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ALARM SYSTEM FOR ACCIDENTAL POLLUTION ON THE RIVER RHINE

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ABSTRACT The Rhine is one of the most important rivers of Europe. Some 50 million people live in its basin of 185,000 km^2. About 20 million people drink water coming from the Rhine. Accidental pollution may have serious impacts on human users as well as on the ecosystem. Due to the Sandoz accident near Basel in Switzerland in 1986 the Rhine was heavily polluted by pesticides, causing death and large environmental damage. This accident triggered the Rhine Action Program. This international plan of actions is aiming at a significant reduction of pollution, ecological rehabilitation (return of the Salmon in the year 2000) and an improvement of the alarm system. In the field of monitoring new systems (e.g. bio-alarm) are applied to detect accidental pollution. Today about 90 % of all known events of accidental pollution is early detected. An important element is also the new Rhine Alarm Model. This computer program calculates the transport of pollutants in case of accidental pollution. The Rhine Alarm Model is used by all alarmstations along the Rhine. Accidental pollution control is improving, but further international efforts are needed to reduce and tackle accidental pollution.

INTRODUCTION

The river Rhine serves a large number of functions: it not only drains a catchment area of some 185 000 km^2, it also provides drinking water for about 20 million people. Furthermore the river is intensively used for shipping, discharge of waste water and cooling water. It provides water for agriculture, recreation and for the many organisms living in or in the vicinity of the river. So the Rhine fulfils an important ecological and socio-economic role as one of the most important rivers of Europe. A number of functions has contradictory interests. Only by realizing an integrated river basin management approach their combination can be maintained.

During the last decades large efforts have been made to solve problems of water pollution. By improved control of the major point-sources, the river Rhine turned from the biggest sewer of Europe into a river of restoring health. In the meantime however a new problem has risen. The cleaner the water, the more sensitive the ecosystem becomes to accidental pollution. The Sandoz-accident near Basel in Switzerland on November 1, 1986 has been a hard lesson. The river was heavily polluted by herbicides and pesticides, causing death and damage to fish and other organisms. A temporary stop of water intake from the Rhine was necessary. However water authorities and drinking water companies lacked essential information for a proper accidental pollution control. A consequence of this lack of information was that the intake of water for drinking water was stopped too early or too late.

The Sandoz-accident triggered the Rhine Action Program. This international plan of actions aims at a significant reduction of the river pollution, ecological rehabilitation (return of the Salmon in the year 2000), improvement of the alarm system and a number of other activities, including the improvement of the forecast of transport of pollutants.

A more detailed description of accidental pollution control of the river Rhine is given in this paper. Three items are discussed: (1) how the information network in the Rhine basin is organized, (2) which type of alarm model is used for the forecasting of transport of pollutants and (3) how alarms are used to trigger necessary measures.

THE INFORMATION NETWORK

Accidental pollution is inevitably related to human activities. In case something happens, the responsible people who have to decide on measures, have to receive the most recent, relevant and accurate information on the precise situation. On the river Rhine this information is collected via two information networks.

(a) the alarm network

Accidental water pollution can be detected by people (citizens, shippers, water policemen), and/or by water quality monitoring stations. The Rhine has a set of these stations. The most utilized monitoring station along the Rhine is Lobith in the Netherlands (Dutch - German border). A large number of waterquality parameters is continuously monitored: temperature, turbidity, acidity, oxygen, ammonium, electro conductivity, chloride, fluoride. Micropollutants are monitored as well: heavy metals (cadmium, copper, lead, zinc) and organic micropollutants. In order to detect unknown pollution bio-alarm systems are operational (fish, daphnia) or will be applied (algae, bacteria). A more detailed description of these bio-alarm systems is given by Botterweg *et al.* (1989). On-line monitoring of volatile micropollutants as well as polar micropollutants is planned for the near future. Every alarm is verified and transmitted to an alarm station.

The International Commission for the Protection of the Rhine against Pollution (ICPR) installed a network for warning and alarming. This network consists of eight alarm stations (Fig. 1). These stations are manned 24 hours per day and inform each other and other parties in case of accidental pollution. Each station tries to find out which substances were discharged, how much was spilled in the water and for how long the discharge lasted. For exchanging messages telex, phone and fax are used.

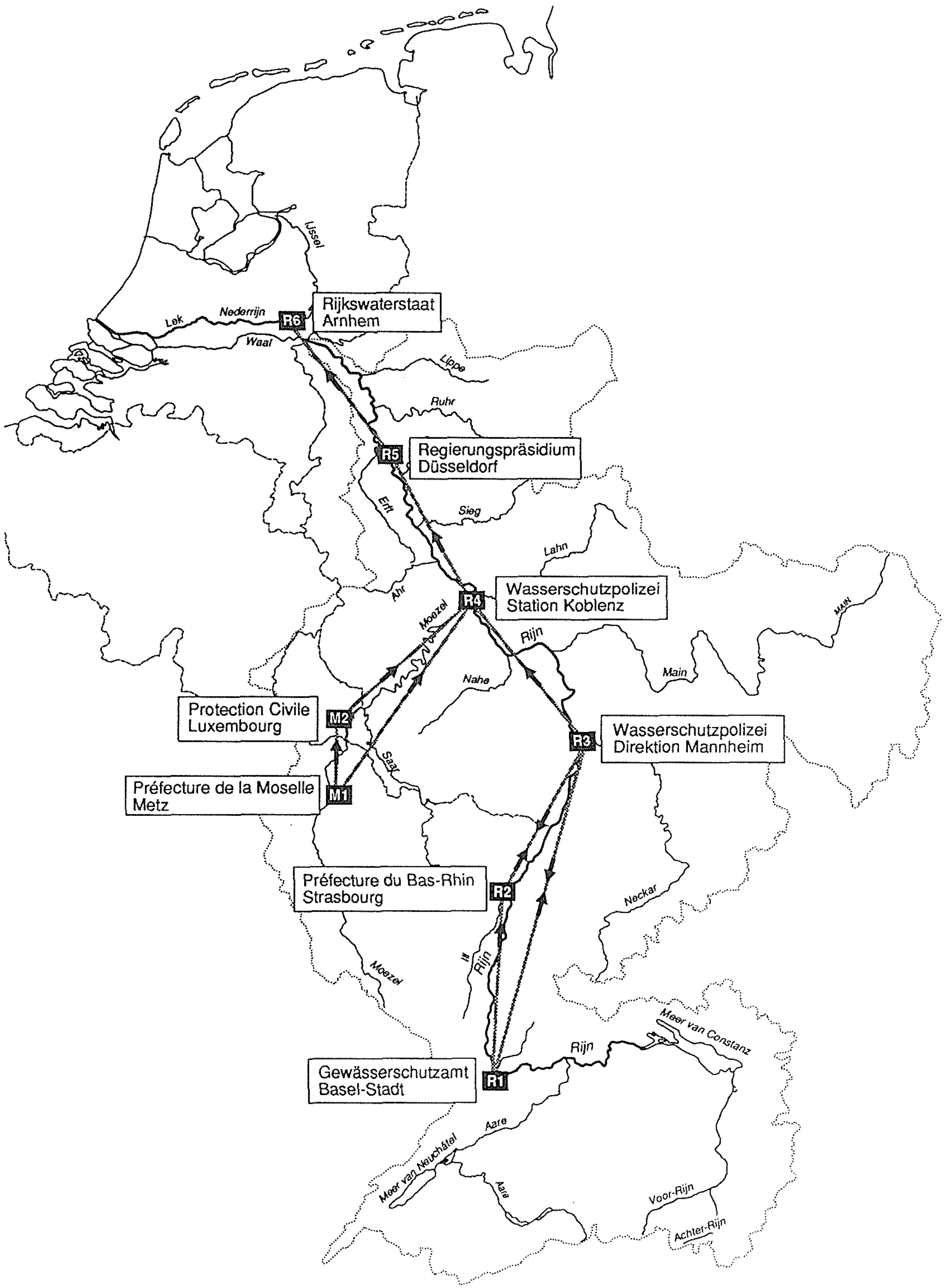

Fig. 1. *Alarmstations of the ICPR.*

Each station is responsible for the further distribution of information to downstream stations.

(b) the hydrological network

Information on the hydrological situation of the river basin is collected on a daily basis by the national water authorities. This is done to inform shippers on the available draught and headway, to forecast floods and low flow conditions, etc. An extensive network of water level gauging stations along the Rhine and its tributaries provides this hydrological information (Sprokkereef, 1989). Generally, the required meteorological information is obtained from the national weather services. Depending on the hydrological situation and the location in the basin, the information is updated every 6 to 24 hours. Forecasts of rainfall and river flows are also available.

Hydrological information of the river is essential for a good forecast of the travel time of pollutants. This forecast is made by the alarm stations, using the Rhine Alarm Model.

RHINE ALARM MODEL

To improve the alarming the International Commission for the Protection of the Rhine against Pollution (ICPR) and the Commission for the Hydrology of the Rhine Basin (CHR) formed a joint Expert Group to develop an alarm model. This group took up the work in 1987, produced a preliminary version of the Rhine Alarm Model in 1989 and is now updating this version by adaptation of the modelling concept, extension of the schematization, inclusion of the results of international tracer experiments and improvement of the output presentation.

The Rhine Alarm Model makes a forecast of the arrival time of a pollutant and a concentration profile at a certain point along the Rhine. Because of the high time pressure in case of an alarm, the Alarm Model should have a short runtime on a personal computer, should be easy to handle by the staff of the alarm stations and should be reliable in its calculations.

Since its first release (Griffioen, 1989), the model was improved step by step. Nowadays the model covers the Rhine from Lake Constance to the cities of Kampen, Vuren and Hagestein in the Dutch delta; tributaries like Mosel, Main, Neckar and Aare are included; the Dutch northern Delta area is added; new hydraulic calculations lead to an update of the relations between water level and travel times. The influence of stagnant zones is now incorporated in the model. The model was calibrated and verified using the results of a number of international tracer tests with Uranine and Rhodamine WT. A new laboratory technique has been developed to measure Rhodamine WT up to very low concentrations.

The advection (transport by flow) of the pollutant is calculated using the average flow velocity over the wetted non-stagnant cross section in a river branch. Each branch is divided in compartments. A compartment is defined as a river section in which the average flow velocity over the length can be assumed as constant; its length is typically a few kilometres. The flow time over a branch is calculated by summing up the flow times for its compartments. The average flow velocity in each compartment is calculated by calibrated hydraulic river models. These calculations enabled the construction of tables for the water level - flow time relation per branch. These relations were used in the model.

The pollutant transport is calculated by solving a one dimensional advection-diffusion equation. For an instantaneous pollution input the solution of this equation is known as the Taylor solution (Taylor, 1953, 1954). An analytical solution for this equation does not exist in the case a stagnant zone is taken into account in the model. Only an approximation can be given (Chatwin, 1980):

$$C(x,t) = \frac{M}{A.\sqrt{(4\pi Dt)}} \cdot \exp\left(\frac{-(x-ut)^2}{4Dt}\right) \cdot \left(1 - \gamma \cdot H_3 \cdot \left(\frac{(x-ut)}{\sqrt{(2Dt)}}\right)\right) \qquad (1)$$

with:

C:	concentration in (x,t)	[kg/m^3]
x:	coordinate in length direction of the river	[m]
t:	time	[s]
M:	mass of pollutant	[kg]
A:	wetted cross section	[m^2]
D:	longitudinal dispersion coefficient	[m^2.s^{-1}]
u:	mean velocity in a compartment	[m.s^{-1}]
$H_3(z)$:	Hermite polynomial with $z = (x - ut)/(\sqrt{(2Dt)})$	[-]
γ:	skewness parameter	[-]

The advective transport velocity (c) is calculated from the average flow velocity u with:

$$c = u / (1+\beta) \qquad (2)$$

with:

β:	stagnant zone parameter	[-]
c:	advective transport velocity	[m.s^{-1}]

The longitudinal dispersion coefficient is calculated with the Fischer equation (Fischer, 1979):

$$D = \frac{\alpha\, u\, B_x^2\, C}{a_x \sqrt{g}} \qquad (3)$$

with:

α:	constant	[-]
B_x:	width of the river	[m]
a_x:	river depth	[m]
C:	Chézy value $(25.(a_x/k_n)^{1/6})$	[m$^{1/2}$.s^{-1}]
k_n:	Nikuradse constant (=0.2)	[m]
g:	gravity acceleration (=9.81)	[m.s^{-2}]
u:	shear flow velocity along the bottom	[m.s^{-1}]

Special arrangements were made in the program to handle the parallel river section in the upper part of the Rhine (Oberrhein) and for the three branches in the Rhine delta (IJssel, Nederrijn/Lek and Waal). A special problem was the inclusion of the effect of the weir regimes. The user-languages of the model are Dutch, German, French and English. Version 2.0 of the model was released in the beginning of 1991. The end of the project is planned in 1992.

In its present form the Rhine Alarm Model is not applicable to pollutants which are transported along the bed of the river, nor in cases of quickly changing discharges. A linear decay of a substance can be simulated as well as floating pollutants. For reliable results the river flow should be between Q_{15} and Q_{95} and its flow conditions should be relatively constant. The pollution input is either a pulse or a time-dependent load. The flow time is calculated from the water levels at 18 gauges along the river. The output of the model is a concentration forecast in time at a certain location. An example is given in Fig. 2.

It is also possible to present the forecasted maximum concentrations along the river. A dynamic presentation (film on screen) is planned.

It is possible and rather easy to apply the Rhine Alarm Model to other rivers in the world. Essential information which is needed: a) schematization; b) relations between water levels and travel times; c) results of tracer experiments.

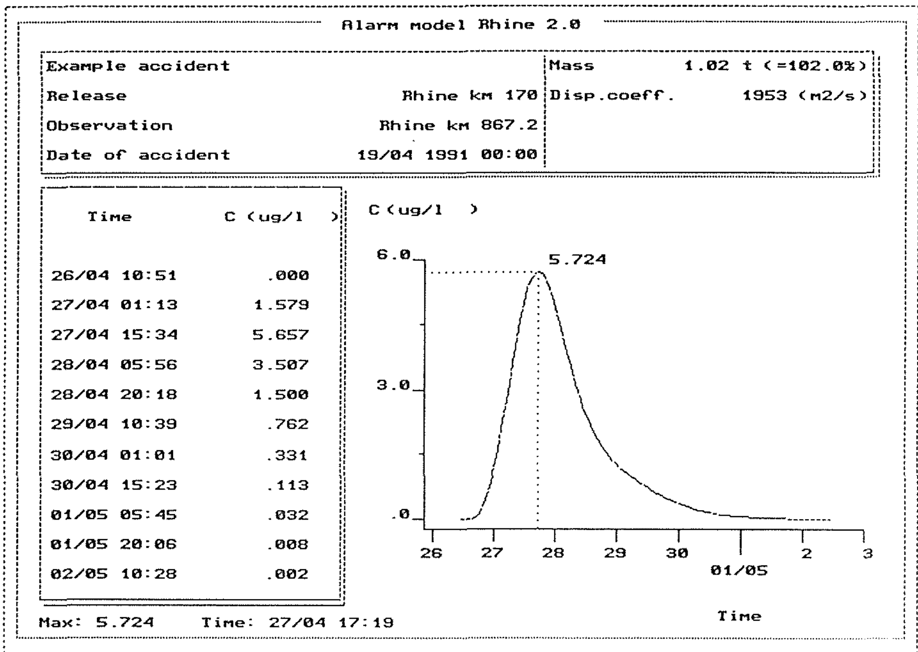

Fig. 2. Example of output of the Rhine Alarm Model.

PRACTICE OF ALARMING

Once the forecast of transport is made, an estimation of the possible damage can be made. This is done by comparing the calculated concentration profile with toxicological standards. These standards are found in a number of chemical or ecotoxicological handbooks (e.g. Alabaster and Lloyd, 1980; Verschueren, 1983; Mayer and Ellersiek, 1986; Quality, 1986; Canadian, 1987). In the near future this information will be available in a computerized information system. Such a system is being developed for Dutch watersystems and is called AQUABEL. In co-operation with water authorities and drinking water companies practical threshold values are being developed for alarming. Even if there is a slightest indication that a certain group of users (e.g. drinking watercompanies) is affected by accidental pollution, the responsible people receive an alarm message from the alarm stations, so they can take the appropriate actions in time. For example: the intake of water to prepare drinking water can be stopped for a certain period.

In practice accidental pollution occurs frequently. At the Dutch - German border 63 events have been recorded in 1987, 29 in 1988 and 72 in 1989 (Schäfer, 1990). About 90 % of all known events of accidental pollution is detected early.

CONCLUSIONS AND FINAL REMARKS

Accidental pollution control by water authorities and drinking water companies along the Rhine is still improving. The presence of a good alarm system contributes to preventing damage and is therefore of great economic and ecological value. The Rhine Alarm Model contributes to an efficient and effective alarm system. In general further international research is however needed to reduce the number and size of events of accidental river pollution as well as to improve the control of these pollutions. This research should focus on risks, monitoring, dynamics of transport processes, alarm thresholds, communication networks and measures.

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