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PROTEUS, a technical and management model for aquatic risk assessment of industrial spills

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Abstract

The assessment of risks to the aquatic environment related to industrial installations is a priority in environmental pollution control in the Netherlands. Major accidents to the surface water such as the Sandoz incident, but also the high number of smaller accidents that occur every year has invoked the need for an effective method to assess these risks. Two different models have been used in this field in the Netherlands over several years. These two software applications, VERIS and RISAM were developed from two different perspectives: VERIS from the perspective of supplying major accidents related information in the safety report, RISAM form the perspective of controlling risks for both smaller and larger facilities that may pollute surface waters through accidents. Both systems comprised particular strong points: VERIS considers safety management aspects in the assessment, RISAM considers differences in surface water vulnerability and involves quantitative probabilities in the assessment. It was decided to integrate both methods and maintain these strong points in the resulting method. This paper describes the new integrated risk assessment method that now has been developed in a concerted effort between the Ministry of Transport, Public Works and Water Management, the Ministry of Housing, Spatial Planning and Environment, and the National Institute for Public Health and Environment. It also describes the essential elements of the computer program PROTEUS that is based on the new method and that makes the assessment of aquatic risks for industrial activities an easy task, partly due to the automatic generation of the assessment report. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Industrial hazards; Aquatic risk; Risk assessment; Risk model; Risk management; Quantitative risk analysis; Hazards

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1. Introduction

The assessment of risks to the aquatic environment related to industrial installations has high priority within the Dutch environmental pollution control policy. In addition to the Sandoz fire, some national accidents resulting in huge emissions of aromatic compounds and chlorinated hydrocarbons to surface water gave reason to develop a systematic approach. In some cases aquatic ecosystems were adversely influenced due to toxicological effects, lack of oxygen as a result of massive biodegradation or the formation of floating layers.

For the aquatic environment a systematic approach was developed which is used in licensing procedures. Currently, two models (software applications) are used for the assessment of risk to the aquatic environment. The first model was developed by the Ministry of Housing, Spatial Planning and Environment as a tool to supply major accidents related information in safety reports. This MS-DOS application, VERIS, focuses on procedures related to safety management resulting in an index for aquatic risk. The model output is a non cumulative qualitative frequency–consequence curve.

The second model was developed by the Ministry of Transport, Public Works and Water Management as a tool for licensing procedures concerning discharges of wastewater. These procedures focus on the protection of the quality of the watercourse on which the discharge of waste water takes place. In order to do so a methodology was developed based on technical aspects of industrial activities, the management of spills and local conditions concerning the discharge of wastewater. This methodology formed the basis of the MS-DOS application RISAM. The output of the software model is a frequency–consequence curve expressed as cumulative quantitative probabilities and amounts of contaminated surface water.

Working experience with the two models confirmed that failures and accidents depend on both technical aspects and human factors. This also led to many discussions with industry on which model should be used for risk assessment. To address these aspects a project was started aimed at combining the two software models in an integrated model for the assessment of risk to the aquatic environment due to failures in industry. The resulting model, which is called PROTEUS, combines the possibility to account for the risk management quality together with risk calculations based on standard QRA methodology.

The introduction of default values in PROTEUS makes it possible to carry out a quick analysis. Moreover all defaults can be adjusted to make a detailed and specific analysis. Finally, PROTEUS is better linked up to the variety of spills and water management in industry. This paper presents the integrated software model PROTEUS.

2. The new integrated methodology

The new methodology is based on the concept that all activities take place on specific areas like tank bunds in case of storage tanks or liquid tight floors in case of production or handling of chemicals. These areas can be modelled as a primary containment with several outlets, as presented schematically in Fig. 1.

This new concept offers the opportunity to differ routes of the spill. For example, in the Netherlands the drain of a primary containment is usually linked to a process sewer. Overflows however, usually enter the rainwater sewer system. The fate of fire water depends of local conditions.

As mentioned previously, activities take place in a primary containment. Each activity has its own scenario by which release of substances into the primary containment is defined. An exception is made for tank bunds because of the possibility of jet releases, spigot releases and topping. These scenarios may result in a direct overflow. Due to a leak in the side of a tank a jet release or spigot can occur so that substances arrive outside the primary containment. Topping may occur after instantaneous failure of a tank resulting in a partial overflow of the tank bund.

Within the primary containment flammable releases can result in a fire. In case of a tank bund or warehouse domino effects are taken into account in this methodology.

When the capacity of a containment is not sufficient, overflow provisions will be drawn on. Furthermore, fluids might leave the containment via the buffer valve. This might be the situation in case a deluge is used to cool down tanks in a tank bund. Finally, fluids leave the containment through the drain.

In order to assess the frequency to draw on one or more of these routes a probabilistic approach is applied. The concept of the methodology is presented schematically in Fig. 2.

The methodology starts with the generic QMFT and ends with an aquatic risk. The generic QMFT describes the hydraulic flow (Q in m^3/s), the mass of chemicals involved (M in kg), the frequency (F in $1/y$) and the time-span of a spill (T in s). These parameters are calculated using primary data concerning the activity itself and the amount of chemicals involved. At this level the frequency and time are generic. This means that specific conditions concerning technical design or operation are not yet taken into account. The generic frequency and time are determined by the Commission on the Prevention of Hazards (in Dutch CPR) in which national experts from industry and the

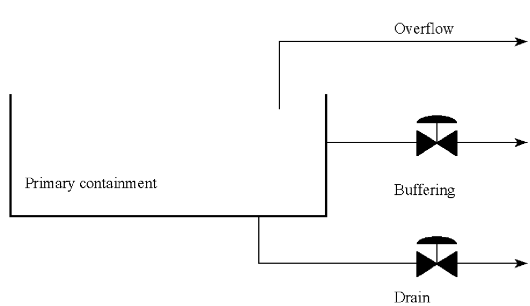


Fig. 1. Schematic representation of a primary containment.

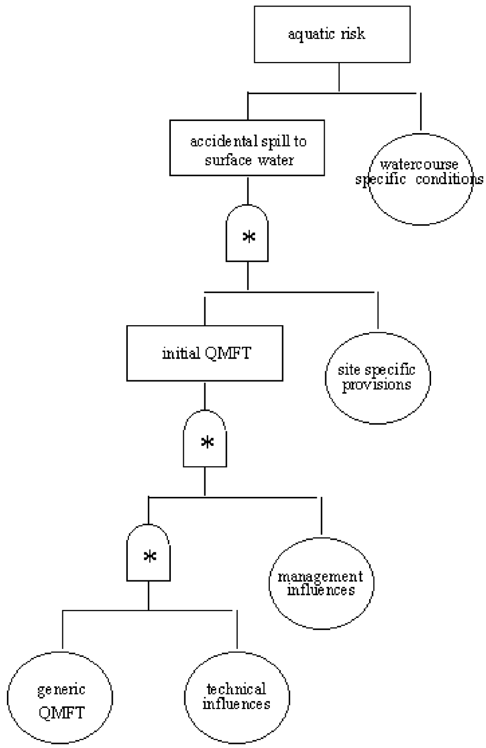


Fig. 2. Concept of the methodology for the assessment of risk to the aquatic environment related to industrial installations.

government are delegated. This work is published by the Ministry of Housing, Spatial Planning and Environment [1].

Since this QMFT describes an average situation, correction factors are needed in order to assess the risk from an activity under local circumstances concerning technical design and safety management. A distinction is made between technical and management aspects since the design only influences the QMFT of the activity involved whereas management procedures influence all activities on the site.

The technical correction factors are based on the work of TNO and CPR [1,2]. These quantitative factors describe the influence of, for instance, alarms, automatic stops and the choice of construction materials on the amount and probability of a spill. The technical correction factors are drawn from broad databases containing causes of incidents.

An expert opinion method is used in order to determine correction factors regarding the influence of management on the frequency and successfully re-routing of spills. For this purpose, five areas of influence (AOI) are distinguished [1,3]:

1. Safety management systems (a site level evaluation of management and communication procedures);

2. Skills of operators (a site level evaluation of craftsmanship and training of personnel);
3. Working procedures;
4. Efficiency of repression;
5. Distinctive characterisations of installations (evaluation of qualitative characteristics of installations at a site level).

Insight in the influence of management is gained by means of 46 questions. This questionnaire requires input per item in terms of total implementation of safety management and provisions (excellent), average, partially implemented (bad) or totally absent (worse). Per AOI, a score is calculated which interacts on three aspects of safety management:

1. Probability of a spill due to failure of primary catchment provisions, influenced by AOI-1 and AOI-5;
2. Probability of a spill due to inadequate operations, influenced by AOI-2 and AOI-3;
3. Inadequate repression of spills (AOI-4).

These three aspects equally influence the probability of a release. In case all management aspects are totally implemented the correction factor is based on the minimum frequency. Likewise, a high correction factor is linked with total absence of safety management. This is demonstrated in Fig. 3.

The scope in frequencies is related to 99% confidence-interval which is derived from work done by Aminal [4]. The corresponding correction factors are derived from previous work concerning the development of VERIS [1] completed with data from Lees [5].

Now the initial QMFT (see Fig. 2) of a spill leaving the primary containment is determined. Subsequently, the spill will enter the sewer system. The hold-up in the sewer systems offers opportunities for interference on the development of the spill, like re-routing to a calamity basin or treatment facilities. In some cases it is possible to block certain branches of the sewer system preventing the spill to reach surface water. The effects of these interferences are taken into account in this method.

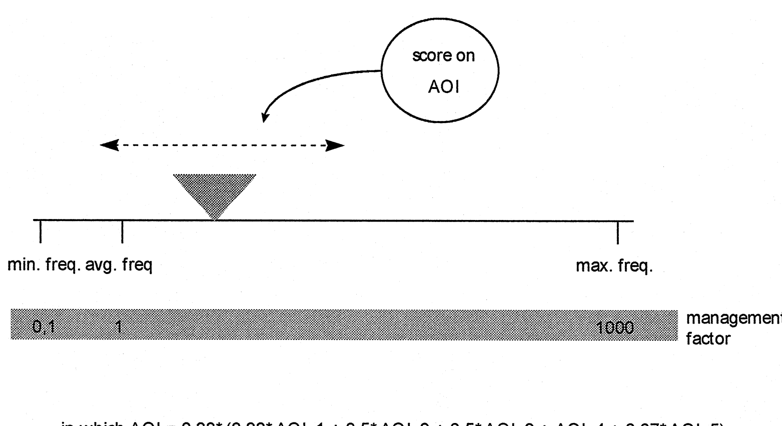


Fig. 3. Example of the determination of a management correction factor from five areas of influence given a scope in frequencies.

Finally a QMFT to surface water or a communal waste water treatment plant is calculated. Regarding surface water, the effect of a spill is calculated assuming the spill disperses as a half circular slick. The actual shape will depend on whether the surface is unilateral limited, like lakes, or bilateral, like canals and rivers [3,6]. Subsequently, soluble pollutants may diffuse to the water phase. Concentrations of soluble pollutants in the receiving surface water are calculated using Gaussian dispersion equations not taking into account any decay as a result of degradation (biological nor chemical), evaporation or (ad)sorption [3]. The volume of potentially contaminated surface water is calculated separately for toxic effects, lack of oxygen and formation of a floating layer.

(1) The volume of potentially contaminated surface water relates to an area in which the predicted environmental concentration (PEC) was at any moment higher then the effect concentration (EC) for aquatic organisms. The EC is the lowest reported EC_{50} for acute toxicity towards algae, arthropods or fish.

(2) Regarding a possible lack of oxygen due to a spill of readily biodegradable components a so-called cascade model is used.

(3) The extent of a floating layer is calculated using a simple spreading model. To do so a fixed 0.004-m thickness of the layer is applied.

From these three effects, the maximum effect is selected. Combined with the probability of the spill entering the surface water, this is reported as the risk for the activity involved.

Regarding communal waste water treatment plants inhibition of sludge is evaluated. Calculations result in whether or not the treatment plant is subject to failure due to a spill.

3. Software model

Based on previous described methodology the software model PROTEUS is developed. PROTEUS is a Windows application (Windows 3.11, 95, 98). The application is developed using the object orientated programming technique OMT [7].

The user can model a specific situation placing icons on a worksheet and subsequently connecting them with a simple mouse movement. There are icons available for several activities like storage, production and internal transport as well as for sewer systems, mitigating facilities, watercourses and communal waste water treatment plants (see also Appendix A).

In PROTEUS a database on properties of chemicals is included. This database, SERIDA [8], contains all relevant data such as physico-chemical properties and toxicity data needed for the risk assessment by PROTEUS. The model can also deal with mixtures of chemicals.

A risk assessment can be performed based on a minimum set of data regarding the name and amount of chemicals involved and the way these chemicals are stored (tanks or packing). Combined with default values for technical and management correction factors a quick scan is made. Mentioned default values compare to the Dutch situation with respect to the best available techniques on safety management [9]. Using additional site or activity specific data a more sophisticated risk assessment can be performed.

PROTEUS generates a report containing the calculated effects, the data defined by the user as well as the default values for these properties. The calculated effects are reported in the form of frequency–consequence curves [10]. The consequence is presented in four different ways:

(a) the volume of adverse affected surface water,

(b) the amount of substances released,

(c) the number of toxic units, being the mass divided by the corresponding acute toxicity,

(d) the amount of fire fighting water.

An example of a frequency–consequence curve is given in Appendix B.

The document generated by PROTEUS can be used directly for reporting to the competent authorities. Moreover, the model is very suitable for simulation of the efficiency of risk reduction measures. A specific tool generates overviews of risk bearing activities sorted by a user-defined key such as activities, chemicals or parts of the sewer system (see also Appendix C). This information can be used as a leaving-point for preventive, repressive or mitigating measures, as well as a basis of a risk management system.

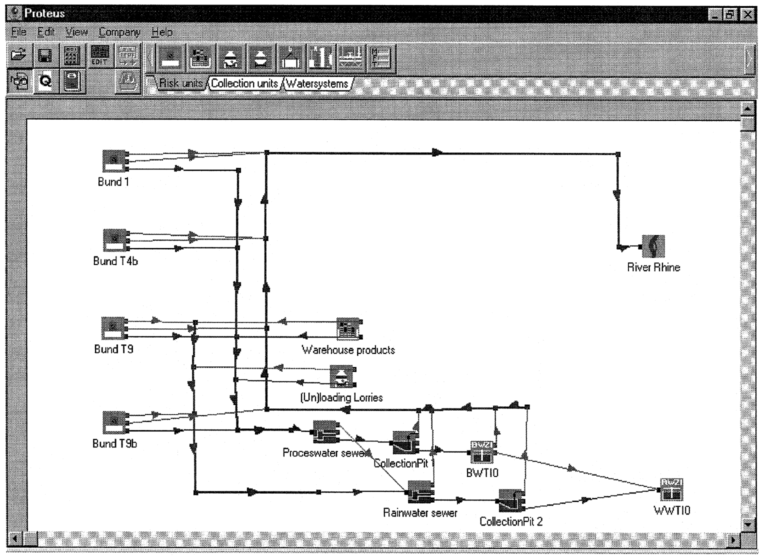
4. Discussion and future developments

PROTEUS is developed as a tool to assess risk for the aquatic environment related to industrial installations. The model is suitable for supplying accident related information in safety reports as well as a legislation tool concerning the protection of surface water quality. Hence, the model will be used by complex industrial sites as well as smaller industrial facilities using hazardous chemicals, like warehousing firms for agricultural chemicals, electroplating industries. The wide scope of industry as well as the huge variety in activities causing a possible risk to the aquatic environment invoked a need for objective criteria for the selection of activities to address in a risk assessment procedure.

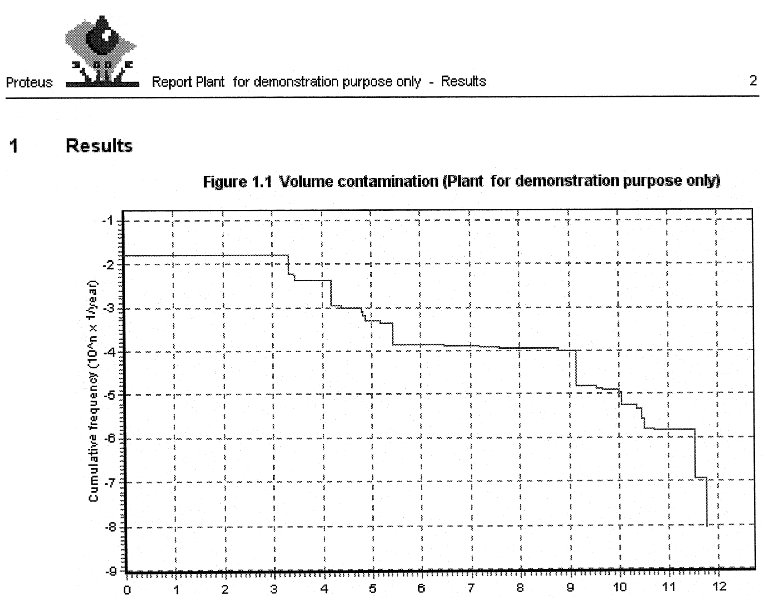
For this purpose, the Dutch authorities developed a system for the selection of risk bearing activities. Based on data concerning the amount of chemicals, relevancy to aquatic ecosystems as well as the vulnerability of surface waters relevant risk bearing activities are selected.

After application of the selection system, the risks to the aquatic environment can be determined using PROTEUS. Evaluation of the results by the government is the next step. However, the question of which risks can be considered acceptable cannot be answered yet since there are no limit values for aquatic risk available. With respect to this question, a parallel project is started. Currently, representatives of the Dutch government and industry devised a possible risk criterion scheme based on work described by AEA [11] and BUWAL [12]. This working group will report in early 1999. However, according to all relevant actors in the Netherlands, a final risk criterion scheme is to be developed on an international level. The Dutch proposal may contribute to international discussions regarding limit values for risk.

Appendix A. Example of user defined risk bearing activies in an establishment



Appendix B. A typical frequency–consequence curve (type a)



Appendix C. An overview of risk bearing activities for a user defined establishment generated by PROTEUS

Proteus Facility Analysis Plant for demonstration purpose only 0

Calculated effects on watersystems

Scenario / Installation / Part of installation	Effect: Mass outflow* [kg]	Frequency [1/year]	Expected value [kg/year]
1 • Leak (un)load connection lorry	13.57168	0.01201	0.04795
- (Un)loading Lorries	13.57168	0.01201	0.04795
2 • Tank overload lorry	1357	0.00347	1.38743
- (Un)loading Lorries	1357	0.00347	1.38743
3 • (Un)loading	2880	0.00198	0.1188
- Warehouse products	2880	0.00198	0.1188
- section 1	720	0.00049	0.0297
- section 2	720	0.00049	0.0297
- section 3	720	0.00049	0.0297
- section 4	720	0.00049	0.0297
4 • Small fire	2799136	8.7429e-5	10.70486
- Warehouse products	1955670	8.7208e-5	10.65938
- section 1	488918	2.1802e-5	2.66484
- section 2	488918	2.1802e-5	2.66484
- section 3	488918	2.1802e-5	2.66484

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