Probabilistic approximation to risk assessment of basins by ecotoxicological evaluation

C. Fernández, G. Carbonell, and J.V. Tarazona

I.N.I.A. Laboratory for Ecotoxicology. Department of the Environment.

Ctra. A Coruña km 7.5, 28040 Madrid, Spain

Abstract: The present work shows a computer model for Risk Assessment of Basins by Ecotoxicological Evaluation (RABETOX), using a probabilistic approximation based on Monte Carlo analysis. This feature extends the forecasting capability of the model and provides the information needed to cover variability and uncertainty when supporting decision making. The model, based on system dynamics, has been developed on a spreadsheet (Microsoft Excel) under the following conditions: 1) The model comprises three subroutines: Volume Management, Hazard Management and Risk Forecasting. 2) The Volume Management block estimates flows for a variable number of segments settled on a constant time basis. Flow changes, inputs/outputs, and corrections based on measured data, are associated to the segments. Cumulative time an cumulative distance are also calculated. 3) The Hazard Management flow has as inputs, the effluent characteristics (Input position, flow, toxicity, half life and margin of safety) needed to calculate de hazard of each particular emission. The program calculates the initial hazard in the input points and their evolution downstream depending on the half life of each effluent. 4) The establishment of a general protocol for WEA, must deal with total hazard of effluents assessing not only toxicity but other parameters such persistence and bioaccumulation. These parameters have been introduced in the model through half live (persistence) and margin of safety (bioaccumulation). 5) The Risk Forecasting has been implemented by the Crystal Ball 2000 application (Decisioneering, Inc) based in Monte Carlo analysis. The risk probability distribution for the risk associated to each segment is presented.

The RABETOX model is able to manage the whole risk of a complete basin, with different effluents inputs, informing about the risk characterization in every point of the basin and forecasting about the probability eds.

Keywords: *Risk assessment; Effluent; Probabilistic Model*

INTRODUCTION

Environmental risk management of river basins is a difficult task. Multiple pollution points, variability of flow rates and changes in effluent composition depending on the industrial activities, requires complex approximations when assessing the overall risk within the river basin (Hynning, 1996).

Whole Effluent Toxicity Testing (USEPA, 1995) on several aquatic trophic levels (algae, invertebrates and fish), and a new strategy for wastewater discharges covering bioaccumulation and persistence in addition to toxicity based on "Whole Effluent Assessment" WEA (OSPAR Commission, 2000) offer several possibilities, which after modification of the current approaches, could be used in risk assessments.

At the river basin level, a high variability is expected for most input parameters, and therefore, probabilistic risk estimations should be recommended. Parameters will be affected by variability and uncertainty and both aspects should be considered.

Monte Carlo simulation is one established solution, and can be implemented in a spreadsheet, combining the features of spreadsheets with the ability to run and analyse simulations. Crystal Ball (Desioneering UK, Ltd), is a user-friendly, graphically oriented forecasting and risk analysis Microsoft Excel add-in software that use Monte Carlo simulation to help you analyse the risk and uncertainties associated with spreadsheet models (Goldman 2002). Crystal Ball allows users to define probability distributions on uncertain model variables, and then uses simulation to generate random values from within the defined probability ranges.

Earlier works have used probabilistic models to develop the risk-based TMDL assessment (Rousseau 2002) or to design/retrofit of wastewater treatment plants (Rousseau 2001); on the other hand exposure simulations in river

basins have been assessed by computer models using the Geographical Information System (GIS) in order to calculate the distribution of predicted environmental concentrations (PECs) (Schowanek 2000), but without forecasting features.
The present work shows a computer model for Risk Assessment of Basins by Ecotoxicological Evaluation (RABETOX), able to manage the overall risk of a complete river basin, with different effluents inputs, informing about the risk characterization in every point of the basin and forecasting the probability for effects. The model uses a probabilistic approximation based on Monte Carlo analysis extending the forecasting capability of the model and provides the information needed to cover variability and uncertainty when supporting decision-making.

MATERIALS AND METHODS

The model, based on system dynamics, has been developed on a spreadsheet (Microsoft Excel) combined with Crystal Ball 2000 Professional Edition as add-in software. A general protocol for WEA was designed, quantifying the total hazard of each effluent assessing not only toxicity but also persistence, bioaccumulation or other hazards established by the user.
The model comprises three main subroutines: Volume Management, Hazard Management and Risk Forecasting.

Volume management subroutine

The model presents the basin as a main river with tributaries represented as inflows. The portion of basin chose in the analysis is settled by the user, establishing a variable number of segments according to a time constant. This constant is defined as the time needed by water to go from one segment to the next. This constant permits to establish variable lengths for each segment depending on the linear water speed. Each Excel row represents a river segment with segment number, time constant, linear water speed, length and cumulative time and distance from the origin.
The Volume Management block estimates flows for a variable number of segments settled on a constant time basis. Flow changes, inputs/outputs, and corrections based on measured data, are associated to the segments and are introduced by the user in the corresponding arrow according to the real position in the main river. Model design permits up to four input/outputs in each segment and so many segments as arrows has the Excel spreadsheet.

Hazard management subroutine

This subroutine has as inputs the effluents characteristics (input segment, effluent flow, toxicity, persistence, and margin of safety for covering other hazards). Users introduce these characteristics for each effluent and the model calculate the hazard units and the maximum initial risk in the input river point. Model design permits to introduce up to 13 effluents, but could be expanded to as many effluents as required. The model calculates the initial hazard in the input points and their evolution downstream depending on the measured half-life for the toxicity of each effluent and the additional dilution.

Risk Forecasting

The Risk Forecasting has been implemented by the Crystal Ball 2000 application (Decisioneering, Inc) based in Monte Carlo analysis. Cells containing variable inputs as flows of effluents and rivers, toxicity data and half life are converted from single values to probability distributions. In Crystal Ball, probability distributions are referred to as "assumptions" and are the basic inputs you use to define the uncertainty in the model. The program has a distribution gallery to help the user in these assumptions.
The user can select different points in the main river to perform the forecast selecting the graphic output settings and the number of trials to run.
Before running the simulation, interactive histograms outputs are displayed on the screen allowing the user to evaluate the probabilistic risk in each selected point.

This model was applied in the following real scenario:

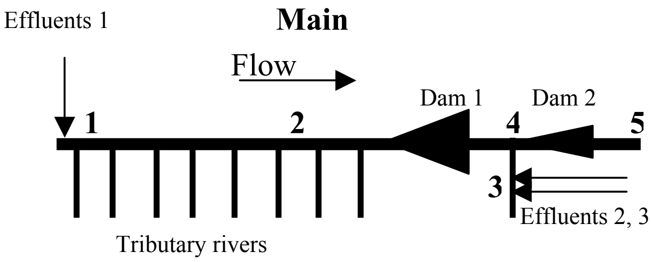

Figure 1: Scheme of analysed basin

This scenario comprises 3 effluents, 9 tributaries, 2 dams and the main river with a total length of 698 km.
Characteristics of effluents and rivers introduced in the model were the following:
Effluent 1: Flow 0.0277 m^3/seg, 1000 toxicity units, 2 days (172800 seg.) half-life, margin of safety 100, input point 50 km downstream from the origin.
Effluent 2: Flow 0.0017 m^3/seg, 2000 toxicity units, 10 days (864000 seg.) half-life, margin of

safety 100, input point 50 km downstream from the origin.
Effluent 3: Flow 0.055 m^3/seg, 1000 toxicity units, 5 days (432000 seg.) half life, margin of safety 100, input point in a secondary river. This tributary enters at 579 km downstream from the origin.
Tributary river: flows between 0.5 to 150 m^3/seg and a linear speed of 0.5 m/seg.
Main river in point 1: 19 m^3/seg, linear speed 0.5 m/seg., assumption: triangular distribution (min 7.4, max 90) obtained from a data base of 10 years. The flow is recalculated, in each zone, according to the different inputs of secondary rivers.
Dam 1 placed between 427 and 529 km, with a transit time of 30 days and a linear speed of 0.04 m/s. Dam 2 placed between 592 y 616 km with a transit time of 1 days and a linear speed of 0.25 m/s.

Probabilistic risk of effluents 2 and 3 are evaluated in a previous scenario on secondary river and the combined risk is treated as a new diluted input effluent in the main river.
As outputs the model supplies the deterministic risk in the complete basin and the probabilistic risk in several points (1: input of effluent 1, 2: intermediate point, 3: input of effluents 2 and 3, 4: input of the last secondary river and 5: mouth of the river) displayed as a frequency chart of Risk Units (RU).
This outputs can be directly selected by users labelling the corresponding excel cell according to the position in the main river.

RESULTS

In the previous scenario the model calculates the deterministic risk in the secondary river with effluents 2 and 3 (see Figure 1). In this scenario the risk decreases sharply and at 20 km downstream from spill point, is bellow 1 risk unit. Figure 2, shows the risk profile in the tributary river. There are no main tributaries, and therefore, the risk reduction is directly related to the degradation of the toxic compounds, estimated from the dissipation of toxicity observed in the laboratory persistence assays.

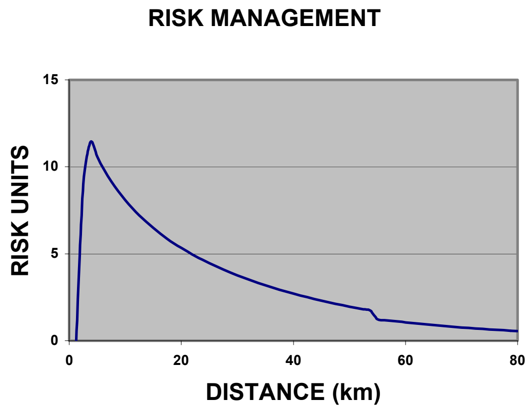

Figure 2. Risk profile in the tributary river receiving effluents 2 and 3.

In a second step, the model calculates the deterministic risk in the total basin, direct emissions to the main river and the contribution of the tributary with industrial discharges are considered. This contribution estimated as input point with independent assessments for hazard and water management, 579 km downstream from the origin. As shows Figure 3, the main risk is associated with inputs of effluent 1, remaining up to 200 km downstream with more than 25 risk units (5 days from the spill point) .

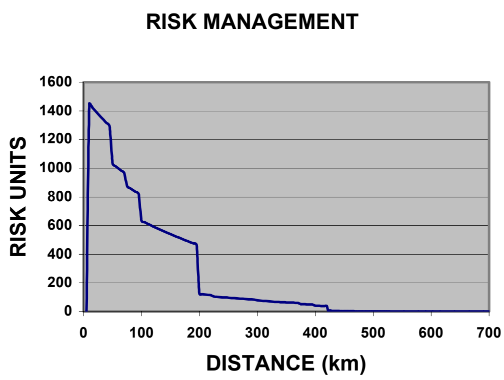

Figure 3- Risk profile of the main river

The contribution of effluents 2 and 3 is negligible, due to the auto-depuration processes within the tributary. For effluent 1, dilution with other tributaries plays a major role that depuration in the risk reduction.
Crystal Ball add-in software, was incorporated into the model to estimate the probabilistic risk in the selected points (see figure 1).

Figures 4 to 8 show the corresponding frequency charts.

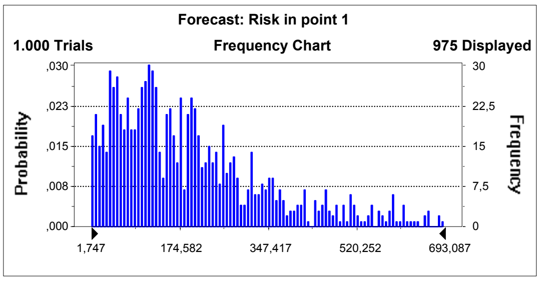

Figure 4: Probabilistic risk in point 1

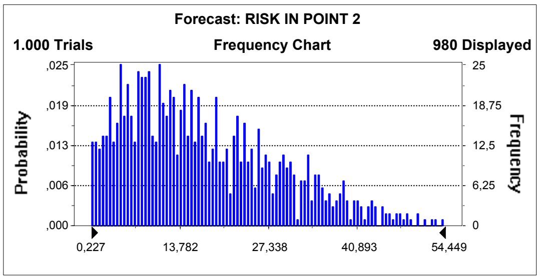

Figure 5: Probabilistic risk in point 2 (input of effluent 1)

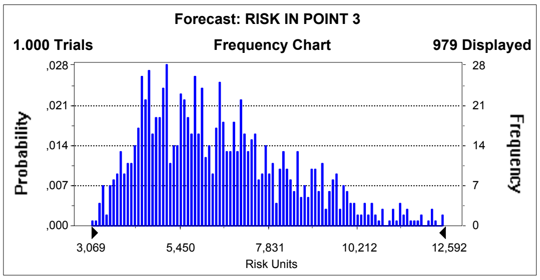

Figure 6: Probabilistic risk in point 3 (input of effluent 2 and 3)

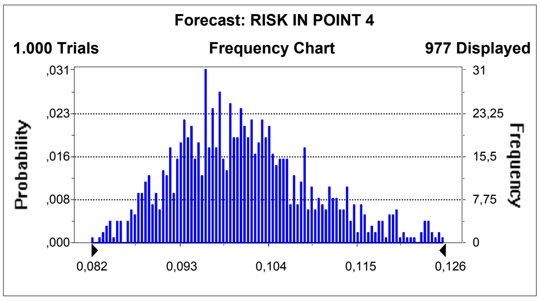

Figure 7: Probabilistic risk in point 4 (input of the last secondary river)

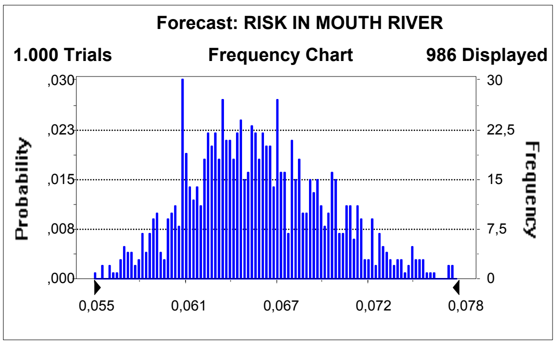

Figure 8: Probabilistic risk in point 5 (mouth river)

As expected, the probabilistic estimations offer a low risk likelihood than that estimated from the deterministic method.

In fact, for the tributary, where the variability on effluent flow and toxicity are limited, the likelihood for reaching a value close to that estimated from the deterministic method is between 3-4%; while the likelihood for observing a risk equal to or higher than one half of the deterministic estimation is 58%.

The differences are much higher for the main river, where the 95th percentile for the probabilisitic distribution is around one half of the deterministic estimation; and the likelihood for reaching one fourth of the maximum predicted level is about 30%.

The probabilistic approach offers a better estimation of the likelihood for risk, escaping from the unlikely worst-case assumption of deterministic estimations.

Soldan (2003) has recently review the use of toxic based risk in the Odra rive basin. The data presented in this report are based on results from direct toxicity assessment. Obviously, alternative methods, such as risk estimations based on ecotoxicological thresholds (Tarazona, 1997) for specific contaminants (e.g. Preston and Shackelford, 20002), can also be incorporated in our model.

The hazard estimations used in this example are based on the application of a margin of safety of 100 on acute toxicity data; which has been considered as generally acceptable in different fora, including the European regulations on pesticides and veterinary medicines (see the revision by CSTEE, 2001).

Obviously, other margins of safety, like the factor of 1000 recommended in Europe for industrial chemicals (EU, 1996), can also be incorporated.

In conclusion, a versatile and tiered approach for the direct risk assessment of complex situations in river basins, allowing the incorporation of direct toxicity assessments and the incorporation of additional hazards, such as persistence, for moving from WET to WEA is offered.

ACKNOWLEDGEMENTS

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REFERENCES

EU (1996) Technical Guidance Document in support of Commission Directive 93/67/EEC on risk assessment for new notified substances and Commission Regulation (EC) 1488/94 on risk assessment for existing substances. PARTS I, II, III and IV. Document. ISBN 92-827-8011-2. Luxembourg: Office for Official Publications of the European Communities, 1996

EUROPEAN COMMISSION (2001) CSTEE opinion on the available scientific approaches to assess the potential effects and risk of chemicals on terrestrial ecosystems. Reports of the Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE), Brussels, 178 pp. (Internet publication available, paper publication in press).

Goldman I.L., Crystal Ball Professional Introductory tutorial, *Proceedings of the 2002 Winter Simulation Conference,* 1539-1554, 2002.

Hynning P-A., Separation, identification and quantification of components of industrial effluents with bioconcentration potential, *Wat. Res. ,* 30 (5): 1103-1108, 1996.

Preston BL., Shackelford J., Risk-based analysis of environmental monitoring data: application to heavy metals in North Carolina surface waters, *Environ. Manage.,* 30(2): 279-93-82, 2002.

Rousseau D., Verdonck F., Moerman O., Carrette R., Thoeye C. Meirlaen J., Vanrolleghem PA., Development of risk assessment based technique for desing/retrofitting of WWTPs, *Water Science & Technology,* 43(7): 287-94, 2001.

Rousseau AN, Mailhot A, Villeneuve JP., Development of a risk-based TMDL assessment approach using the integrated modeling system GIBSI, *Water Sci Technol* 45(9):317-24, 2002.

Schowanek D., Webb S., Examples of exposure assessment siumulation for pharmaceuticals in river basins with the GREAT-ER 1.0 system, *Proceedings KVIV Seminar "Pharmaceuticals in the Environment"* , March 9, Brussels, 2000.

Soldan P., Toxic risk surface water pollution-six years of experience, *Environ. Int.,* 28(8): 677-82, 2003.

Tarazona JV., The identification thresholds of acceptability and danger: The biological route, *Arch. Toxicol.,* Sup 19: 137-146, 1997.

USEPA, (1995). Methods for measuring the acute toxicity of effluents and receiving water to freshwater and marine organisms. EPA/600/4-90/027F, EPA/600/4-91/002, EPA/600/4-91/003K.