies concerned with rational environmental management. The envisioned methodology will make environmental risk analysis more realistic than is currently possible using the existing methods.

No single project can solve all of the complex and difficult problems associated with risk assessment for sub-lethal, chronic exposures to mixtures of chemicals in the aquatic environment. The objective of DREAM is to establish a general and realistic framework upon which future researchers can build. A key component of the project will be the demonstration of the concept for produced water discharges to the marine environment. The DREAM project is thus based on research in this area undertaken by Statoil, Norsk Hydro and OLF over the past five years, and further development of the results from this work. A pre-runner of the DREAM model, PROVANN, is presently available, and has been applied for regional risk assessment studies in the Norwegian seas.

Introduction

Most chemical waste streams to the aquatic environment involve the discharge of low concentrations of a wide range of chemicals. Plumes of discharged chemicals may be carried many kilometres from a discharge point before being reduced to insignificant levels through vertical and horizontal mixing, biological uptake, degradation, adsorption to organic particles, or volatilization.

Existing risk assessment models are typically based on a comparison of exposure level, as inferred from a potential environmental concentration (PEC) and sensitivity, as measured by a predicted no-effects concentration (PNEC). Such models are well established and accepted in the European Community for the assessment of effects from exposure to a continuous concentration of a single chemical. For actual field situations, further elaboration is needed to include realistic dynamic concentration fields, biological exposures, doses, and potential effects of time-variable exposures to mixtures of chemicals.

A typical example of an established model not including simulation abilities, is the Chemical Hazard Assessment and Risk Management - CHARM. Since 1991 the North Sea countries (authorities, chemical industry and oil and gas producing industry) developed the CHARM-model for hazard assessment of offshore exploration and production chemicals. This model calculates a Hazard Quotient for substances and preparations on the basis of a PEC/PNEC approach, which means that a concentration (that is assumed to be constant over time) of a chemical at fixed distance from the platform is compared with the toxicity threshold of biota for that chemical.

The purpose of the CHARM model is ranking of chemicals used offshore with respect to environmental hazards and risks.. CHARM is not a simulation model, which is the necessary type of tool to be able to make dose-related effect assessments of chronic discharges (the propose of DREAM). DREAM can be regarded to be an extension of the CHARM-model, where the comparison of a constant PEC with a constant PNEC will be replaced by a dynamic exposure module using chemical and species specific uptake and elimination constants.

The model PROVANN has been developed through a joint industrial project involving several of the partners in DREAM. PROVANN is a simulation model, being able to describe dilution and dispersion of the discharge plume, uptake and PEC/PNEC based effects of single chemicals. The physical fates component has been tested against field observations from offshore platforms and some numerical modeling work has been performed to allow long term simulations for chronic exposure problems. Thus a foundation for the DREAM model has already been established, and PROVANN will be extended to encompass low level, potentially sub-lethal chronic environmental effects of complex discharges.

The general problem to be addressed by DREAM can be subdivided into discrete components as follows:

1. time-space variations of discharge concentration fields;
2. exposure of organisms with different behavior patterns;
3. assessment of mixtures of chemicals;
4. assessment of sublethal chronic effects.

In most field situations organisms are not continuously exposed to a constant concentration because the environmental concentration fluctuates and because many organisms actively migrate within the environment. Effects of chemicals on organisms are the result of exposure to fluctuating concentrations, rather than constant concentrations in the water phase. In addition, most discharges to the aquatic environment involve mixtures of chemicals. Constituent chemicals can differ greatly in their physical-chemical characteristics, which in twn determine their fate and toxicity. The sensitivity of biota to such a mixture of chemicals is a key factor in determining the actual risk of the effluent.. Finally, the physical range and magnitude of acute effects is generally small in the aquatic environment, due to rapid dilution, as well as discharge regulations based on acute toxicity considerations.

Biological and physical dynamics dictate that actual exposure times in the field will vary from minutes to weeks or months, with concentrations varying over many orders of magnitude. On the other hand, exposure times in laboratory toxicity tests are typically on the order of days, and concentrations tend to be unrealistically high.

Degradation in the water column is not important at short distances from a source, due to the short period of time needed for

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transport. At larger distances, and in the sediments, degradation becomes increasingly important. Benthic organisms are exposed to chemical concentrations in the sediment which are a result of the equilibrium between water and sediment. This equilibrium and the potential degradation are both dependent on environmental factors like temperature, redox potential and the organic content of the sediment.

The internal concentration in an organism is determined by uptake and elimination processes.

Uptake is to a large extent a function of the lipophilic nature of a chemical and the exposure of an organism to the chemical. Elimination is the result of metabolism and passive and active secretion of chemicals.

Description of the DREAM model

The purpose of DREAM is to link these processes together within a unified model system, including databases, operating within a graphical user interface on a personal computer, such that more realistic yet relatively inexpensive assessment of environmental risk can be performed.

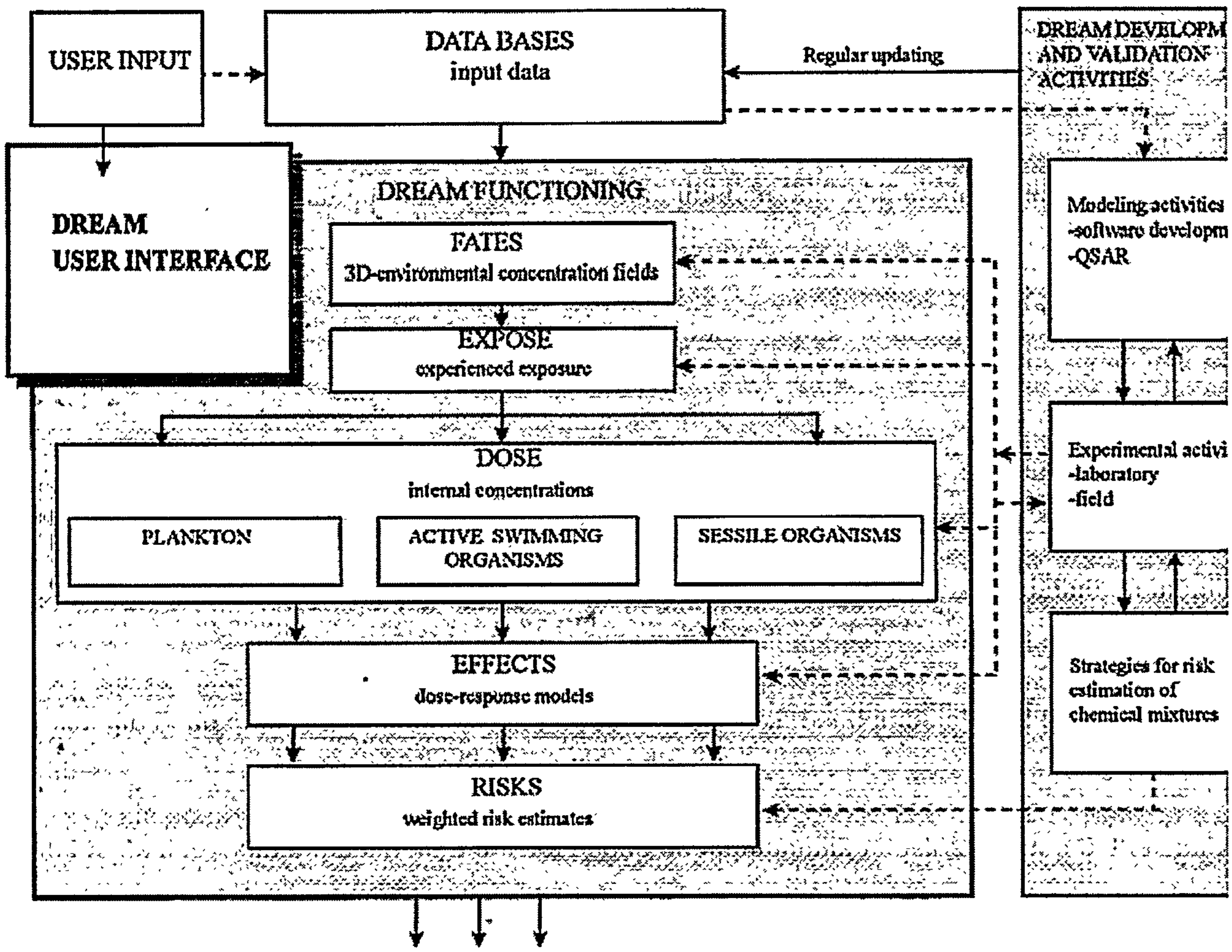

Figure 1. Overview of the DREAM-concept (left) and the corresponding main activities (right) requiredfor development of the computer-model for risk assessment of time-varying exposure to chemical mixtures in aquatic environments.

The conceptual configuration of submodels within DREAM is shown in Figure 1. Differences between PROVANN; CHARM and DREAM are outlined in Table 1.

The three-dimensional FATES module as it exists in PROVANN accounts for the following processes:

- continuous releases
- multiple sources
- advection
- vertical and horizontal mixing
- degradation
- volatilization
- suspended particulate adsorption-desorption kinematic
- mixing in sediments
- dissolution from sediments

Development of the FATES module will focus primarily on methodologies for computing concentration fields for user-defined mixtures of chemicals, improvement, testing and calibration of the existing process algorithms against laboratory and field data, and the establishment of and coupling to climatological physical environmental databases for the Mediterranean, Baltic, and North Seas.

Output from FATES is a time-series of three-dimensional concentration fields which account for vertical and horizontal transport and mung, degradation, volatilization, and adsorption desorption dynamics. Output from FATES is therefore the simulated environment within which the biological exposures and doses will be computed.

EXPOSE will compute the time-varying exposure concentrations of representative individual organisms to the chemical plume, and the accumulated chemicals in the sediments.

The DOSE component of the model, which will probably be embedded within EXPOSE, will integrate the instantaneous exposure levels to compute a time series of the instantaneous internal body burden within the organism. This data will then be made available to the EFFECTS component.

An important component of the exposure module is one which allows realistic representation of animal movements based on readily available data and expert opinion. Such a model has already been developed for birds and marine mammals, and will supply both a theoretical and software basis for the development of the animal movement component of the DREAM system. Capabilities will be included for categories of organisms which behave significantly differently, a tentative list being

- phytoplankton
- zooplankton
- small pelagic fish
- large pelagic fish
- demersal fish
- benthos.

EFFECTS will deal with dose-effect relationships for acute mortality and sub-lethal effect endpoints (e.g. growth, reproductive potential). The method will be based on a comparison between a no-effect level (specified for time and mixture) and the actual body burden calculated in EXPOSE and DOSE. Special emphasis will be given to the toxicity of complete mixtures. The 'cluster' approach, in which chemicals are grouped in clusters on the basis of their physical, chemical and toxicological properties, will be the starting point for the evaluation of the toxicity. On the basis of the results of experiments with bacteria, algae, zooplankton and fish several concepts for a description of the toxicity of the complete mixture will be evaluated.

Within each chemical cluster, it will be necessary to sub-cluster in terms of biological activity, so that concentration fields can be interpreted over to potential effects. Once the clusters have been established the exposure concentration in different environmental compartments, specified in time and space, can be calculated for each.

It is recognized that we will have to accommodate both acute and chronic effects as possible endpoints. High exposure for a short time and low exposure for a long time might result in the same dose to the organism, yet the former might be fatal whereas the latter might result in reduction of reproductive potential. A major task in the experimental and modeling work will revolve around the derivation of appropriate representations of these chronic and acute effects relationships.

Within the RISK module the actual risk for the environment is calculated. For a situation with continuous release, hke the discharge of effluents from chemical production, and oil and gas refineries, the risk is calculated from the anticipated collective results of the EFFECTS module for species of local importance

Table 1. Comparison of CHARM, PROVANN and DREAM capabilities

Module	CHARM	PROVANN	
	• single source, not site-specific	• single source, site specific	• multiple sources.
FATES	• single component (limited to petroleum exploration and production chemicals)	• single component	• mixtures of chem
	• no environmental input; fixed dilution at specific distance from source	• limited database for currents, winds, and bathymetry	• physical environ Mediterranean, B
	• offshore application	• offshore and coastal applications	• general aquatic a
	• no explicit exposure calculation	• random swimming patterns for fish	• user-defined daily
EXPOSE	• no spatial or temporal distribution	• passive drift of eggs and larvae from random initial placement in the study area; instantaneous release	• passive drift and spawning areas;
	• gross exposure estimate through water, sediment and food chain	• exposure from water only	• exposure from wa defined food web
	• single chemicals or mixtures	• exposure to single chemicals	• exposure to mixtu
	• no dose calculation (BCF multiplied by dissolved concentration gives body burden)	• body burden computed dynamically from uptake and depuration rate constants, with BCF computation as fallback	• body burden com and depuration ra computation as fa
DOSE	• user-supplied BCF	• user-supplied BCF or uptake/depuration rate constants	• supplied database QSAR and parall testing/verificatio
	• single static body burden for one or more components	• output is time series of body burden for one component	• output is time ser discharge
	• no effect calculation (PNEC calculation for exposure through water, sediment and foodchain)	• single-component critical body burden (CBB) defined as BCF multiplied by PNEC	• critical body burd long-term exposu components in a
	•		• acute effects (mo and acute CBB
EFFECT	•		• CBB for long ter QSAR analysis a
RISK	• PEC / PNEC > 1 implies non-negligible risk	• risk threshold set for the ratio of the maximum computed instantaneous body burden to the critical value: BB/CBB ≥ 1.0	• risk distributed o - phytoplank - zooplankto - benthos - pelagic fis - demersal f
			• risks summed ove
			• risk contour maps

Example Application of PROVANN/DREAM. Body burden in fish.

In the following, two examples of PROVANN applications are given. These examples give an impression of how the output from the DREAM model will appear.

Figure 2 shows a "snapshot" of a concentration field developing in the north-eastern Adriatic near Triest. The figure is a horizontal cross-section of the plume at 10 m depth.

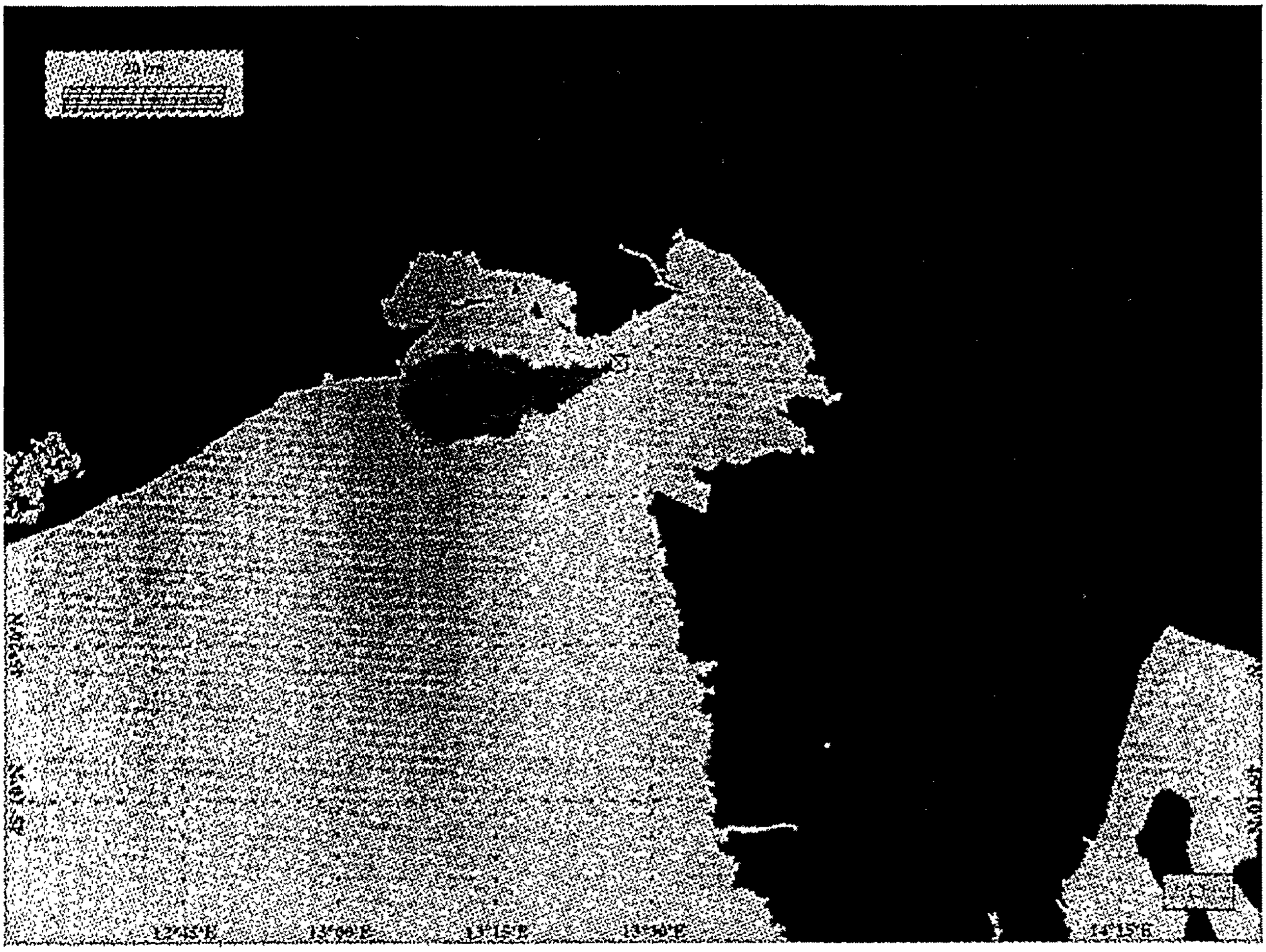

Figure 2. Example snapshot of horizontal concentration contours at 10 m depth for a near-shore release in the near-shore Adriatic.

Figure 3 depicts time series of the body burdens computed for four representative pelagic fish in the area. Fish may enter the plume (e.g. fish no. 88 after about 16 days), leave the plume and depurate, and reenter the plume at a later time (fish no. 88, about day 55). (Since body burdens below the user-defined background level are not recorded in the model output, there are no data points for fish no. 88 between days 20, when the fish has depurated to background level, and day S5, when the fish reenters the plume.)

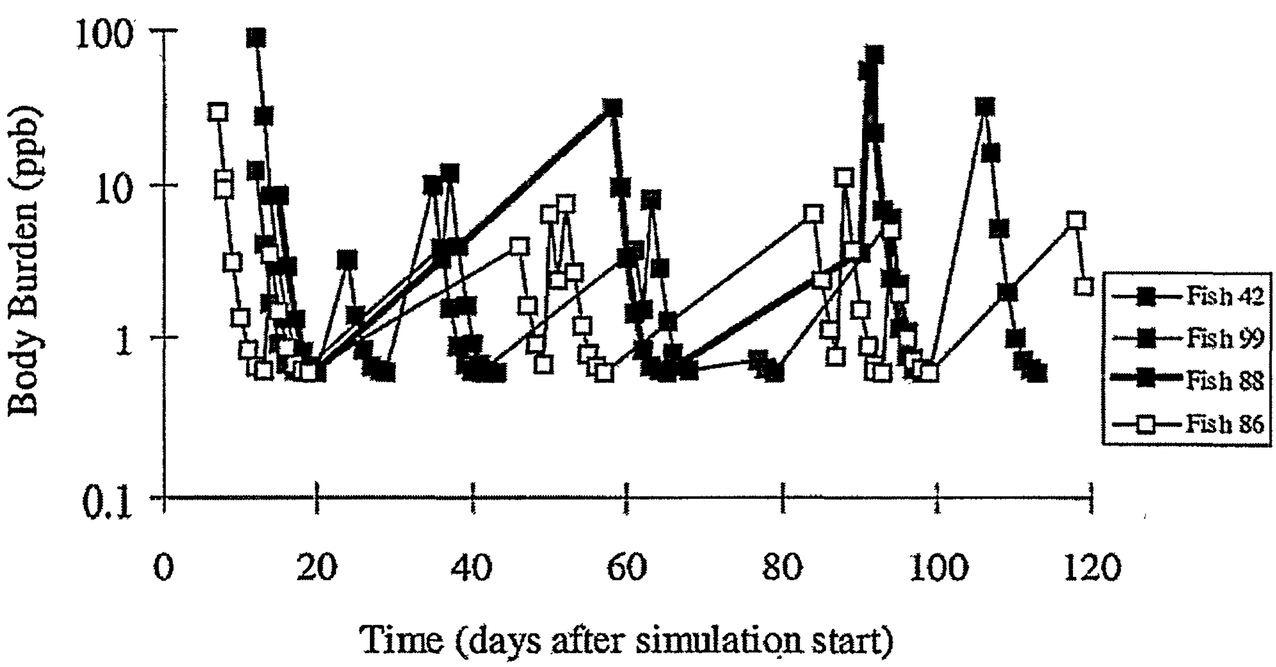

Figure 3. Example time series of body burdens for selected small pelagic fish exposed to the release. Fish no. 42, 99, 88 and 86 are four representatives from a total simulated population of 1000 individuals.

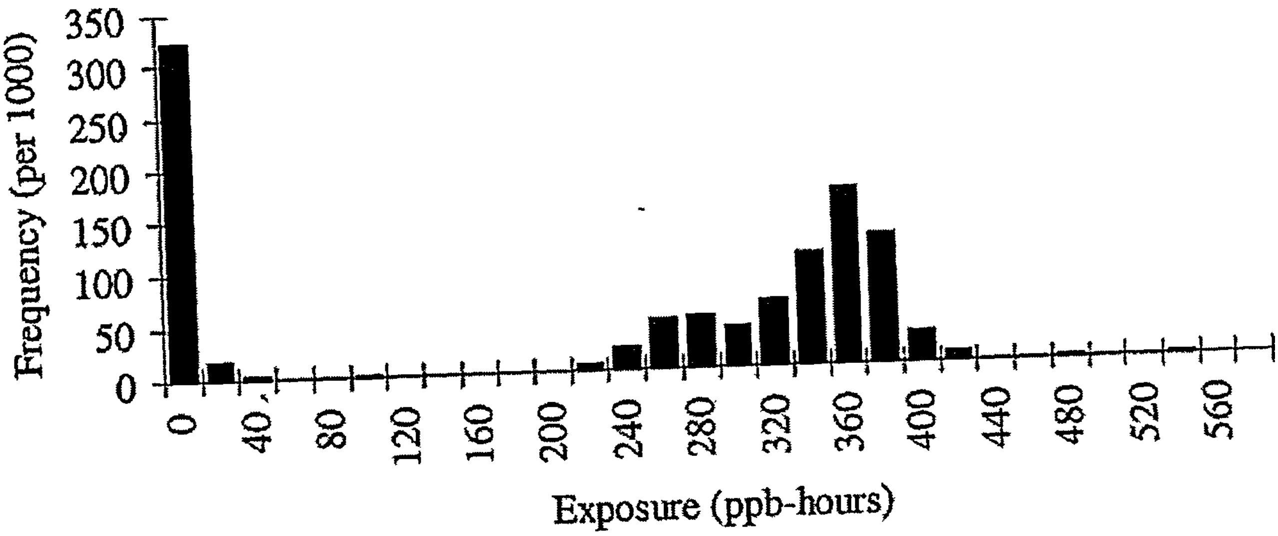

Figure 4. Distribution of larval fish exposures. Approximately 33% of larvae spawned in the area are not exposed in this example.

Figure 4 is an example of exposure statistics calculated by the model for ichthyoplankton released upstream of the plume. Gyres, fronts, and up welling /down welling regions can result in complex, discontinuous frequency distributions for exposure of planktonic organisms.

Figure 5 summarizes the Expose/Dose information for the portion of the overall population represented in the simulation.

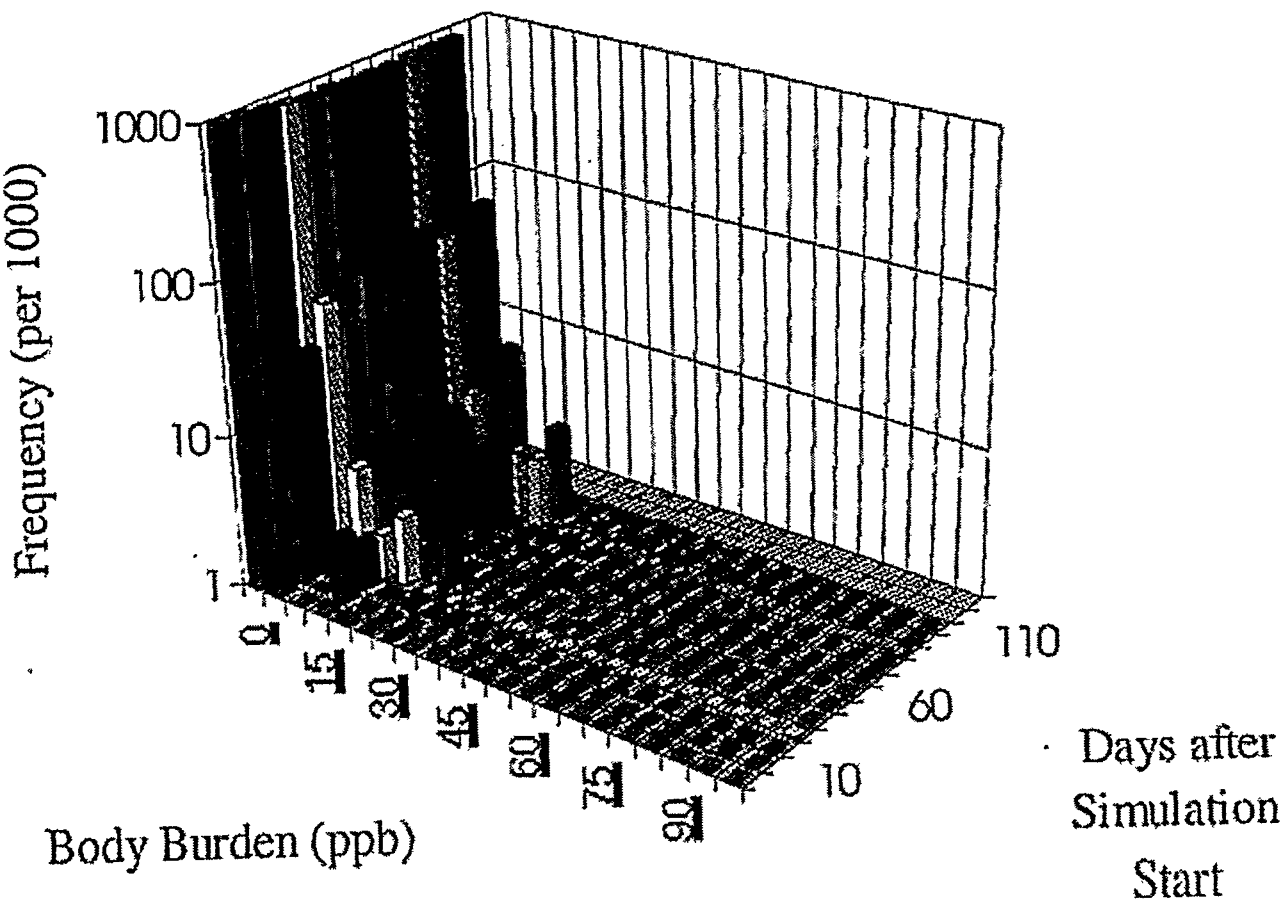

Figure 5. Population profile of body burdens small pelagic fish during the simulation.

In this particular example, no quantitative risk calculations were performed. DREAM will determine the risk for effects as function of the internal doses (body burden) described above and the critical body burden measured under the project period.

Example Application of PROVANN/DREAM. Total risk of environmental effect.

The next example of PROVANN/DREAM applications demonstrates how the PEC/PNEC ratio can be applied in PROVANN to determine risk of environmental effect. In the final DREAM model this function will be replaced by the BB/CBB (body burden/critical body burden) ratio, determined experimentally under the DREAM project. However, the presentation output from DREAM will be comparable to what is shown here.

Produced water discharges from a major Norwegian oil field were modelled with respect to dilution and potential environmental effects. The produced water was divided into 8 compartments' each representing a class of similar chemical compounds. Since PROVANN can only handle single chemicals, the dilution and environmental risk of the chemicals were determined for each compartment individually, by applying the PEC/PNEC ratio method. The total risk was determined by adding the risk of each of the 8 groups.

Table 2 shows the 8 groups and their corresponding PNEC values, biodegradation rates (half life) and estimated background level in the area. A single compound was selected as representative for each group, and the respective values for this compound was applied for the whole group.

Table 2. Input values to PROVANN for the simulation

Group	Type of chemicals	Background (ppb)	PNEC (ppb)0	Biodeg (1/2-life) (hours)
1	BTEX monoaromatics	Unknown	23.7	48
2	Naphthalenes	0.05	13.4	144
3	PAH	<0.01	0.97	144
4	Phenol	<0.01	72	144
5	Alkylated phenols	<0.01	4.1	144
6	Aliphatics	5	40.4	144
7	Organic acids	Unknown	242	48/
8	Metals	0.02	2.5	Unlimited
One representative chemical was selected for each group and values for this compound were applied				

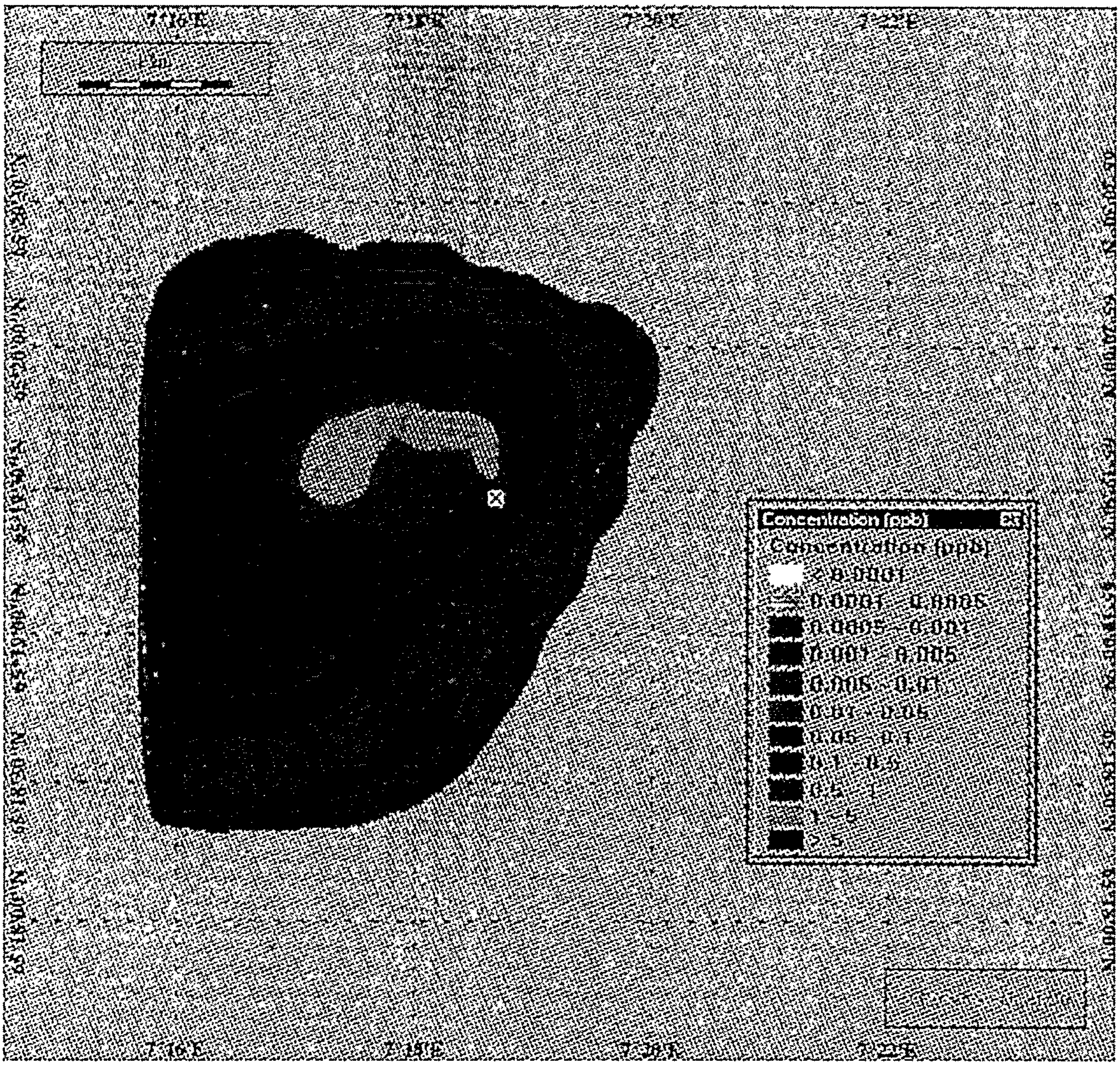

Figure 6. Concentration map of produced water discharges from a major oil field in the Norwegian sector, generated by PROVANN.

Figures 6 and 7 show a concentration field for alkylated phenols at a certain time of the simulation period and the corresponding environmental risk map for the total discharges in the area. In this particular case, no risk higher than the acceptable limit of 5% can be seen. This result may of course vary with discharge rates, discharge composition and actual weather situation, i.e. dilution picture. The figures indicate how PROVANN and in the future DREAM can be used to predict and monitor the environmental impact of discharges to the aquatic environment.

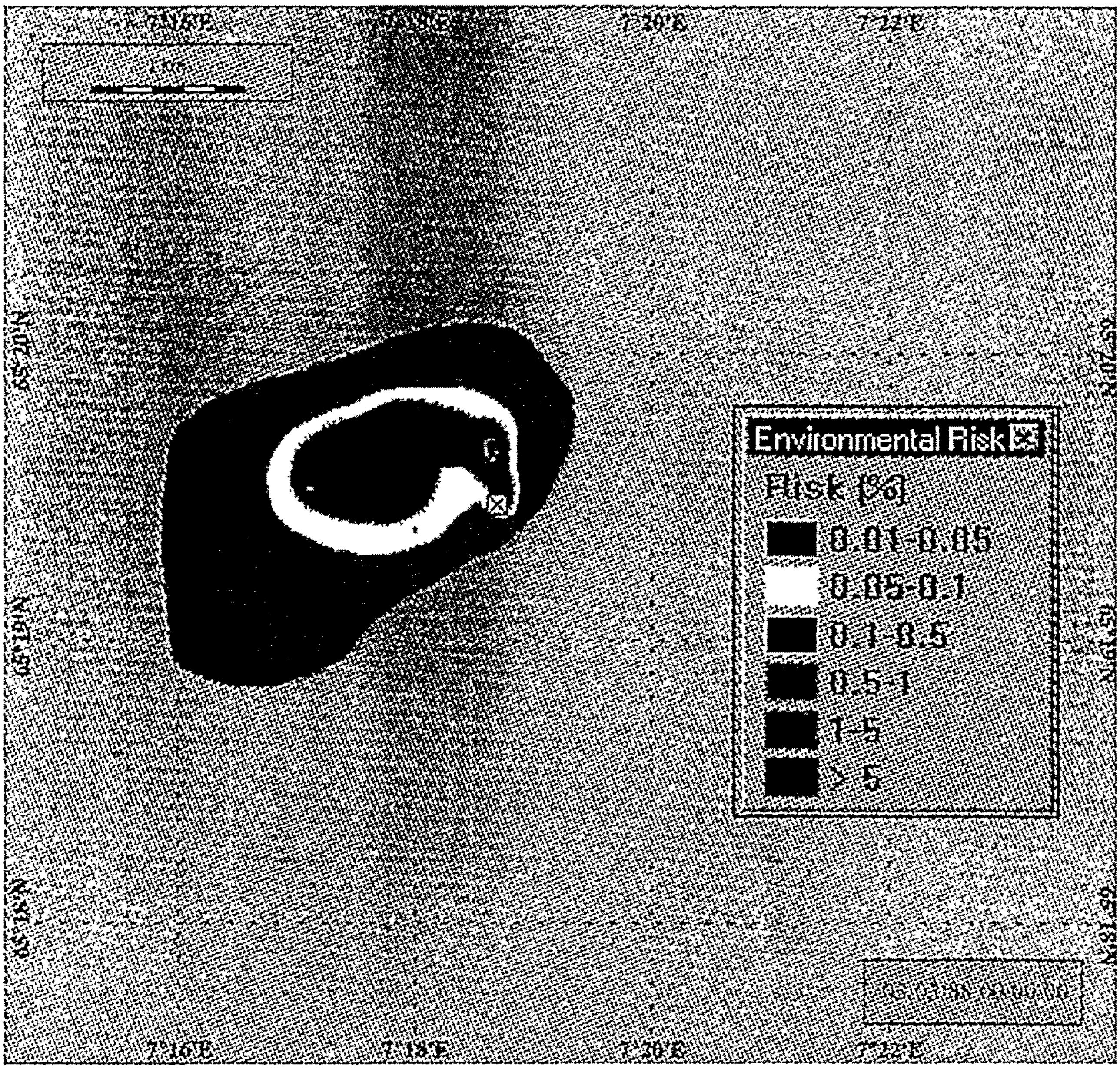

Figure 7 Risk (PEC/PNEC ratio) map for a major oil field in the Norwegian sector generated by PROVANN.

Conclusive remarks.

The DREAM project will be initiated during the fall this year (1997), and an operating model will be available in the year 2000. In the mean time, PROVANN will serve as a tool for predicting environmental risk and effects of offshore discharges of produced water. Results from this model will be employed as a basis for decisions concerning produced water reinjection on operating oil fields in the North Sea. A project running parallel with DREAM, focusing on possible reproductive effects from alkylated phenols on cod will also be initiated in 1997. The results from this research and other relevant projects will be implemented in DREAM.

DREAM, as opposed to CHARM, will become a generally applicable risk assessment tool which takes into account all constituents of discharged effluents (and not only production chemicals as CHARM does) for freshwater-, coastal- and offshore-systems