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EVALUATION AND NETWORK OF EC-DECISION SUPPORT SYSTEMS IN THE FIELD OF HYDROLOGICAL DISPERSION MODELS AND OF AQUATIC RADIOECOLOGICAL RESEARCH

Assessment of environmental models and software

Edited by

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EVANET-HYDRA
NETWORK
CONTRACT N° FIGE-CT-2001-20125
European Commission

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Assessment of environmental models and software

LUIGI MONTE, DMITRY HOFMAN, JOHN BRITTAIN

Abstract

The present report describes the results of an assessment of state-of-the-art computerised Decision Support Systems based on environmental models for the management of fresh water ecosystems contaminated by radioactive substances. The models are examined and compared to identify their main features, the application domains, the performances, etc., for a rationale of the entire sector in view of the needs of potential users. A similar assessment was performed for the software products implementing the Decision Support Systems. This work was carried out in the frame of the network EVANET-HYDRA financed by the European Commission

Keywords: Contaminants, Models, Decision Support Systems (DSS), Countermeasures, Radionuclides

Riassunto

Il presente rapporto descrive i risultati della valutazione dello stato dell'arte di "Decision Support Systems" sviluppati a livello internazionale per il management degli ecosistemi acquatici contaminati da sostanze radioattive. i modelli sono stati esaminati e confrontati per individuarne le caratteristiche, le funzionalità, i domini di applicazione, ecc. per la sistematizzazione razionale dell'intero settore in vista delle esigenze di degli utenti. Una simile analisi è stata effettuata per i prodotti software che implementano i "Decision Support Systems". Il presente lavoro è stato svolto nell'ambito del network EVANET-HYDRA finanziato dalla Commissione Europea.

EVANET-HYDRA

NETWORK

CONTRACT N° FIGE-CT-2001-20125

European Commission

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Foreword

Computerised Decision Support Systems (CDSS) aimed at assisting experts to assess the appropriateness of suitable strategies for the management of aquatic ecosystems contaminated by radionuclides are essentially based on:

- Models for predicting the time behaviour of radionuclides in the fresh water environment, the effects of the interventions (countermeasures and restoration actions), the ecological, the social and the economical impacts of such interventions;
- Methodologies for ranking the different feasible interventions accounting for the mentioned impacts;
- Software components realising the above models and methodologies, joining all the DSS components into the unit system and supporting the system with the user-friendly interface;
- Data storage and analysis tools (GIS and data bases).

The classification of the approaches of the various components of CDSSs, the determination of their essential features, the identification of similarities and differences among them and the definition of their application domains are essential for the harmonisation of the existing CDSSs with a view to their wide application throughout Europe.

Analyses of existing environmental models demonstrated that most of the accepted conceptual approaches can be integrated in a general, harmonised perspective supported by a variety of experimental evidence. Important lessons can be learnt from the model assessments and exercises performed during the project. The wise application and use of predictive environmental models require that end-users must be aware of model performance, mainly in relation to the output uncertainty levels and how these should be taken account of in the decision making process.

The network was also aimed at assessing the techniques used for the evaluation of the effectiveness of the strategies for the management of contaminated water bodies and the features of the CDSS software in view of the expectations of potential users. Among the different methodologies used to assess the effectiveness of management policies, Multi-Attribute Analysis (MAA) is, probably, the best to consider multiple objectives together with the decision maker's preferences. CDSSs based on MAA structure the decision process helping a critical analysis of the available information for a more aware consent of the decision makers about the selected options.

The assessment of the features of the software of the examined CDSSs in view of the expectations of potential end-users was carried out. Feedback was obtained on which to plan improvements of the software architecture of the existing CDSSs. Such improvements are relevant to the upgrading and customisation of user-friendly methods required to facilitate critical assessment procedures for the selection of appropriate management strategies and for the development of software procedures to enable enhanced exchange of data and information among different CDSSs.

PART 1

PART 2

The EVANET-HYDRA network: introduction

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The project EVANET-HYDRA was financed by the European Commission within the 5th framework programme (CONTRACT N° FIGE-CT-2001-20125). It was aimed at assessing the state-of-the-art of models and computerised Decision Support Systems (DSS) for the off-site management of fresh water and coastal ecosystems contaminated by radionuclides following nuclear emergencies.

Such an overall objective was achieved by

- The critical evaluation and assessment of the components of dsss by experts from the scientific community;
- The wide exchange and dissemination of expert knowledge and end user experiences;
- Supporting and harmonising the customisation and application activities as performed by the user community;
- Supplying recommendations for dsss rationale and improvements from the gained experiences and the lesson learnt.

The classification of the approaches of the various components of CDSSs, the determination of their essential features, the identification of similarities and differences among them and the definition of their application domains are essential for the harmonisation of the existing CDSSs with a view to their wide application throughout Europe.

The appropriate management of fresh water ecosystems contaminated by radionuclides requires the assessment of the costs and the benefits of countermeasure and restoration strategies aimed at reducing doses to man. Any environmental intervention may cause, indeed, non-desirable effects of ecological, economic and social nature That should be carefully evaluated.

Computerised Decision Support Systems (CDSS) aimed at assisting experts to assess the appropriateness of suitable strategies for the management of aquatic ecosystems contaminated by radionuclides are essentially based on:

- Models for predicting the time behaviour of radionuclides in the fresh water environment, the effects of the interventions (countermeasures and restoration actions), the ecological, the social and the economical impacts of such interventions;
- Methodologies for ranking the different feasible interventions accounting for the mentioned impacts;
- Software components realising the above models and methodologies, joining all the DSS components into the unit system and supporting the system with the user-friendly interface;
- Data storage and analysis tools (GIS and data bases).

Analyses of existing environmental models demonstrated that most of the accepted conceptual approaches can be integrated in a general, harmonised perspective supported by a variety of experimental evidence. Important lessons can be learnt from the model assessments and exercises performed during the project. The wise application and use of predictive environmental models require that end-users must be aware of model performance, mainly in relation to the output uncertainty levels and how these should be taken account of in the decision making process.

The network was also aimed at assessing the techniques used for the evaluation of the effectiveness of the strategies for the management of contaminated water bodies and the features of the DSS software in view of the expectations of potential users. Among the different methodologies used to assess the effectiveness of management policies, Multi-Attribute Analysis (MAA) is, probably, the most appropriate to consider multiple objectives together with the decision maker's preferences. DSSs based on MAA structure the decision process helping a critical analysis of the available information for a more aware consent of the decision makers about the selected options.

Among the examined DSSs, MOIRA is the only one that assesses the effectiveness of countermeasures by a full application of Decision Analysis Methodologies.

An evaluation of the effectiveness of countermeasures for the management, or restoration, of a contaminated aquatic ecosystem, should be based on well accepted measures of the ecological, social and economic impacts:

- *Ecological impact*

In principle, a quantitative assessment of the ecological impact can be difficult. MOIRA's Ecosystem Index (EI) seems to be the only quantitative methodology to measure the ecological impact of countermeasures on aquatic ecosystems. EI is a tool to give a holistic account for the environmental (and not just radiological) consequences of chemical remedial measures (water and wet land liming, potash treatment and lake fertilisation) carried out to reduce radionuclide levels in water, sediments and biota.

- *Social impact*

The social impact of countermeasures can be broadly linked to the health impact as well as to the alteration on normal living conditions of the population. Obviously, dose assessment to man is a necessary component of any DSS, since this is the direct measure of the impact of the radionuclides. On the other hand, less specific *stress and* *reassurance-related effects* that can result from the accident itself and from the application of countermeasures, can be considered in a subjective, qualitative way. For those countermeasures implying restrictions in normal living conditions, good quantities to measure the social impact could be the number of persons and the surface of the area affected by restrictions together with the duration of such restrictions.

- *Economic* impact

Models for assessing the direct economic impact are basically straightforward. Standard methods for costing the different cost components of the application of countermeasures are usually employed. There exist a number of specific factors that could help to characterise the economic impact of a given countermeasure. They will be normally measured per unit of element affected (e.g. tons of chemical product to be distributed, volume or surface of sediments removed, production lost, etc.). From these factors, some can be evaluated in terms of economic cost (man-power, equipment needed, consumables, cost of management and disposal of wastes generated, etc).

The assessment of the features of the software of the examined DSSs in view of the expectations of potential end-users was carried out. Feedback was obtained to plan improvements of the software architecture of the existing DSSs. Such improvements are relevant to the upgrading and customisation of user-friendly methods in order to facilitate critical assessment procedures for the selection of appropriate management strategies and to the development of software procedures that enable enhanced exchange of data and information among different DSSs.

The assessment of the applicability of the software in order to solve practical tasks of decision-making is of particular importance. For each software product it is necessary to:

- Identify the “application domain” and potential users of each software product;
- Identify if software provides all information required for the decision making support in this “application domain”;
- Identify if presentation of the information and input of the new information with user interface satisfies the requirements of decision makers and operators;
- Identify if data, cost and manpower resources required for the software implementation and customisation of the software to the site-specific conditions correspond to the end-user possibilities;
- Identify if documentation and support currently provided are enough for the end-users;
- Evaluate if software includes the features corresponding current state-of-art and expected by end-users as standard

The assessment suggested several improvements of the existing DSSs:

- Increase help in the decision support via implementation of modules for build-in uncertainty and sensitivity analysis of the results;
- Increase volume of information presented by DSS to the users;
- Optimisation of the time required for the DSS site-specific and scenario-specific data implementation and of the time and costs required for the DSS setting-up installation:

- Increasing of models speed performance;
- Development of the common basis for easy communication between different DSSs both on local computer and via network;
- Providing documentation and internet-based constant support for the users.

Three of the twelve project meetings were devoted to the dissemination of expertise and to exercises of DSSs. These meetings were intended to create a user communion, in which, by means of presentations, the end-users gave information about their customisation progress and supplied feedback to model developers from an end-users point of view. The developers were asked to give presentations on the different models of the developed DSSs to inform end-users or potential end-users about the model features. The end-users themselves were stimulated to give presentations of their national projects concerning the customisation of some specific DSS such as RODOS-HDM and MOIRA. DSS and model application exercises were carried out during these meetings. Benchmarks were performed to give the end-users clear information about the use and the specific characteristics of the different models.

The project activities have clearly demonstrated the need of a sustainable co-operation among modellers, DSS developers and potential end-users within the frame of a network of experts. Such a network could be effectively exploited for the management of environmental emergencies from nuclear accidents. The complexity of any fresh water management problem, the novelty inherent to any potential environmental emergency, the need of a proper and aware usage of DSSs in view of the many difficulties encountered by their applications in real circumstances to complex ecosystems, the many subjective elements proper of the decision making process and the uncertainties that affect any prediction, strongly support the belief that the proper management of any emergency should be primarily based on a flexible and effective response from the expert community. It is quite obvious that such expertise should be saved and properly transferred to new generations. In this respect human expertise and experience should be considered vital and the very value that deserve to be preserved. It seems clear that DSSs can properly assist a rational decision process only if they are used for critical evaluations and when their results are analytically assessed and compared within the frame of the community of expert.

The achieved results were relevant to the rationalisation of the existing DSSs and of the methodologies and models used by DSSs. Links between DSS users and model developers have been strengthened to assure that the aims and objectives of state-of-the-art DSSs comply with needs and expectations, at a European level, both from an environmental and a social point of view. DSS users from several countries have been involved in the network. This was an important result as it has been recognised that the management of contaminated environment must be carried out at a multinational level.

The network experiences and activities contributed a) to the harmonisation, at a European level, of methodological approaches for the management of fresh water ecosystems and coastal areas contaminated following the accidental introduction of radioactive contaminants in the environment; b) to the maintenance and improvement of expertise in DSS development and usage and, c) to set up and strengthen co-operation links between several European Institutions involved, at different levels, in the activities relevant to the nuclear emergency management.

The network has contributed to increase the dissemination of knowledge, and improved expertise of GIS technology and environmental modelling and restoration.

The assessment and the CDSS exercise carried out during the network activities offered the possibility of planning a number of improvements of the models and the software products developed to support the Decision Making for the management of fresh water systems contaminated by radionuclides.

Consequently, suitable plans for the improvement of DSSs in view of the needs of the users' communities were developed. Information about existing DSSs was widely disseminated through the communities of potential users.

During the meetings several demonstrations of DSSs were supplied. Progresses in the implementation and customisation of these DSSs were presented by users.

The project contributed to strengthen the co-operation links among DSS developers and potential end-users and to create an international network of experts that can be promptly and effectively exploited for supporting the management of future environmental emergencies in Europe.

Suitable actions have been implemented for the dissemination of the network results. The network results are available on the web site http://info.casaccia.enea.it/evanet-hydra. Some articles have been published in international journals for a broad dissemination of the network results:

Monte, L. Brittain, J. E., Håkanson, L., Smith, J. T., van der Perk, M. (2004) Review and assessment of models used to predict the migration of radionuclides from catchments. Journal of Environmental Radioactivity 75:83-103

Monte, L. Brittain, J. E., Håkanson, L., Heling, R., Smith, J. T., Zheleznyak, M. (2003) Review and assessment of models used to predict the fate of radionuclides in lakes. Journal of Environmental Radioactivity 69:177-205

Monte, L. Brittain, J. E., Håkanson, L., Smith, J. T., Boyer, P. Lepicard, S.(2005) Review and assessment of models used to predict the migration of radionuclides through rivers Published in Journal of Environmental Radioactivity 79:273-296.

The present report describes the results of an assessment of state-of-the-art computerised Decision Support Systems based on environmental models for the management of fresh water ecosystems contaminated by radioactive substances. The DSSs are examined and compared, in relation to the implemented models (Part 1) and software codes (Part 2), to identify their main features, the application domains, the performances, etc., for a rationale of the entire sector in view of the needs of potential users.

PART 1

REVIEW, ASSESSMENT AND RATIONALE OF MODELS IMPLEMENTED IN DECISION SUPPORT SYSTEMS FOR THE MANAGEMENT OF FRESH WATER BODIES CONTAMINATED BY RADIONUCLIDES.

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SECTION 1: GENERAL PRINCIPLES

Introduction

The appropriate management of fresh water ecosystems contaminated by radionuclides requires the assessment of the costs and the benefits of countermeasure and restoration strategies aimed at reducing doses to man. Any environmental intervention may cause, indeed, non-desirable effects of ecological, economic and social nature. Consequently, critical evaluations of alternative management strategies are necessary to determine which of these reach the optimal balance between the related benefits and costs.

Such an assessment requires two sets of necessary tools:

a) Models for predicting the behaviour of radionuclides in the fresh water environment, the effects of the countermeasure interventions (restoration actions) on the levels of pollution and the ecological, the social and the economic impacts of such interventions;

b) Methodologies for ranking the different applicable countermeasures according to their effectiveness when the benefits due to the dose reductions and the ecological, the social and the economic detriments are accounted for.

Predictive models and appropriate methodologies for assessing the effectiveness of any environmental intervention strategy are, therefore, essential for the development of suitable plans for the management of contaminated areas.

It is necessary to manage a great deal of data and information as well as to use the above models and methodologies for this assessment. Computerised Decision Support Systems (CDSS) are the response to these needs (Appelgren et al. 1996).

CDSSs are software codes showing a high degree of complexity and which address problems of great relevance for the practical management of the aquatic environment. These software products reach certain defined goals running quantitative evaluations, simulating the consequences of selected interventions, calculating costs and analysing benefits. They organise and structure the knowledge of experts and allow decision makers to use many different types of models appropriate for different environmental, social and economic situations and for each specific contamination scenario.

It is essential that a CDSS is aimed at answering specific demands from environmental managers and other potential users.

Several projects of the IVth EC framework programme (”Radiation Protection”) focused on developing models and Computerised Decision Support Systems for the management of fresh water systems polluted by radionuclides. Techniques for the assessment of countermeasure effectiveness were also developed.

Due to the wide variety of developed models and CDSSs, it seems wise to review and assess these to identify and classify their approaches, to define their application domains, to ensure that they comply with expectations of potential users and, finally, to synthesise the experience gained for improving the models and the CDSSs and for the rationalisation of the whole sector.

EVANET-HYDRA (“Evaluation and Network of EC-Decision Support Systems in the field of Hydrological Dispersion Models and of Aquatic radioecological Research”) is a thematic network for

- users;
- experts from environmental protection agencies and the scientific community;
- model and software developers;

whose main aim is the above review and assessment.

The network is based on the critical evaluations and experiences gained by experts and end users during the processes of analysis, testing, application and customisation of the models and CDSSs.

Criteria for a classification of the achievements and results of the projects in relation to potential applications as Decision Support Systems.

Any assessment of the state-of-the-art of a scientific or technological sector requires a preliminary census of the relevant available products.

EVANET-HYDRA network is mainly (but, in principle, not only) concerned with models and CDSSs developed in the frame of projects financed by the EC or, more generally, developed by European Institutes.

Table 1 lists some important projects, most of which were financed by the European Commission, to develop models and CDSSs for the management of radionuclide contaminated fresh water ecosystems. VAMP, BIOMOVS and BIOMOVS II projects, although not financed by EC, are considered here as their results were exploited, at least partially, by some EU projects and are of paramount importance for the aims of EVANET-HYDRA.

The achievements and the results of the above projects can be classified in three broad categories: a) improvement and verification of scientific knowledge; b) exercises and applications of methodologies and models; and, c) development of models and of the relevant codes.

Obviously, it is difficult to categorise the projects according to a clear-cut classification as the previously listed tasks have been, more or less, within the scopes of each project.

Accounting for their main aims, the projects can be classified as follows:

a) improvement and verification of scientific knowledge:
ECOPRAQ, AQUASCOPE, AQUASTAR, MOIRA, TRANSURANIC, SPARTACUS

b) exercises, validation and applications of methodologies and models:
COMETES, BIOMOVS, VAMP;

c) development of models and codes:
ECOPRAQ, AQUASCOPE, AQUASTAR, MOIRA, CASTEAUR, RODOS, SPARTACUS

In the most trivial and general way a Decision Support System may be defined as any tool based on the organic structuring of expert knowledge to help decision-making.

In principles, models for predicting the behaviour of radionuclides in the fresh water environment may be, therefore, obvious examples of DSS if they are aimed at answering specific demands from environmental managers or other potential users. Some software codes developed in the frame of the previous projects show a high degree of complexity and address problems of great relevance for the practical management of the aquatic environment. They show the essential features of a CDSS listed in the previous paragraph. MOIRA and RODOS Decision Support Systems belong to such a category. From now on we define them as “Computerised Decision Support Systems”.

Structure of CDSSs

CDSSs aimed at assessing the appropriateness of suitable and feasible countermeasures for restoring aquatic environment contaminated by radionuclides are based, essentially, on

- A complete set of models for predicting the time behaviour of radionuclides in the fresh water environment, the effects of the countermeasure interventions (restoration actions) on the levels of pollution and the ecological, the social and the economical impacts of such interventions;

- Methodologies for ranking the different applicable countermeasures according to their effectiveness when the benefits due to the dose reductions and the ecologic, the social and the economic detriments are accounted for.

Obviously, the CDSS software must be structured to guide decision makers to approach problems, and to manage different solutions by "navigation" through different possible options. The user interface that is aimed at reaching such goals is an essential component of any CDSS.

Therefore, the process of assessment and evaluation of the Decision Support Systems object of EVANET-HYDRA network will be split in three main branches:

1) Modelling:Model selection, demonstration and assessment;
2) Methodologies for ranking the effectiveness of environmental interventions: Selection, demonstration and assessment of methodologies for the evaluation of countermeasure effectiveness;
3) Software: Assessment of software quality, software design, user interfaces and customisation tools; organisation and management of users' group activities.

Modelling

Introductory remarks

It seems reasonable to fix some principles of general nature about modelling, modelling approaches and basic ideas underlying modelling. These will be useful for the objective of the assessment of the environmental models in the present network.

Obviously, a general, comprehensive review of the fundamental modelling concepts, approaches, techniques, etc. is not within the scope of the present network. Indeed, it is supposed that they belong to the background of knowledge of any modeller. Nevertheless, some "myths" deserve to be analysed and discussed in details in order to clarify those particular points that are responsible of insignificant but, unfortunately, seemingly important differences of opinion among environmental modellers.

Modelling, in its broader meaning, is aimed at constructing the "rational reproduction" of natural systems. In other words, models structure knowledge concerning a natural system in a rational framework allowing the logical deduction of the properties of the system from some basic assumptions that, obviously, are substantiated by experimental evidences. As mathematics is, essentially, logic, it is trivial to accept such a definition for environmental mathematical models (Thom, 1975).

Mathematics is, therefore, an essential component of any environmental model. It is quite obvious that a model must be logically coherent and mathematically correct in relation to its hypotheses (including approximation).

A myth that must be dismissed is the assumption that models based on some rather complex mathematical procedures are more sophisticated and then more "scientifically" founded then models based on simpler calculation techniques. This can be true in several cases but is not *always* true. It is surprising that the previous a point of view has often induced modellers to claim a supposed (although not proved) superiority of techniques based on partial differential equations compared with compartment models. It is well known that there are no differences between the two techniques from the logical, the mathematical and the practical points of view.

Numerical solutions of partial differential equations are essentially based on the definition of derivative

$$\frac{\partial f(x,y)}{\partial x} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x, y) - f(x)}{\Delta x} \tag{1.1}$$

Therefore, the numerical solutions of box models, that are based on the subdivision of volumes in "boxes" of size Δx, are, in principle, equivalent to the numerical solution of the corresponding partial differential equations. Differences may be due to different approximation techniques. *These techniques allow one to achieve, more or less rapidly, the convergence of the calculated numerical solutions to theoretical "exact" limit values.* Nevertheless, such differences are generally negligible compared with many important factors of uncertainty related to environmental variability that can never be predicted with sufficient accuracy. *Moreover, the experimental uncertainties of the measured quantities that a model aims at predicting are, generally, significantly larger than the calculation errors due to the used approximation technique.*

The previous discussion is not a mere philosophical discourse. Indeed, many codes and CDSSs object of EVANET-HYDRA network make use of software programmes (Ithink and Powersim) that allow the modeller to solve, by numerical methods, "box" models. The assessment of models we are going to carry out will not consider the mathematical "sophistication" as an index of quality of a model unless it is clearly demonstrated that easier methods do not show a sufficient degree of accuracy in relation to the practical applications for which the models have been designed.

A second myth is related to the presupposition that smaller values of Δx and of Δt (the time integration step of a code) correspond to solutions more accurate in space and time. The choices of small values of Δx and of Δt can be illusory for the accuracy of the model results as the lack of knowledge of the dynamics and spatial dependence of many processes at the level of Δx and Δt represents an important reason of uncertainty. The Time Resolving Power (TRP) and the Spatial Resolving Power (SRP) of a model are controlled by the processes that are not intended to be modelled in sufficiently detailed time and space scales. Therefore, the impossibility of modelling in sufficient detail (both in time and space) the natural processes is the main factor controlling TRP and SRP. The predictions of a model are meant to be values averaged over the TRP and SRP intervals. The attempt of improving at will the Resolving Power of a model results in an increase of the output uncertainty. To ask the question "what is the predicted value of a quantity averaged over a certain region of space and over a certain interval of time?" seems more wise and realistic than to ask "what is the value of a quantity at a certain instant in a specific point of the space?".

Similarly, increasing the model complexity by including more and more details in the model structure, can result in an increase of the model uncertainty as many modellers have experienced:

...an increase in model complexity is usually associated with an increase in uncertainty in predictions, due to the increase in the number of parameters used in the model. Up to a point the benefits received by increasing accuracy outweigh the problems of higher uncertainty, but beyond that point adding complexity contributes little to improved accuracy and continues to increase uncertainty. Increasing the resolution of model predictions beyond that of the data available for testing the model has little merit. (Kirchner, 1990).

Risks of word misusing

Words are often used in different way by different groups of people. In some cases the misuse of words is not a serious problem as anyone can clearly understand the meanings of specific words according to the text and the addressed problem. For instance the word "mechanistic" has often referred to the mechanisms (of any nature, physical, chemical, biological, etc.) controlling the environmental processes. The same term means, also, "pertaining to or holding mechanical theories in biology or philosophy". This last meaning has deep philosophical implications although it is quite clear that modellers speaking of "mechanistically-based" models are in general considering the first mentioned meaning.

On the contrary, the misuse of word "holistic" is perilously misleading. The pristine meaning of "holism" (from Greek *holos* = whole) is "the tendency in nature to produce wholes from the ordered grouping of unit structures" (The Oxford English Dictionary).

Such a definition is more than a simple convention (someone deems, indeed, that the meaning of words is a mere matter of agreement among individuals). It holds a fundamental point of view of methodological and philosophical nature that was clearly summarised by Jørgensen and Mejer (1983):

... The ....direction of approach is more pragmatic, and it is based on the experiences of ecological modelling. Not only from a computer point of view is it impossible to cope with the ecosystem complexity in a direct way but also from the biological point of view. To describe in detail all the individual subunits and their behaviour under all possible circumstances and to know all the parameters involved in such a detailed description exceeds man's possibility. It implies that other methods which we could name ***holistic*** *methods have to be found....*

Therefore the holistic approach is not based on the knowledge of the "totality" of processes occurring in the examined environmental system to develop, conceitedly, an "omniscient" model. The holistic approach aims at individuating aggregated units and emerging processes and relationships among them to structure knowledge concerning the behaviour of a system.

Many modellers are guided by principles that refer to the pristine meaning of the word “holistic”. Many models and CDSSs are holistic according to the previous definition.

Most models are based on “atomic” elements or “holons” that are the elementary “building blocks” of a “hierarchically organised” greater whole (the system) (Patten et al. 1976).

Unfortunately, the adjective holistic has recently been used as a synonym of “everything”. Thus it could be interpreted as a term for defining an approach aimed at accounting for the totality of subunits and processes. In some circumstances, it has mistaken for the word “comprehensive”. The above discussion would not be so important if the meaning of the word was merely conventional, but it is clear that “holism” has, for many modellers, a deep significance with important implications from the methodological point of view.

The misleading use of this word represents a unacceptable step back for environmental modelling. As the quoted text of Jørgensen and Mejer back to 1983, it is disappointing that radioecological modellers are forgetting the meaning of “holism”. This is worrying.

The dynamics of complex systems are often modelled by subdividing them into separate compartments and accounting for the radionuclide fluxes among them. The compartments are considered as “black boxes”, i.e. the modeller disregards the internal structure of the compartment itself and consequently the radionuclide distribution and dynamics within it. Compartments must be defined in an appropriate way depending upon the characteristic of the system and the specific purpose for which the model is being designed.

Basically, the approach requires the definition and the identification of suitable compartments and of the pollutant fluxes among the various compartments or from the compartments to the surrounding environment and vice-versa.

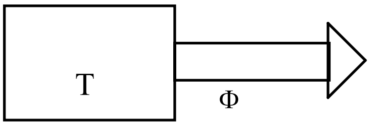

Figure 1.1

The flux Φ (mass or Bq per unit time) is related to the total amount T (mass or Bq) of contaminant in the compartment by means of suitable equations that accounts for the time behaviour of the flux and for the effects of the known processes controlling such a flux. The most simple equation that correlates the flux to the amount of pollutant is a proportionality relationship (see figure 1.1):

$$\Phi = kT \tag{1.2}$$

where k is a rate constant (time^{-1}).

In case of linear processes, the pollutant flux at instant t following a single input pulse D of contaminant into the compartment at instant τ, is a very important function for modelling the system. We will indicate such flux as $GF(t-\tau)$.

If function GF is known, it is possible to evaluate the pollutant flux for any time-varying contamination input. Indeed, if $D(\tau)$ is the contamination input rate (mass or Bq per unit time) at instant τ, the flux at any time t may be calculated as follows

$$\Phi(t) = \int_0^t GF(t-\tau)D(\tau)d\tau \tag{1.3}$$

The above formula is of useful when experimental evaluations of GF are available.

The above approach allows predictions for time-dependent contamination events on the basis of a knowledge that, although not detailed, is nevertheless based on experimental evidence.

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Table 1.1 The projects considered in the present assessment

Project	Aims	Radionuclides	Environmental systems	Note			
				Model	Code	CDSS	
ECOPRAQ	Model development and testing	radiocaesium and radiostrontium	Lakes	YES	YES	NO	models implemented in MOIRA
AQUASCOPE	Model development and testing	radiocaesium and radiostrontium	Lakes and rivers	YES	YES	NO	
AQUASTAR	Model development	H-3, C-14, P-32, Co-60, Zn-65, Sr-89,90, I-125, 131, Cs-134, 137, Pu-238, 239, 24, Am-241, U-234,235,238	Rivers	YES	YES	NO	
MOIRA	CDSS development	radiocaesium and radiostrontium	Lakes, rivers, coastal areas	YES	YES	YES (Lakes and rivers)	
CASTEAUR	Model development	^{110m}Ag, ^{241}Am, ^{58}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn and ^{106}Ru	Rivers	YES	YES	NO	
RODOS	CDSS development	all	Lakes, rivers	YES	YES	YES	
COMETES	Model and CDSS testing and improvement	Radiocaesium and radiostrontium	Lakes, rivers	YES	YES	YES (MOIRA v. 2)	
SPARTACUS	Model development		Catchments	YES	YES		
TRANSURANIC	Assessment of radionuclide balances in lakes	Transuranic	Lakes	-	-	-	
BIOMOVS and BIOMOVS II	Model testing	radiocaesium, Np-237, Pu-239, Sr-90, Ra-226, Th-230	lakes, rivers, creeks, groundwater	NO	NO	NO	
VAMP	Model testing	radiocaesium, radiostrontium	Lakes, rivers, reservoirs	NO	NO	NO	Results exploited for MOIRA

SECTION 2: LACUSTRINE ECOSYSTEMS

ASSESSMENT OF MODELS FOR PREDICTING THE BEHAVIOUR OF RADIONUCLIDES IN LAKES.

Introduction

In the past decades a variety of models for predicting the behaviour of radionuclides in lakes were developed in the frame of many international research projects.

Therefore, it is of paramount importance to assess the state-of-the-art of the whole sector by classifying the approaches of the various models and determining their essential features, identifying similarities and differences among them and defining their application domains in view of possible improvements and of the rationale of the entire sector.

The present assessment is focused on the models developed within the frame of the most important projects financed by the European Commission during the 4th framework programme: ECOPRAQ, MOIRA, AQUASCOPE and RODOS.

Preliminary remarks: basic characteristics of the models

The projects considered in our assessment were aimed at developing models for predicting the behaviour of different radionuclides:

- ECOPRAQ: models were developed for ^{137}Cs (^{137}CS-ECOPRAQ) and for ^{90}Sr (^{90}Sr-ECOPRAQ);
- MOIRA: ^{137}CS-ECOPRAQ was implemented in the MOIRA Computerised Decision Support System; a specific model for ^{90}Sr was implemented in the present version of MOIRA (^{90}Sr-MOIRA); MOIRA makes also use of a model (^{137}Cs-MARTE) for predicting the behaviour of ^{137}Cs in lakes or reservoirs in complex river/catchment systems;
- AQUASCOPE: models for ^{137}Cs (^{137}CS-AQUASCOPE) and ^{90}Sr (^{90}Sr-AQUASCOPE) were developed;
- RODOS: the RODOS Computerised Decision Support System includes the model LAKECO for predicting radionuclide behaviour in lakes together with other models aimed at assessing the non-homogeneous radionuclide dispersion in large or stratified waterbodies.

^{137}CS-ECOPRAQ, ^{90}Sr-ECOPRAQ, ^{90}Sr-MOIRA (Monte, 1998; Monte, Kryshev & Sazykina 2002) , ^{137}Cs-MARTE (Monte, 2001), ^{137}CS-AQUASCOPE, ^{90}Sr-AQUASCOPE and LAKECO in RODOS supply predictions of radionuclide concentrations in water averaged over the entire volume of the lake water and of sediment (lumped models). The other models in RODOS are aimed at predicting radionuclide concentrations at different points or depths in the water body (distributed models).

The models are aimed at supplying predictions of radionuclide concentrations in the abiotic and the biotic components of a lacustrine system. Moreover, some of them allow one to assess the effects of selected countermeasures on contamination levels.

Basically, they all comprise three main sub-models:

a) A sub-model for predicting radionuclide migration from catchment to water body;

b) A sub-model for predicting the behaviour of radionuclides in the abiotic components of the aquatic system; and

c) A sub-model for predicting the behaviour of radionuclides in the biotic components of the lake.

These sub-models are linked by a “one-way” flux of input data as shown in figure 2.1. Sub-model b) (abiotic lake components) makes use of data (radionuclide flux form the lake catchment) calculated by means of sub-model a) (catchment) and supplies to sub-model c) the necessary input data (concentration in the abiotic components of the lake) for evaluating the concentrations of radionuclide in biota.

Therefore comparisons and assessments of model features can be done separately for each sub-model.

Models for predicting the migration of radionuclides from lake catchments will be considered in connection with the assessment of the methodologies for predicting radionuclide behaviour in complex catchments.

Our focus shifts now to assess the methodologies for predicting the behaviour of radionuclides within the lake’s abiotic components (internal processes).

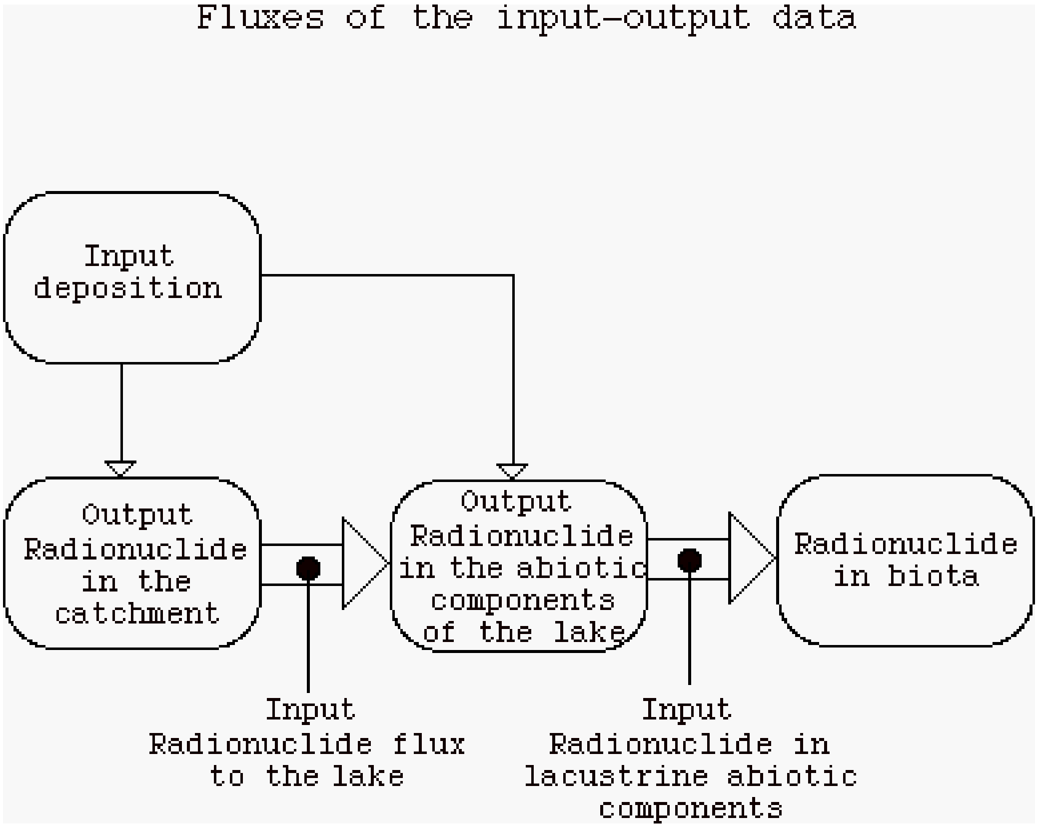

Figure 2.1 - Scheme of the data fluxes among the sub-models of a model for predicting the behaviour of radionuclide in the lacustrine ecosystem.

Modelling the behaviour of radionuclides in the abiotic components of lake ecosystems

An important hydrological process occurring in lacustrine systems that influences the behaviour of radionuclides in the lake is obviously the outflow of water from the outlet. Such a process is, indeed, responsible of the removal of radionuclides from the water body. The process is usually modelled according to the following formula:

$$\Phi_r = \Phi C_W \tag{2.1}$$

where Φ_r is the flux of the radionuclide (Bq s^{-1}) removed by the outlet, Φ is the outlet flux (m^3 s^{-1}) and C_w is the radionuclide concentration in the lake water.

^{137}CS-ECOPRAQ, ^{90}Sr-ECOPRAQ, ^{90}Sr-MOIRA, ^{137}Cs-MARTE and LAKECO are typical first order models (box models). They comprise three compartments corresponding to the radionuclide in the lake water and in two layers of bottom sediment (see figure 2). The structures of these models do not show substantial differences.

The models developed in the frame of AQUASCOPE project although, at first sight, seem based on a different approach is substantially similar to the other box models. AQUASCOPE models are indeed based on the evaluation of the response of water contamination to a single pulse deposition input of radionuclide.

The radionuclide concentration in water at instant t following a single pulse deposition event at instant τ is

$$C(t) = DG(t-\tau) \tag{2.2}$$

where G(t-τ) is the response to a deposition pulse of 1 Bqm^{-2} and D ($Bq\ m^{-2}$) is the radionuclide deposition per square metre.

The radionuclide concentration C(t) for deposition processes depending on time (D(t) = radionuclide deposition rate $Bq\ m^{-2}\ s^{-1}$) is:

$$C(t) = \int_0^t D(\tau)G(t-\tau)d\tau \tag{2.3}$$

It is possible to demonstrate that any linear model such as ^{137}CS-ECOPRAQ, ^{90}Sr-ECOPRAQ, ^{90}Sr-MOIRA, ^{137}Cs-MOIRA and LAKECO is characterised by a function G(t-t) that allows one to evaluate the radionuclide concentration in water (or in any other target variable) by equation (2.3). From now on we will call G(t-τ) the Green Function (GF) of the model.

It is instructive to start our analysis by considering ^{90}Sr behaviour in the water-sediment sub-system of a lake.

We compare, for instance, the model ^{90}Sr-AQUASCOPE with the ^{90}Sr-MOIRA model.

^{90}Sr-AQUASCOPE predicts ^{90}Sr concentration in the water of “closed” lakes by the following equation:

$$C(t) = \frac{D}{h}e^{-Kt} + D\eta e^{-gt} \tag{2.4}$$

In considering the radionuclide behaviour in closed lakes, the hypotheses of:

- negligible contribution of radionuclides from the lake catchment;
- negligible removal of radionuclides by lake outlet;

offer the opportunity of assessing the model performances in relation to the processes occurring within the sub-system “water-sediment” (internal processes).

The ^{90}Sr-MOIRA model for predicting the migration of radionuclide from water to sediments is composed of two active boxes (see figure 2.2) (Monte, 2001):

a) Radionuclide dissolved in water (Water, C_w, Bq m^{-3});

b) Radionuclide deposited in sediment (Bottom sediment, D_s, Bq m^{-2});

and a "passive box" (Deep sediment) representing the radionuclide subject to non-reversible removal processes from the active deposit.

The equations controlling the radionuclide migration processes are the following:

$$\begin{aligned} \frac{dC_W}{dt} &= -\frac{v_{WS}}{h} C_W + \frac{K_{SW}}{h} D_S \\ \frac{dD_S}{dt} &= v_{WS} C_W - (K_{SW} + K_{dS}) D_S \end{aligned} \qquad (2.5)$$

where h is the average depth (m) of the lake, v_{ws} is the migration velocity (m s^{-1}) of radionuclide to the bottom sediment, K_{sw} is the migration rate (s^{-1}) from bottom sediment to water, K_{ds} is the removal rate (s^{-1}) of radionuclide from the bottom sediment and t (s) is the time.

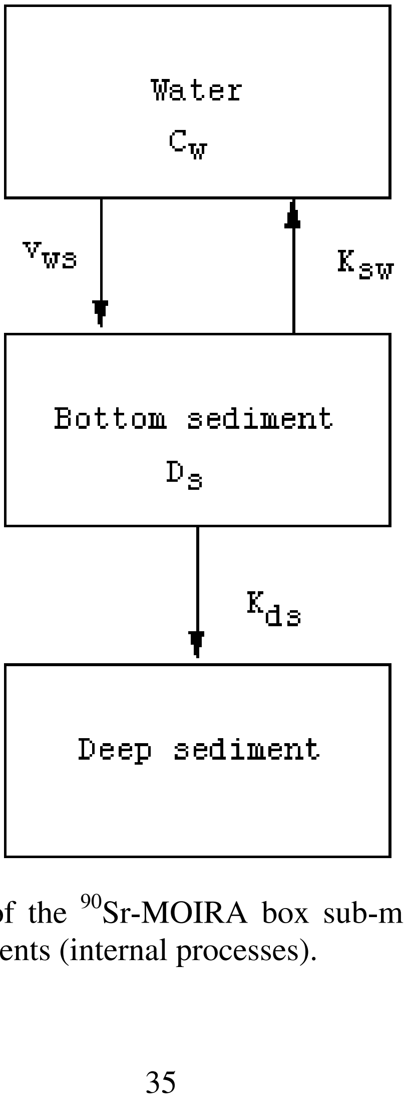

Figure 2.2 - Structure of the ^{90}Sr-MOIRA box sub-model for predicting ^{90}Sr migration from water to sediments (internal processes).

The solution of the previous equation system, following a deposition pulse D (Bq m^{-2}) at time 0, is

$$C_w(t) = \frac{D}{h(\lambda_2 - \lambda_1)}\left[\left(\lambda_2 - \frac{v_{ws}}{h}\right)e^{-\lambda_1 t} - \left(\lambda_1 - \frac{v_{ws}}{h}\right)e^{-\lambda_2 t}\right]$$
$$D_s(t) = \frac{D\,v_{ws}}{h(\lambda_2 - \lambda_1)}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right) \qquad (2.6)$$

where λ_1 and λ_2 are the eigenvalues of system (2.5):

$$\lambda_{1,2} = -\frac{-\left(\frac{v_{ws}}{h} + K_{sw} + K_{ds}\right) \pm \sqrt{\left(\frac{v_{ws}}{h} + K_{sw} + K_{ds}\right)^2 - 4\frac{v_{ws} K_{ds}}{h}}}{2} \qquad (2.7)$$

Radioactive decay is included by adding a term λ_r (the radioactive decay constant) to the eigenvalues (2.7) and by multiplying the concentration in water and the deposit by $e^{-\lambda_r t}$. Similarly, it is possible to account for the radioactive decay in equation 2.4 by multiplyng the right side by $e^{-\lambda_r t}$.

The Green Function of the MOIRA model is

$$C_w(t) = \frac{D}{h}\frac{\left(\lambda_2 - \frac{v_{ws}}{h}\right)}{(\lambda_2 - \lambda_1)}e^{-\lambda_1 t} + \frac{D}{h}\frac{\left(\frac{v_{ws}}{h} - \lambda_1\right)}{(\lambda_2 - \lambda_1)}e^{-\lambda_2 t} \qquad (2.8)$$

$C_w(t)$, the concentration of radionuclide in water, has two exponential components and depends on four independent parameters (h, v_{ws}, K_{sw} and K_{ds}).

Similarly, the solution of ^{90}Sr-AQUASCOPE model for closed lakes is the sum of two exponential components and depends on four independent parameters (h, K, η and g) (equation 2.4).

Comparing formulae (2.8) and (2.4) we obtain

$$K = \lambda_2 \quad (2.9)$$

$$g = \lambda_1 \quad (2.10)$$

and

$$\eta = \frac{1}{h}\frac{\left(\lambda_2 - \frac{v_{ws}}{h}\right)}{(\lambda_2 - \lambda_1)} \quad (2.11)$$

Therefore, the above models are, essentially, equivalent. Indeed, they supply similar output for a suitable choice of their parameters.

For instance, figure 2.4 shows the values of η calculated by formula (2.11) supposing $v_{ws} = 1.04\times10^{-7}$ m s^{-1}, $K_{sw} = 5.62\times10^{-9}$ s^{-1} and $K_{ds} = 8.79\times10^{-10}$ s^{-1}. The calculated values are close to the conservative estimate (η= 0.05 m^{-1})of Smith (2002).

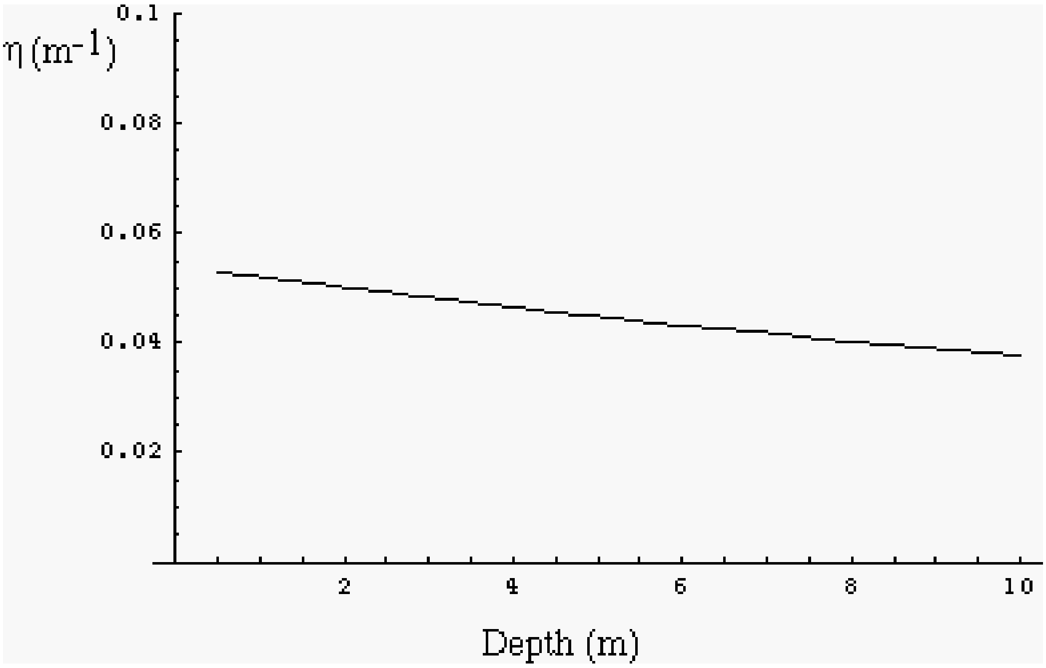

Figure 2.4 - η as function of lake depth for "closed" lakes. η was calculated by eqution (2.11) assuming $v_{ws} = 1.04\times10^{-7}$ m s^{-1}, $K_{sw} = 5.62\times10^{-9}$ s^{-1} and $K_{ds} = 8.79\times10^{-10}$ s^{-1}. The calculated values are in agreement with the average, conservative value (0.05 m^{-1}) suggested by Smith (2002)

Figure 2.5 shows the product K*h as function of the lake depth for “closed” lakes. K was calculated by formula (2.9). The model ^{90}Sr-AQUASCOPE recommend the following estimate of the removal rate K for radiostrontium:

$$K = \frac{\text{Constant}}{h} \tag{2.12}$$

where the constant is 1.16×10^{-7} m s^{-1} . Figure 2.5 clearly shows that values of K*h calculated by formula (2.9) range from $1. \times 10^{-7}$ to 1.6×10^{-7} m s^{-1}, in approximate agreement with the average value recommended by Smith (2002).

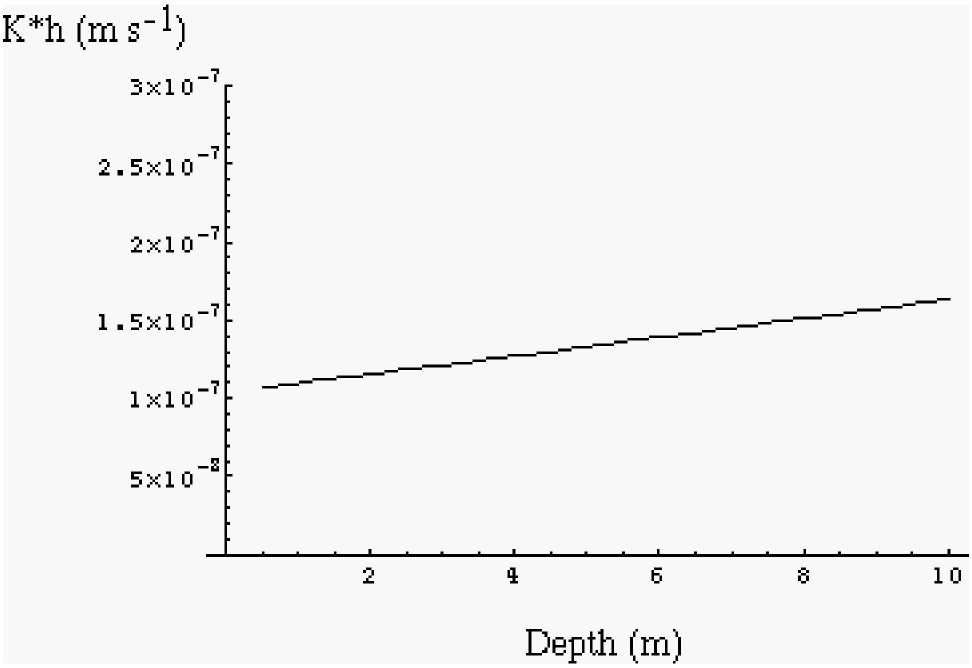

Figure 2.5 - The product K*h as function of lake depth for “closed” lakes. K was calculated by formula (2.9) supposing $v_{ws} = 1.04 \times 10^{-7}$ m s^{-1}, $K_{sw} = 5.62 \times 10^{-9}$ s^{-1} and $K_{ds} = 8.79 \times 10^{-10}$ s^{-1}. The calculated values are in agreement with the hypothesis that K=Constant/h where Constant $\approx$ 1.16×10^{-7} m s^{-1} (Smith, 2002).

As figure 2.6 shows, the average value of g (7.93×10^{-10} s^{-1}) suggested by Smith (2002) is close to the values calculated by formula (2.10).

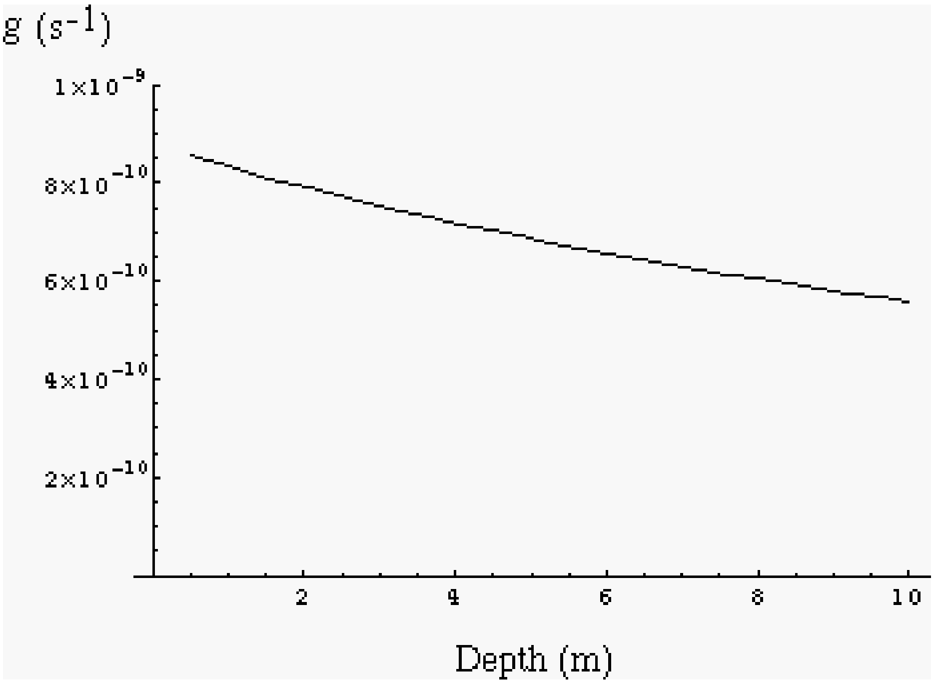

Figure 2.6 - g as function of lake depth for “closed” lakes. g has been calculated by formula (2.10) supposing $v_{ws} = 1.04\text{x}10^{-7}$ m s^{-1}, $K_{sw} = 5.62\text{x}10^{-9}$ s^{-1} and $K_{ds} = 8.79\text{x}10^{-10}$ s^{-1}. The calculated values are in agreement with the value ($7.93\text{x}10^{-10}$ s^{-1}) from Smith (2002).

Therefore we expect that both models for shallow (depth<7 m), closed lakes supply similar results.

The outputs of the models are compared in figure 2.7. The models were applied to a hypothetical scenario of a shallow closed lake (depth = 2 m) contaminated following a deposition of 1 Bq m^{-2} of ^{90}Sr.From the figure we can conclude that, over a period of ten years following the deposition, the two models supply solutions that are practically the same.

Figure 2.8 shows the relative difference Δr

Δr= 100*(Aquascope output-Marte output)/Aquascope output

Such a relative difference is lower than 10% and decreases rapidly with time.

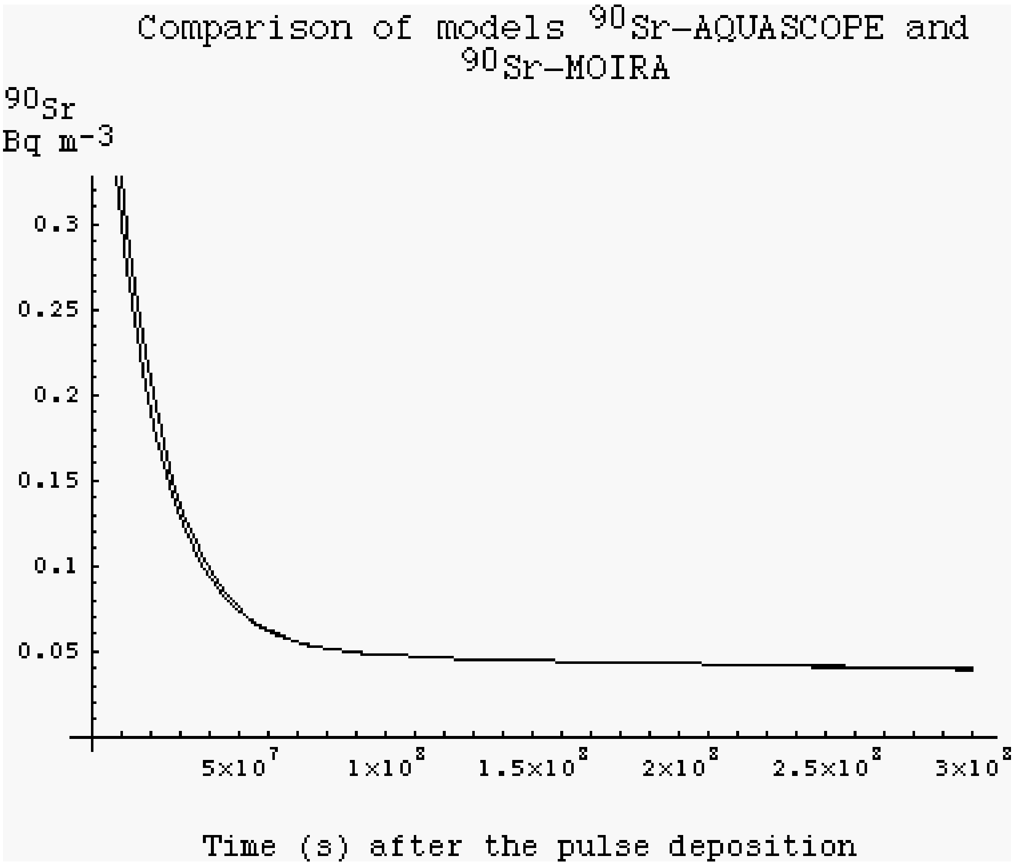

Figure 2.7 - Comparison of the results (concentration in water of ^{90}Sr) of models ^{90}Sr-AQUASCOPE and ^{90}Sr-MOIRA. . The model were applied to a hypothetical scenario of a deep close lake having depth = 2 m contaminated following a deposition of 1 Bq m^{-2} of ^{90}Sr.

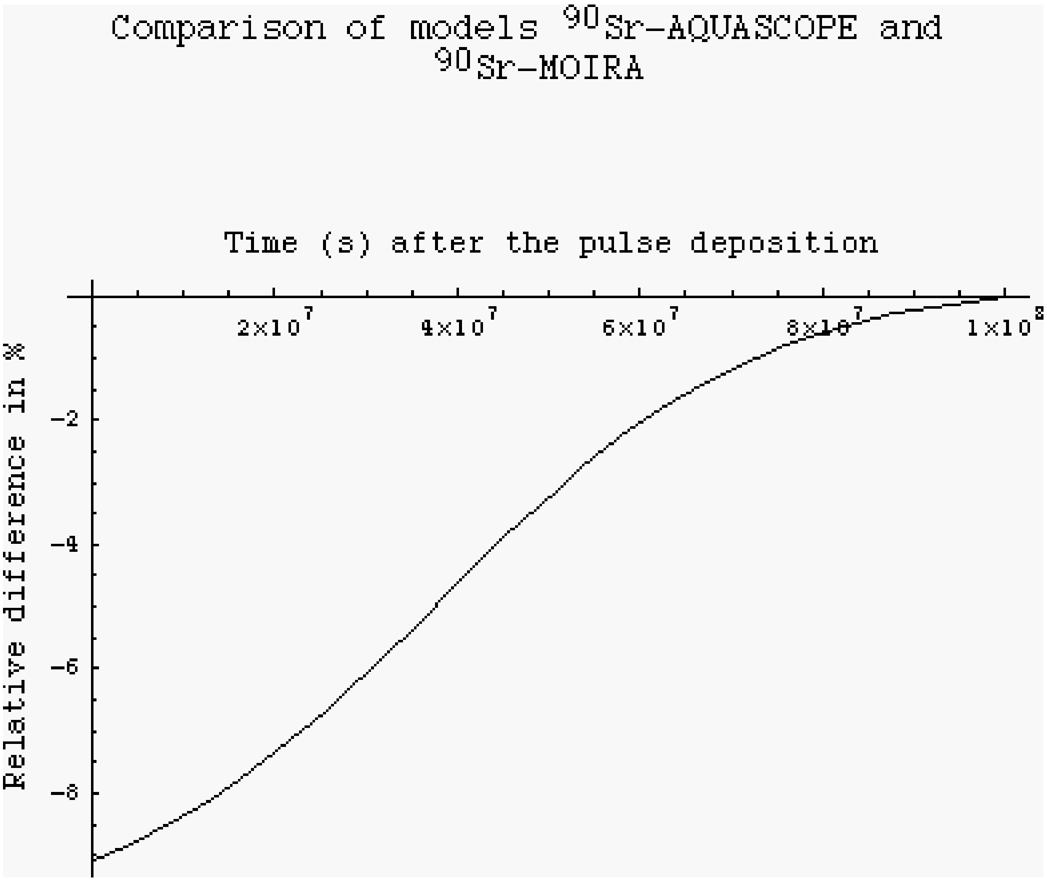

Figure 2.8 - Comparison of the results (concentration in water of ^{90}Sr) of models ^{90}Sr-AQUASCOPE and ^{90}Sr-MOIRA. The relative difference between the output of the models is lower than 10% and decreases rapidly with time.

The model ^{137}Cs-AQUASCOPE for "closed" lakes is based on three exponential components:

$$C(t) = \frac{D}{h} e^{-Kt} + D \eta_1 e^{-K_2 t} + D \eta_2 e^{-K_3 t} \tag{2.13}$$

where we have omitted, as usual, the multiplicative term $e^{-\lambda_r t}$.

The values of parameters in equation (2.13) are as follows:

$K_2 = 1.3 \text{x} 10^{-8}$ s^{-1}

$K_3 = 6.3 \text{x} 10^{-10}$ s^{-1}

$\eta_1 = 4.0 \text{x} 10^{-2}$ m^{-1}

$\eta_2 = 8.5 \text{x} 10^{-3}$ m^{-1}

K is the effective decay constant of radionuclide in water due to the removal processes from the water column. Smith et al. (2002) suggests four different formulae to calculate K according to the levels of detail of the input data. The following options are considered:

a) only the deposition is known;

b) the deposition and the lake depth are known;

c) the deposition, the lake depth and the sedimentation velocity of the matter suspended in water are known;

d) the deposition, the lake depth, the sedimentation velocity and the potassium concentration in water are known.

We will assess option b) that corresponds to the application of a "generic model" (a model that does not make use of site specific information).

K is calculated by the following equation:

$$K = \frac{A}{h} + B \qquad (2.14)$$

where $A = 2.5 \times 10^{-7}$ m s^{-1} and $B = 3.2 \times 10^{-8}$ s^{-1}

From the value of K_3, it follows that the third component is characterised by a half time of approximately 35 years.

Neglecting the third component it is possible to compare the features, in the medium term (<10 years), of ^{137}Cs-AQUASCOPE and ^{137}Cs-MARTE models. Table 2.1 reports the values of v_{ws}, K_{ds} and K_{sw} used by model ^{137}Cs-MARTE and the corresponding values calculated by applying formulae (2.9), (2.10) and (2.11) to the parameters of the first and second components of ^{137}Cs-AQUASCOPE model.

The model ^{137}Cs-MARTE relates the values of the parameters controlling the migration of radionuclide from water to sediment and vice-versa to certain hydrological characteristics of the water bodies.

Different values are used for lakes, rivers and reservoirs. The migration velocities depend on the so called "dynamic ratio" that represents a measure of the intensity of interaction between the water and the bottom sediment. The dynamic ratio D_r is defined as follows (Håkanson & Jansson, 1983):

$$D_r = \frac{\sqrt{S}}{h} \qquad (2.15)$$

where S is the surface (m^2) of the water body and h is the lake depth.

The values of the model parameters (table 2.1) show similar orders of magnitude. It is quite obvious that, like for ^{90}Sr, models ^{137}Cs-AQUASCOPE and ^{137}Cs-MARTE supply similar results if the values of their parameters are suitably chosen.

Table 2.1- Model parameter values for ^{137}Cs in lakes and reservoirs

Parameter	MARTE (lakes)		MARTE (reservoirs)		AQUASCOPE	
	Dynamic ratio ≤ 1000	Dynamic ratio> 1000	Dynamic ratio ≤ 1000	Dynamic ratio> 1000	Depth 2 m	Depth 10 m
v_{ws} (m s^{-1})	5.9×10^{-7}	1.2×10^{-6}	9.3×10^{-7}	1.6×10^{-6}	2.9×10^{-7}	3.9×10^{-7}
k_{ds} (s^{-1})	5.8×10^{-9}	1.2×10^{-8}	1.2×10^{-8}	1.2×10^{-8}	1.4×10^{-8}	1.9×10^{-8}
k_{sw} (s^{-1})	3.0×10^{-8}	1.5×10^{-8}	1.5×10^{-8}	1.5×10^{-8}	1.1×10^{-8}	1.2×10^{-8}

The model MARTE, in a very crude way, accounts, also, for the processes of rapid adsorption of radiocaesium onto bottom sediment. It is assumed that a thin layer of sediment (interface layer) strongly interacts with radionuclide dissolved in water and that radionuclide concentrations in such a layer quickly reaches equilibrium with the radionuclide in water. Such a rapid process corresponds to a very fast exponential component.

We deem it sufficiently demonstrated that, although AQUASCOPE models are based, in principle, on a particular methodology they are equivalent to the other box models object of the present assessment.

As previously stated, box models are based on the evaluation of the time dependent balance of radionuclide in the various compartments of an environmental system by accounting for the radionuclide fluxes among these compartments.

The complex processes of radionuclide migration through the water-sediment system are often schematised in terms of the following fluxes:

- Molecular diffusion of radionuclide through sediment porewater;
- Sedimentation (particle scavenging) of contaminated particles in water and consequent removal of radionuclides from the column water and transport to sediment;
- Sediment mixing due to physical processes and bioturbation;
- Burial mechanisms and other non reversible processes of radionuclide interaction with bottom sediments.

The model LAKECO (IAEA 2000, Heling, 1997) makes use of the following equations for predicting, in detail, the quantitative behaviour of the above processes.

Migration from water to top sediment layer:

$$k_{ws} = \left(\frac{D_m}{d_{s1} h} + \frac{\varepsilon R_w \phi_1}{h} + \frac{R_w \rho_{d1} K_{ds1}(1-\phi_1)}{h} + \frac{\sigma K_{dw}}{h}\right) \frac{1}{1+K_{dw} L} \tag{2.16}$$

the four terms on the right side of previous equations are:

- The rate constant of diffusion from water to sediment porewater;
- The rate constant for radionuclide transfer from surface water to porewater in sediment due to physical mixing and bioturbation;
- The rate constant for radionuclide transfer from the water column to top sediment layer due to physical mixing and bioturbation;
- Sedimentation.

Migration from top sediment to water column:

$$k_{sw} = \left(\frac{D_m}{d_{s1}^2 \phi_1} + \varepsilon \frac{R_w}{d_{s1}}\right) \frac{\phi_1}{\phi_1 + K_{d1} \rho_{d1}(1-\phi_1)} + \frac{R_w}{d_{s1}} \frac{K_{d1} \rho_{d1}(1-\phi_1)}{\phi_1 + K_{d1} \rho_{d1}(1-\phi_1)} \tag{2.17}$$

The terms on the right side are:

- The rate constant for the radionuclide diffusion from sediment to water;
- The rate constant for radionuclide transfer from sediment porewater to water column due to physical mixing and bioturbation;
- The rate constant for radionuclide transfer from top sediment layer to the water column due to physical mixing and bioturbation.

Migration from the top sediment layer to the deep sediment layer:

$$k_{s1s2} = \frac{D_m}{d_{s1} d_{s2} \phi_1} \frac{\phi_1}{\phi_1 + K_{d1} \rho_{d1}(1-\phi_1)} + \frac{\sigma}{\rho_{d1}(1-\phi_1) d_{s1}} \frac{K_{d1} \rho_{d1}(1-\phi_1)}{\phi_1 + K_{d1} \rho_{d1}(1-\phi_1)} \tag{2.18}$$

The terms on the right side are:

- The rate constant for diffusion from the top to the deep sediment layer;

- The rate constant for the migration from the top to the deep sediment layer due to burial mechanisms.

Migration from the deep to the top sediment layer:

$$k_{s2s1} = \frac{D_m}{d_{s2}^2 \phi_2} \frac{\phi_2}{\phi_2 + K_{d2} \rho_{d2} (1-\phi_2)} \qquad (2.19)$$

Finally, radionuclide burial from the deep sediment layer

$$k_{s2->} = \frac{\sigma}{\rho_{d2} (1-\phi_2) d_{s2}} \frac{K_{d2} \rho_{d2} (1-\phi_2)}{\phi_2 + K_{d2} \rho_{d2} (1-\phi_2)} \qquad (2.20)$$

Table 2.2 - List of symbols in equations (2.16) -(2.20)

h is the depth of the water column;

L is the suspended sediment concentration;

K_{dw}, K_{ds1}, K_{ds2} are the values of the distribution coefficient in water, in the top sediment layer and in the deep sediment layer, respectively;

D_m is the diffusion coefficient in the pore water;

d_{s1}, d_{s2} are the thickness of the top sediment layer and of the deep sediment layer;

ϕ_1, ϕ_2 are the values of the porosity of the top sediment layer and of the deep sediment layer;

ρ_1, ρ_2 are the density of the top sediment layer and of the deep sediment layer;

R_w is the sediment reworking rate;

ε is a proportionality constant;

σ is the sedimentation rate.

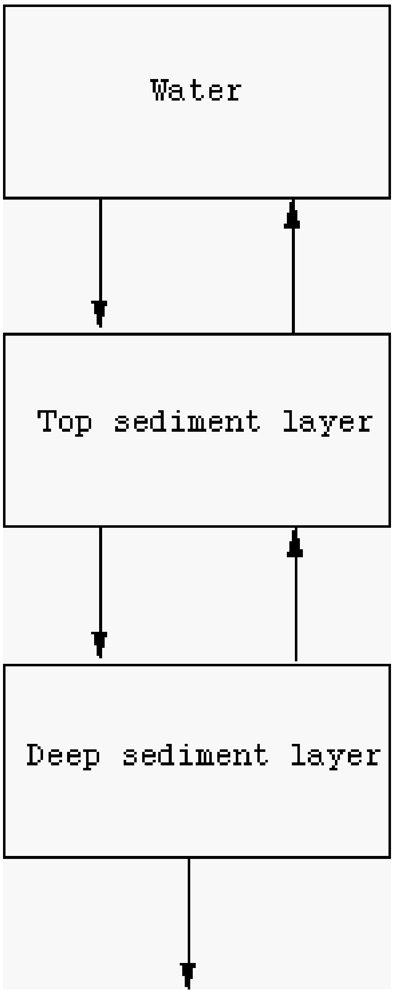

Figure 2.8 Structure of the LAKECO model. The five fluxes are controlled by five parameters. Such a structure correspond to a 3 components exponential function representing the radionuclide concentration in water following a pulse event of contamination.

LAKECO calculates the values of the five aggregated parameters k_{ws}, k_{sw}, k_{s1s2}, k_{s2s1} and k_{s2}-> by 14 primary parameters most of which are related to fundamental processes like the molecular diffusion of the radionuclide through water and the interaction of the radionuclide in dissolved form with sediment particles. In principle the reliability of the model is strictly dependent on the accuracy of the values of these primary parameters. From now on we will call such kind of models “fundamental process specific” as they relate the behaviour of radionuclides in the environment to specific physical and chemical fundamental processes.

LAKECO is a so called “reductionistic model”. In other words, it includes, at least in principle, as many relevant details as reasonably possible by modelling them according to primary laws from fundamental disciplines such as physics and chemistry.

On the contrary, MARTE, AQUASCOPE and ECOPRAQ models are based on a holistic approach. They are “environmental process specific”, that is, they relate the behaviour of radionuclides in the environmental systems to relevant *environmental* characterSistics and processes. As such they aggregate a great deal of elementary, fundamental processes of physical, chemical, geochemical, biological etc. nature.

Holism and reductionisms are elements of a unsoluble controversy in ecosystem theory (Müller, 1997)

Like MARTE, the "box model" ECOPRAQ for predicting the behaviour of ^{137}Cs in lakes (ECOPRAQ model is a module of MOIRA DSS) is based on the assessment of radionuclide balance in the lacustrine system.

According to the ECOPRAQ modelling approach, the lake is divided in three components:

- the water column;
- the sediment A-area
- the sediment ET-Area.

The A-area and ET-Area are, respectively, the bottom sediment areas where the processes of sediment accumulation (A) and of erosion-transport (ET) prevail. Figure 2.9 shows the structure of the model.

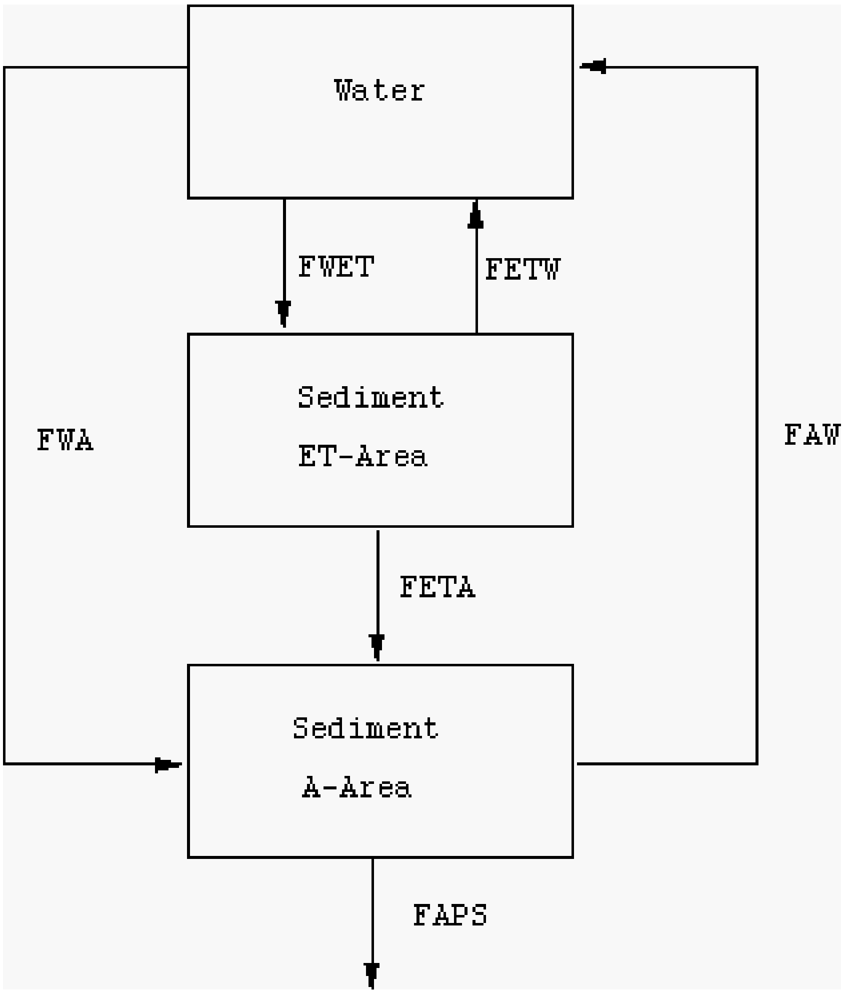

Figure 2.9 Structure of model ECOPRAQ (abiotic components of the sediment-water system). The radionuclide fluxes are as follows: FWA=flux from water to A-are, FAW=flux from A-area to water; FWET=flux from water to ET-Area;

FETW=flux from ET-area to water; FETA= flux from ET to A-area; FAPS= flux from A-area to deeper, passive sediments.

The fluxes are related, as usual, to the total amount of radionuclide in each compartment by a proportionality constant (the rate). These rates are calculated by sub-models that account for the most important factors controlling the radionuclide migration in different environmental situations. As the descriptions of such sub-models can be very complex the interested reader can find further information in the scientific literature (Håkanson, 2002). The ECOPRAQ model is therefore based on process and parameter aggregation and on the attempt of relating the values of the latter to the prevailing *environmental* characteristics of the site. It is a good example of a modelling strategy substantially different from the “reductionistic” approach.

We think right to summarise one of the main criticisms to the reductionistic approach from the holistic point of view. As seen from the description of LAKECO, the reductionistic approach is based on the development of many sub-models that require additional parameter values and whose results are affected by non negligible uncertainty. This traditional strategy for developing predictive models does not seem appropriate when applied to complex environmental systems. Indeed, it is based on the belief of a "pyramidal" structure of the set of the natural phenomena. It is assumed that some fundamental processes, belonging at the top-vertex of the logical pyramid, may be modelled in terms of logical-mathematical primary principles from which all other natural processes may be derived. This modelling strategy is based on the assumption that, starting from the actual system to be modelled, it is possible to climb the “bottom-up pyramid” to reach a small set of fundamental equations that can be used to model the system itself. The following example illustrates such a procedure. Let suppose that we have to calculate the velocity of water discharged through a small hole in the bottom of a large bucket. It is well known that this problem may be solved by a direct application of the Bernoulli’s theorem. This theorem can be derived from the main principles of the mechanics through very familiar concepts and laws, such as mechanical work and continuity equation. Figure 2.10 shows the position of the Bernoulli’s theorem in the knowledge pyramid. It is interesting to notice that the calculated velocity is only function of the acceleration of gravity (g) and of the bucket height (h): $\sqrt{2gh}$. The values of h and g are affected by very small uncertainties. Therefore the velocity of water through the hole can be accurately predicted.

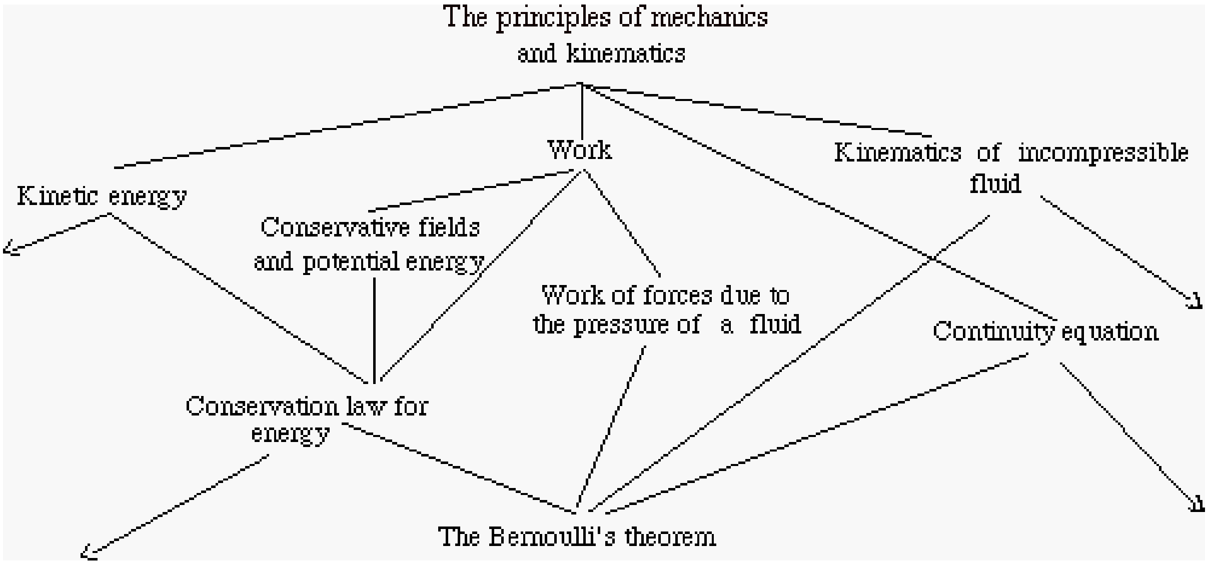

Figure 2.10 - The "pyramidal structure" of knowledge. Each "statement" has is own place and can be derived from few fundamental principles.

At first sight, there appears little doubt that the development of reliable environmental models requires the *totality* of the processes occurring in the examined system. Such "omniscient" models have the merit of framing, in rational structures, the phenomena and their relationships. Unfortunately, this means that knowledge concerning a great deal of environmental parameters is needed, and these are often difficult to measure and evaluate.

As a consequence, these models, often, cannot be used in practical circumstances. On the other hand, model complexity does not guarantee, necessarily, the accuracy of results. Model uncertainty can increase if more and more parameters are accounted for modelling the system. (IAEA, 2000). Indeed, the overall model uncertainty increases as result of the contribution of non negligible uncertainties from a large number of parameters. Figure 2.11 shows an example of development of an environmental model by trying to climb the "knowledge pyramid".

The ratio "total radionuclide concentration in water/dissolved radionuclide concentration" may be related to k_d (the partition coefficient) and W_{ss} (the weight of suspended matter per cubic metre of water) by a simple formula: $f = 1 + k_d w_{ss}$. W_{ss} and k_d may be related to some properties such as the size of suspended particles, the erosion rate, the sedimentation rate (this, indeed, controls the balance of the suspended matter).

Once suitable sub-models have been obtained to predict f in terms of the above quantities, it is necessary to predict these last as functions of many other environmental characteristics and processes such as the actual erosion mechanisms, the characteristics of the rocks in the catchment, the water regime, etc.

This procedure may be repeated for an innumerable set of process "shells" around the target variable f. Therefore, as result of this model structuring strategy we get more and more complicated models that are difficult to manage.

We can conclude that it is practically impossible to find the exact position of “f” in the knowledge pyramid.

To decide whether the effort for developing complex models is really justified in view of the uncertainty of the model results is a crucial point for structuring environmental models.

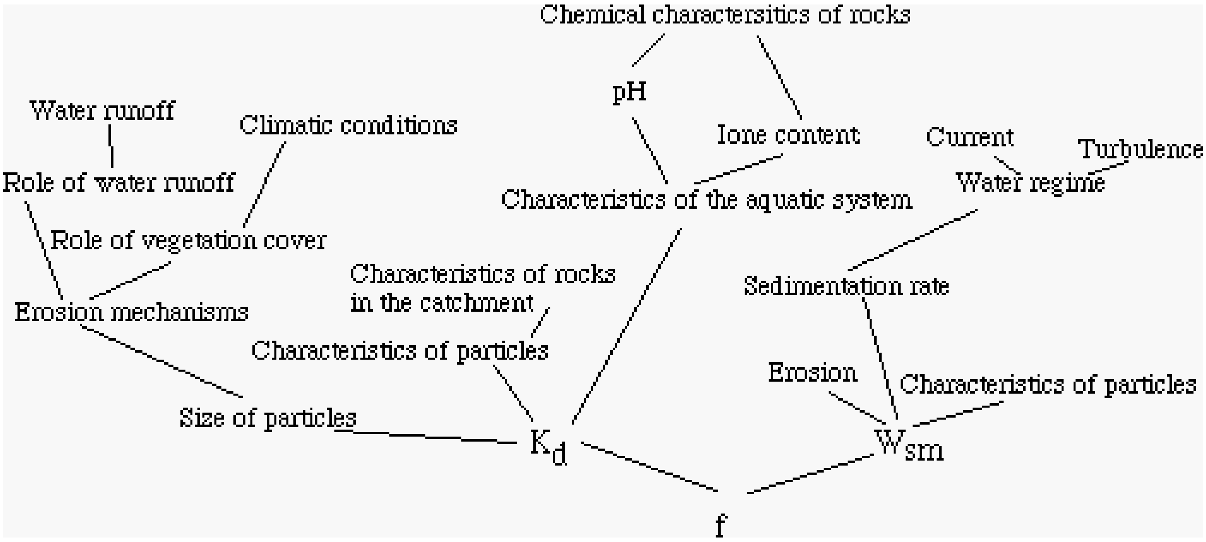

Figure 2.11 - The effect of an attempt for developing an environmental model by climbing the “knowledge pyramid”. At each step the model becomes more and more complex and requires more and more parameters showing non negligible uncertainties

Therefore, it is more wise to develop simplified models involving some degree of “aggregation” by grouping system variables and parameters and to search for quantitative, experimental relationship among these.

On the other hand, the main criticisms from the followers of the reductionistic approach to holism in ecology are based on the considerations that holism detracts from a deep insight into the fundamental properties of natural systems, circumvents the understanding of processes and phenomena and worses the model quality.

Obviously, aggregation influences the uncertainty of the model output. Overaggregated model may ignore some details of importance for a reliable prediction of the behaviour of a system. Nevertheless, it is more easy to manage aggregated models having simple structure especially for practical applications.

Although the conflict seems insoluble, it is worthwhile to notice that the assessed models are often hybrids showing characteristics that can be attributed to both philosophical approaches. The experience gained during the last decades suggests taking advantage from aggregation and from the application of empirically based sub-models for predicting some parameters that can be hardly evaluated by a reductionistic methodology.

Predicting radionuclide transport and diffusion in large, deep lakes

The previously assessed models are aimed at predicting the average behaviour of contaminant in water over intervals of time that are, approximately, of the order of the TRP of the model on the hypothesis of the complete mixing of radionuclide through the water body.

Three-dimensional models are used to simulate the diffusion and the transport of radionuclides in lakes when more detailed time and spatial resolutions are required. These models are based on the well-known formulae:

$$\Phi = -K\frac{\partial C}{\partial x} \qquad \Phi = vC \tag{2.21}$$

where Φ is the radionuclide flux (Bq m^{-2} s^{-1}), C is the radionuclide concentration (Bq m^{-3}) and K (m^2 s^{-1}) and v (m s^{-1}) are the diffusion constant and the translation velocity respectively.

Diffusion and advection equations (2.21) are used to predict the dynamics of suspended matter in water as well. The resulting diffusion-transport model is linked to the equation controlling the mechanisms of interaction of dissolved radionuclide with suspended matter and the sedimentation/resuspension processes to simulate the behaviour of the contaminant in the complex system “water, suspended matter, sediment”.

The THREETOX model (Margevelashvily et al., 1997) model, which includes the above processes to simulate radionuclide dispersion in large water bodies, is one of the computer codes of RODOS CDSS. The model is constructed from basic physical considerations to predict the dispersion of radionuclides in water bodies with complicated geometry and time-dependent and spatially non-homogeneous water flows.

THREETOX is aimed at assessing the water body contamination levels for general applications. It has been developed for predictions of the pollution dynamics during both the emergency and non-emergency (intermediate and long term effects) phases of an accident.

THREETOX simulates the three-dimensional hydrodynamic field on the basis of fundamental physical equations (Blumberg & Mellor, 1983) assuming that the water body is incompressible and hydrostatic. The relevant equations are complex and require many data for the boundary conditions. The model is an illustrative example of application of reductionistic methodologies.

Deep lakes and reservoirs may show a stratified thermal structures in connection with specific seasonal conditions. The behaviour of dissolved substances in such water bodies is influenced by these stratification phenomena related to the vertical profile of water temperature and to the relevant differences in the water density. The diffusion of dissolved substances through the water column shows marked seasonal variation as a function of the presence or absence of a vertical gradient in temperature.

Such a process, generally, is simulated by subdividing the water column into specific layers, namely the epilimnion (the upper layer), the thermocline (intermediate layer) and the hypolimnion. The seasonal variation of pollutant diffusion through the water column is modelled by assuming that the radionuclide transfer parameter from contiguous layers is a function of time (Monte, 1991).

The model for predicting the behaviour of ^{90}Sr in deep lakes implemented in the CDSS MOIRA is based on such an approach.

Quantitative assessment of the time behaviour of radionuclides in lake water

The paragraph “Modelling the behaviour of radionuclides in the abiotic components of lake ecosystems” clearly shows that, following a pulse deposition accident, the time behaviour of radionuclide concentration in lacustrine water can be successfully analysed in terms of few exponential components. These kinds of analyses have been carried out by many authors. For instance Zibold and co-workers (2001) calculated the constant rates of the exponential components of radiocaesium concentration in water of lakes Constance, Vorsee and Lugano. As Constance and Lugano are deep lakes with long mean water retention times, it is possible to hypothesise that the time behaviour of radionuclide in the water of these lakes is mainly controlled by processes of sedimentation and removal from the outlet and that, on the contrary, the contributions from the lake catchments do not influence significantly the balance of pollutant in the lakes.

Formulae (2.7), after a slight modification to account for the mean water retention time, allow one to calculate the above rates. Table 2.3 shows the values of the parameters necessary to evaluate λ_1 and λ_2.

Table 2.3 Main characteristics of lakes Constance and Lugano

Lake	Average depth (m)	Mean water retention time (years)
Constance	85	4.1
Lugano	55	2.5

The experimental values of λ_2 and λ_1 were obtained from the following equation applied to the experimental half-lives measured by Zibold et al. (2001):

$$\lambda = \frac{0.693}{T_{1/2}}$$

The calculated values are reported in Table 2.4 In the same table the corresponding values calculated by using the parameter values of model MARTE (Table 2.1) are reported.

Table 2.4. Values of the effective decay rates of ^{137}Cs in water of lakes Constance and Lugano.

Lake	Short component λ_2 (s^{-1})		Long component λ_1 (s^{-1})	
	Experimental	Model MARTE	Experimental	Model MARTE
Constance	5.6×10^{-8}	4.3×10^{-8}	7.8×10^{-9}	7.4×10^{-9}
Lugano	-	4.9×10^{-8}	9.1×10^{-9}	1.1×10^{-8}

Comparison and assessment of sub-models for predicting the behaviour or radionuclide in the biotic components of lake systems.

The behaviour of radionuclides in lacustrine biota is determined by a variety of processes and factors of biological, ecological and environmental nature.

Many experimental studies have demonstrated that the bioaccumulation of radionuclides in biota depends on trophic level, water chemical characteristics, water temperature and fish weight.

All the assessed models are based on the fundamental assumption that the time behaviour of a radionuclide in a biota species can be modelled accounting for the radionuclide excretion from the biota and the radionuclide uptake via ingestion or direct transfer from water. Moreover it is assumed that excretion is a first order process and the uptake is proportional to the radionuclide concentration in the precursor compartment of the food chain or in water:

$$\frac{d\,C_B}{dt} = -(\lambda_r + \lambda_B)\,C_B + K\,C_P \tag{2.22}$$

The main differences among the models are essentially the methodological approach (reductionistic or holistic) for determining the values of the parameters in equation (2.22) and the detail of analysis of the food web.

Figure 2.12 reports the structure of such a model (2.21)

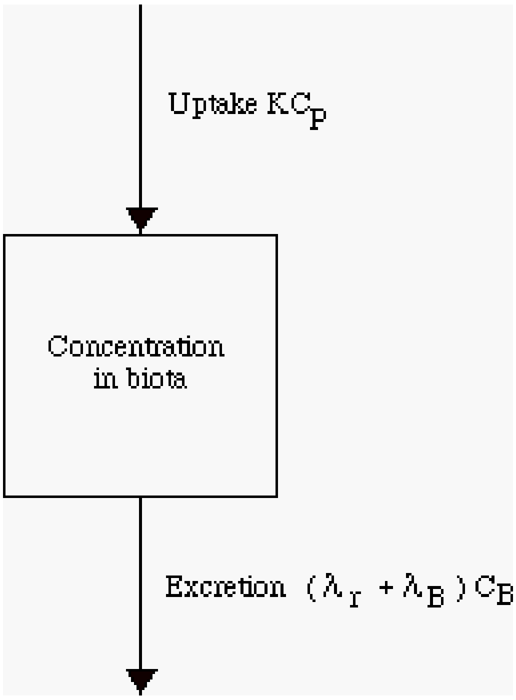

Figure 2.12 - Structure of the model used for predicting the time behaviour of radionuclide in biota accounting for excretion and uptake processes.

Some models (MOIRA-ECOPRAQ for ^{137}Cs and AQUASCOPE) use the above structure for predicting the behaviour of radionuclides in fishes. In contrast, LAKECO considers several components of a complex food web: phytoplankton, zooplankton, filter feeders, deposit feeders, and different levels of prey and predatory fishes. The uptake processes within this complex food-web are modelled, at least in principle, by quantitative assessments of the radionuclide fluxes from every precursor “node” to the successor on the basis of theoretical considerations. For instance the uptake by a predator is calculated as the product of radionuclide concentration in food, the food consumption rate and the food extraction efficiency. The direct uptake from water is calculated as the product of the radionuclide concentration in water, the water “extractability” and the water uptake. This is a typical reductionistic approach. Nevertheless, some of the above listed parameters are estimated by sub-models using measurable characteristics of the water body such as the potassium content due to the difficulty of a complete application of the reductionistic methodology.

Generally, the biological half-lives of phytoplankton and zooplankton are short compared with the corresponding values for prey and predatory fish species. This implies that the radionuclide concentrations in phytoplankton and zooplankton reach steady state conditions in intervals of time that are short compared with the biological turn-over time of radionuclides in fishes. Therefore, phytoplankton and zooplankton components scarcely influence the time behaviour of radionuclides in biota occupying higher levels of the food-web.

In other words, if the rate λ_B of the radionuclide excretion process in a species (S1) is significantly larger than the similar parameters for other species in the food-web, the concentration of radionuclide in that species quickly reaches the steady state equilibrium:

$$C_B = \frac{K}{(\lambda_r + \lambda_B)} C_P \tag{2.23}$$

It is possible to demonstrate, by simple mathematical considerations, that the time behaviour of radionuclide concentration in the food-chain successor (S2) of such biota species can be related by a first order equation (2.22) to the precursor (S0) of S1. This is a kind of "cancellation" law that allows one to simplify the structure of food-chain models. This principle is applied by models such as AQUASCOPE and ECOPRAQ.

AQUASCOPE and MOIRA-ECOPRAQ models predict the uptake of ^{137}Cs by fishes by a simple one-compartment structure:

$$\frac{dC_F}{dt} = -(\lambda_r + \lambda_B) C_F + K C_w \tag{2.24}$$

where C_F is the concentration in fish and C_w is the concentration in water. Such a structure was, essentially, the same used by models assessed in the frame of the VAMP (IAEA, 2000) and BIOMOVS projects. *It is important to notice that MOIRA-ECOPRAQ considers also the uptake of radionuclide from sediment layers. The models that do not include such a pathway are based on the implicit assumption that, due to the slow dynamics of pollutant content in lake water, the overall uptake of radionuclide by fish is approximately controlled, on the short and medium term, by the contamination levels of water. Such an assumption, although reasonable for lakes, is not generally valid for water bodies, such as rivers, showing fast dynamic behaviour of pollutants. For instance, temporary discharges of radionuclide in rivers may result in significant levels of sediment contamination that persist even when the pollutant concentration in water becomes negligible. In such circumstances, the migration pathway from sediment to fishes (for instance through the benthic compartment) significantly contributes to the fish contamination..*

AQUASCOPE and some of the VAMP project models relate the parameters in equation (2.24) to certain properties of the water and to the trophic level of the biota.

For ^{137}Cs biouptake K is inversely related to the concentration of potassium in water (C_k)

$$K = \frac{A}{C_k} \tag{2.25}$$

For ^{90}Sr K is related to the concentration of Ca in water:

$$K = \frac{A}{C_{Ca}^{n}} \tag{2.26}$$

where C_{Ca} is the calcium concentration and n is an exponent. Other similar equations have been suggested in the literature (IAEA, 1994). The values of the parameters in equations (2.25) and (2.26) are also related to the trophic level of the biota (predatory and non-predatory fishes).

The MOIRA-ECOPRAQ model assesses the ^{137}Cs concentration in fishes by relating the biouptake and excretion fluxes to several relevant environmental characteristics of the ecosystem.

The fluxes of radionuclide through the food chain are indeed calculated by accounting for many processes occurring at an ecological level.

Biouptake is related to the allochthonous and autocthonous production, to the concentration of potassium in water, to the level occupied by the biota in the food-web, to the size of the outflow area, to the total phosphorous, to the fish weight and, obviously, to the concentration of radionuclide in water. Excretion is calculated by accounting for the water temperature and the fish weight.

As in the case of sub-model for predicting the radionuclide behaviour in abiotic components of the lacustrine environment, MOIRA-ECOPRAQ aims at assessing the migration process in an ecological perspective. MOIRA-ECOPRAQ is mainly based on the so called ecometric sub-models (Håkanson & Peters, 1995) for predicting the radionuclide fluxes within the mass-balance model in fig. 2.12. Ecometric models describe the empirical relations among ecological effects, contaminant loads and system sensitivity.

The evaluation of the biological excretion rates (BHL) of ^{137}Cs in fish species is an example of these sub-models. MOIRA-ECOPRAQ determines BHL according to the following formulae:

$$BHL = 30\, e^{(-6.583 - 0.111\ln(5\,WF) + 0.093T + 0.326)}$$

where T is the temperature of the water and WF the fish weight.

Some models for predicting the behaviour of toxic substances in the environment are based on the assumption that radionuclides such as ^{137}Cs and ^{90}Sr show chemical (and bio-chemical) behaviours similar, respectively, to potassium and calcium. The model ECOMOD (Sazykina, 1994). belongs to this cathegory. Therefore, as the radioactive nuclides and the corresponding natural stable omologues are indistinguishable for living organisms, the share of radionuclide in the transfer processes is equal to the relative share of radionuclide in the common pool of this element (radionuclide + stable analogues) (Sazykina, 1994). ECOMOD can be classified within the cathegory of reductionistic models.

Discussion

1) Modelling radionuclide migration through lacustrine abiotic and biotic components

AQUASCOPE, MARTE, ECOPRAQ, LAKECO and THREETOX are well-known examples of models for predicting the behaviour of radionuclides in lacustrine ecosystems.

Most models focus mainly on radiocaesium and radiostrontium as these radionuclides are of particular importance for their long radioactive decay times and the consequent persistence in the environment.

Despite their seeming differences the assessed models show, at least in principle, many similarities.

MARTE, ECOPRAQ and LAKECO are compartment models (first order) based on the assessment of radionuclide balance within the components of the lacustrine environment. On the contrary, AQUASCOPE is based on the "response function" of the water-sediment sub-system to a pulse deposition event. It was demonstrated that, from the mathematical point of view, the approaches are equivalent.

The main difference among the models is relevant to the approach for assessing the fluxes from the compartments. In LAKECO the values of the transfer parameters (rates) are predicted from basic processes, such as the Fick's law, that are assumed to control the migration of radionuclide through the lacustrine environment.

The models MARTE and AQUASCOPE are based on a more pragmatic approach. Indeed, these models use generic values for the transfer parameters. The application to many different lacustrine systems suggested that the time behaviour of radionuclides in the water column can be predicted with a reasonable accuracy by these generic models.

In ECOPRAQ the rates, rather than to the fundamental processes and the relevant laws like in LAKECO, are related to the environmental characteristics of the lake. The model is characterised by a deeper insight into the most important phenomena controlling the radionuclide migration through the complex aquatic ecosystem.

Models like THREETOX are based on fundamental equations and are the most representative example of reductionistic models.

As MARTE, ECOPRAQ, LAKECO and AQUASCOPE show some similarity it is reasonable to encourage an effort for harmonising the methodologies, the approaches and, possibly, the models themselves.

The bioaccumulation of radionuclides in fishes is controlled by many physical, chemical, biological and ecological processes. Therefore, the development of models for predicting the migration of radioactive substances through the biotic components of the lacustrine system is a real challenge for modellers.

To have an idea of how variable the bioaccumulation is in relation to different kind of radionuclides, it is sufficient to look at the range of concentration factors measured in different environmental conditions (IAEA, 1994).

Recently, researchers have profited from many experimental results relevant to the migration of ^{137}Cs and ^{90}Sr in complex lacustrine systems. Several EC projects as well VAMP and BIOMOVS gave the opportunity to many scientists of extending knowledge and experience to develop more reliable models for predicting the behaviour of these radionuclides in lacustrine ecosystems.

Some of the models examined here are aimed at predicting the behaviour of ^{137}Cs and ^{90}Sr for general environmental conditions and circumstances. These models, being of general application, can be very helpful tools for the management of any contaminated lacustrine systems. Nevertheless, it is quite obvious that site specific calibrated models can show significantly higher accuracy. Therefore, it seems wise to encourage studies and research aimed at customising the models to site specific conditions of European lakes by profiting from newly acquired data and information and from recently gained experience.

In spite of the great deal of studies for developing ^{137}Cs and ^{90}Sr models, comparatively limited deployment of models for assessing the migration of other radionuclides in the lacustrine environment has been undertaken by modellers at an international level of co-operation.

The occurrence that different models show similar features is not surprising. Indeed, most parts of the assessed models were developed according to traditional approaches (compartment models) and taking advantage of the great deal of experiences and knowledge gained during past decades at an international level.

Moreover, international projects such as VAMP and BIOMOVS, gave the opportunity for significant exchange of this knowledge and experience among modellers of many countries. It was possible to analyse and assess the performances of many models by comparison with experimental information from the environmental contamination following the Chernobyl accident. This was the ground for the development of common and empirically substantiated approaches

2) What is really old, what is really new and what is to do

As previously stated most of the assessed models for predicting the behaviour of radionuclides in the abiotic components of a lake are basically comprised of 2 or 3 boxes that simulate the water column and the bottom sediment layers. They belong to the category of the so called “fully mixed” hydrological dispersion models that have been well described in the scientific literature (IAEA, 1985).

Indeed, before the Chernobyl accident, much research was focused to the development of models for assessing the behaviour of radionuclides in surface waters. The results were summarised in many reports (e.g. NCRP, 1984). Therefore, it seems quite obvious that the scientific community has reached a general agreement on the structure of the models for predicting the radionuclide migration through the system “water column - bottom sediment”. Validation studies carried out in the frame of project BIOMOVS II (Davis et al., 1999) also reached similar conclusions (Kryshev et al., 1999).

Unfortunately, there was not a similar agreement concerning the values of the parameters controlling the processes of migration. Whereas the dispersion fluxes of radionuclides through the water compartment is described at a satisfactory level in many important international publications (IAEA, 2001), the analysis of available literature (IAEA 1982; IAEA, 1994) suggested that little information was available about the values of the parameters controlling the transport of radionuclide from the water to the bottom sediments and vice-versa.

Such a gap has been partially abridged for radiocaesium and radiostrontium following the research carried out during this last decade.

The validation exercise carried out in the frame of project BIOMOVS clearly enlightened the difficulties that modellers came across in choosing appropriate values of the transfer parameters. The exercise was aimed at comparing model predictions utilising experimental data of ^{137}Cs and stable cesium concentration in three lake systems (BIOMOVS, 1991): a) East Twin Lake (USA) contaminated by stable cesium for research purposes; b) Lake Höjsjöen (Norway) and c) Lake Hillesjön (Sweden) contaminated by ^{137}Cs introduced in the environment following the Chernobyl accident.

The following models were used:

1. BILTH (Laboratory of Radiation Research at the National Institute for Public Health and Environmental Protection, the Netherlands)
2. BIOLAKE (Chalk River Nuclear Laboratory, Canada)
3. BIOPATH (Studsvik Eco&Safety AB, Sweden)
4. DETRA (Technical Research Centre of Finland)
5. JAERI (Japan Atomic Energy Research Institute)
6. RISÖ (Risö National Laboratory, Denmark)
7. NRIRR (National Research Institute for Radiology and Radiohygiene, Hungary).

Table 2.5 shows the values of the parameters used by each model. The values of the migration velocity to sediments v_{ws} ranged from $5,50 x 10^{-10}$ to $7,13 x 10^{-7}$ m s^{-1}. The migration rate from sediment to water K_{sw} ranged from $3,17 x 10^{-11}$ to $1,93 x 10^{-7}$ s^{-1}. The migration rate from bottom sediment to deep sediment K_{ds} ranged from $2,85 x 10^{-10}$ to $1,17 x 10^{-8}$ s^{-1}.

The ranges of variation of the parameters were therefore of the order of one thousand and more. It is quite obvious that such large ranges significantly influence the uncertainty of the model output. It is worthwhile to notice that modellers estimated that the uncertainty ranges of these parameters were one order of magnitude and more (Togawa & Homma, 1991). The research carried out following the Chernobyl accident in the frame of the EC projects considered in the present assessment allowed the improvement of model performances by more accurate assessment of the transfer parameters on the basis of many different experimental evaluations.

Unfortunately, at present such studies have only been carried out for ^{137}Cs and ^{90}Sr. There are no similar extensive and reliable data for other radionuclides.

The improvement of the quality of the results of models for predicting the migration of radionuclides other than ^{137}Cs and ^{90}Sr can be achieved by a better knowledge of the relevant transfer parameters. This can be a wise objective for future research activities. It is indeed reasonable to assume that the model parameter uncertainty for these radionuclides is similar to the large uncertainty of the parameters for radiocaesium and radiostrontium estimated before the better assessments of these the last years.

For instance, an exercise of intercomparison of models for predicting the behaviour of ^{226}Ra and ^{230}Th in lakes (BIOMOVS, 1988; Sundblad, 1991) demonstrated that the ranges of some transfer rate parameters of these radionuclides cover several orders of magnitude. Such variability is reflected in the estimated uncertainty of the model results over long-term periods.

Table 2.5 Values of migration parameters used by models included in a BIOMOVS test exercise (BIOMOVS, 1991)

Lake	**East Twin**		
	v_{ws} (m s^{-1})	K_{sw} (s^{-1})	K_{ds} (s^{-1})
	$8,77x10^{-9}$	$1,05x10^{-8}$	
	$3,91x10^{-8}$	$3,49x10^{-8}$	$2,31x10^{-9}$
	$3,49x10^{-9}$	$3,17x10^{-11}$	$2,85x10^{-10}$
	$3,70x10^{-8}$	$9,51x10^{-10}$	$3,17x10^{-9}$
	$1,06x10^{-7}$	$6,34x10^{-9}$	$1,17x10^{-8}$
Lake	**Hillesjön**		
	v_{ws} (m s^{-1})	K_{sw} (s^{-1})	K_{ds} (s^{-1})
	$5,35x10^{-8}$	$8,24x10^{-9}$	
	$1,64x10^{-8}$	$1,05x10^{-8}$	
	$2,40x10^{-7}$	$1,52x10^{-8}$	$1,14x10^{-9}$
	$1,98x10^{-7}$	$2,41x10^{-9}$	$1,14x10^{-9}$
	$1,23x10^{-8}$	$2,22x10^{-10}$	$1,59x10^{-9}$
	$7,13x10^{-7}$	$1,93x10^{-7}$	
Lake	**Höjsjöen**		
	v_{ws} (m s^{-1})	K_{sw} (s^{-1})	K_{ds} (s^{-1})
	$3,51x10^{-9}$	$1,05x10^{-8}$	
	$5,07x10^{-9}$	$1,90x10^{-8}$	$7,61x10^{-10}$
	$5,50x10^{-10}$	$3,17x10^{-11}$	$3,01x10^{-10}$
	$3,68x10^{-9}$	$9,51x10^{-10}$	$1,17x10^{-8}$

The simple structures of the models suggest that the "data assimilation" procedures can be readily applied to obtain more reliable predictions in the medium and long term.

Data assimilation procedure is a technique that enables one to improve the accuracy of predictions taking advantage from the monitoring data acquired. In case of the assessed models it seems very easy and practical to implement computer routines for the "real time" calibration of the models in CDSSs.

A specific project is in progress in the frame of 5th EC Programme (DAONEM, Rojas Palma, 2002).

A real step forward could be represented by the development of suitable sub-models that allow one to assess the values of the transfer parameter for different environmental circumstances. For assuring the reliability of models for practical applications, it is important to relate these values to environmental and geographical information that can be easily obtained. This means that, instead of developing sub-models based on fundamental laws and quantities, it is more wise to study the relationship existing among the aggregated transfer rates, such as v_{ws}, k_{sw} and k_{ds}, and environmental conditions. These can be important topics for further studies relevant to the behaviour of radionuclides and, more generally, of toxic substances through the fresh water environment.

Conclusions

The work done during these last decades by many modellers at an international level has produced some consolidated results that are, generally, widely accepted by most experts. Nevertheless, some new results have been obtained and some improvements are still necessary.

- The structures of models for predicting the migration of radionuclides through the biotic and the abiotic components of the lacustrine environment have been clearly identified and are widely accepted by the scientific community;

- Recently, many experimental studies following the most significant nuclear accidents (Chernobyl, Kyshtym) have provided the opportunity for a quantitative evaluation of the most important transfer parameters for radiocaesium and radiostrontium through the system "water column - bottom sediment" of lakes. Consequently the uncertainty of these parameters and, thus of the models, has become considerably lower than a decade ago;

- Experiences gained from countermeasures implemented after the Chernobyl accident has also led to improvement in models and decision support systems that incorporate remediation;

- ^{137}Cs and ^{90}Sr models based on the previous structures and parameters show levels of uncertainty of a factor 2 or 3 when applied as generic tools for predicting the behaviour of radionuclide in the abiotic components of the lacustrine environment. Nevertheless it is possible that lacustrine systems in extreme environmental conditions cannot be modelled within similar narrow uncertainty ranges. Moreover, a larger uncertainty is expected for predictions relevant to the biotic components of the lacustrine environment;

- As the structures of the models include only few exponential components, data assimilation procedures can be easily applied and can be helpful for improving prediction relevant to the contamination behaviour in the medium and long term following a nuclear accident;

- For the same reason, the widespread assessment of site-specific values of the model parameters may be of importance for improving the model performances for many practical applications;

- For several important radionuclides similar information is not yet available and further assessment is necessary, mainly in relation to the evaluation of model uncertainties;

- It is wise to perform further efforts to harmonise the results of the recent projects in order to develop a *reference lake model* that can be widely applied throughout Europe and that can be implemented in Computerised Decision Support Systems for the management of post-accident consequences.

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SECTION 3: WATER BODY CATCHMENTS

REVIEW AND ASSESSMENT OF MODELS FOR PREDICTING THE MIGRATION OF RADIONUCLIDES FROM CATCHMENTS

Introduction

Models for predicting the migration of radionuclides from catchment basins to fresh water bodies are essential for the assessment of the contamination levels of aquatic ecosystems. The complexity of the migration processes occurring in catchments is reflected in the difficulties encountered in constructing these models. It is a considerable challenge to develop general models that can be reliably applied to catchments in different geographical areas with different environmental conditions and for different possible contamination scenarios.

The radionuclide transport through a catchment is governed by two main classes of processes (Kivva & Zheleznyak, 2000):

i) Hydrological processes:

(1) Water flow

(2) Sediment erosion, transport and deposition

ii) Physico–chemical interaction processes between radionuclides in dissolved form with the rocks in the catchment, and in particular, with soil particles.

The flowing and balance of water in a catchment is controlled by many mechanisms: a) interception of precipitation by surfaces, such as the, above ground vegetation; b) storage of water in depressions; c) snow and ice storage; d) infiltration through the soil; d) overland flow; e) interflow through the unsaturated zone and f) groundwater flow through the saturated zone (figure 3.1).

The hydrological cycle and surface water movement and balance have been thoroughly investigated. Many models have been developed, see, e.g., the textbooks by Wanielista (1990).

The physico-chemical processes of interaction of solute radionuclides with soil and bedrock have been also object of many studies in past decades. An extensive review of the sub-models for the quantitative assessment of such processes relevant to non-radioactive substances but that can be applied conceptually also to radionuclides has been recently published (Delle Site, 2000).

As both classes of processes, i) and ii), have been studied in detail, it seems reasonable, at first sight, to hypothesise that coupling hydrological models and physico-chemical models of the interaction of dissolved radionuclides with bedrocks and soils makes it possible to develop general models for predicting the behaviour of radionuclide migrating from catchments to water bodies. Moreover, the reliability and accuracy of these models can be increased at will by including more and more details relevant to the descriptions of the processes taking place.

Unfortunately, as experienced for many other kinds of models, the inclusion of more processes in a complex model does not generally guarantee greater accuracy of model performance. Indeed the overall uncertainty of the model is strongly influenced by the uncertainty of large numbers of model parameters whose values cannot be known with a sufficient accuracy at site specific level. For example, IAEA (2000) reported the description of a model for assessing the migration of radiocaesium from the drainage area of a lake. The model makes use of more than 20 primary parameters for predicting, among the variety of processes that control radionuclide transport through a catchment, the soil erosion from each elementary "cell" of the drainage area. Of course, further quantities are necessary for modelling the other processes occurring in the catchment. Unfortunately, it is often difficult to obtain accurate site-specific values, for practical applications of many of those parameters, such as "the infiltration capacity of a shower of 30 minutes" or "the bulk density of soil" or the "daily averaged infiltration capacity" in a cell, such as defined andd used by the above model.

It is commonly assumed that three main factors can affect the reliability of a model for predicting the behaviour of complex systems:

a) The lack of detailed knowledge at level of the processes taking place;

b) The uncertainty of the experimental parameters necessary for the quantitative assessment of the processes; and

c) The mathematical approximations and simplifications of the model.

Factors a) and b) are supposed to be the main reasons for the "structural" insufficiency of a model, while factor c) influences the quality of the numerical output of the "code" that implements the model itself.

When an unlimited process of knowledge acquisition is possible, we are enticed by the hypothesis that the structural insufficiency of a model can be progressively reduced in order to increase the model performance. This is the case for hydrological models that can take advantage from the repetitive occurrence of seasonal events. It is presumptuous to debate if this is in general true or false. What is definitely factual is the deceitfulness of such an "unlimited" acquisition of knowledge for those processes that occur and reveal at an environmental systemic levels in relation to occasional events, such as accidents, for which it is not reasonable and indeed desirable that they are recurrent.

The behaviour of complex environmental systems cannot be simulated and investigated by laboratory experiments. Therefore, it is necessary to take advantage from the limited experimental information available at a systemic level, and to consider cautiously the applications of those findings that, although substantiated at the level of laboratory experiments, are not adequately understood and supported at the level of emerging systemic behaviours in relation to the complex interactions of the huge number of components of an environmental system. Laboratory studies are based on the "analysis" of the processes by "dissecting" and "isolating" the various components of the examined system. The complicated interactions among the systems components do not guarantee that such "analytical" procedures allow one to understand those behaviours that emerge at a systemic level.

It is commonly believed that it is possible to improve the mathematical approximations as computers become more and more powerful. Nevertheless, it is quite obvious that the uncertainty of the models is controlled by factors a) and b). It is, therefore, misleading to hypothesise that the accuracy of a model can be significantly enhanced by the mere application of more sophisticated computational techniques.

The development of models for predicting the behaviour of radionuclide migration through catchments should also consider the conclusions recently achieved in relation to the principles for structuring lake models (Monte et al., 2003).

A fundamental concern in radioecology is to model and predict the "peak and the tail" concerning radionuclide concentrations in ecosystems related to a given accidental fallout (see IAEA, 2000). Peak concentrations are generally related to short-term conditions the hours, days or weeks after the fallout, whereas the "tail" concentrations generally are governed by the long-term conditions in the catchment areas regulating fixation, percolation, surface and ground water transport, resuspension and biotic fluxes of radionuclides (Strand et al., 1996).

In this report, we discuss the pros and cons of different approaches to quantify fluxes of substances from land to surface water. General criteria for evaluating model behavior have been discussed by Håkanson and Peters (1995) and IAEA (2000) and include considerations to (1) the highest predictive power when modelled values are (2) validated against independent data on (3) important target variables covering a (4) wide domain of ecosystems from the (5) fewest and (6) most readily accessible set of driving variables.

Many studies (Knoechel and Campbell, 1988; Rochelle et al., 1989; Newton et al., 1987; Duarte and Kalff, 1989) have demonstrated that aquatic systems are affected by catchment characteristics (like area covered by bedrocks, soils and different land-use activities). An important question is then: will the predictive power of water variables (y) increase if one increases the resolution of the catchment area description by increasing the number of x-variables describing the catchment area and by accounting for catchment “zonation” in an more detailed manner?

Discussion

Assessment of models for predicting the radionuclide migration from catchments: pre-Chernobyl status

Attention is focused on those sub-models aimed at assessing the migration of radionuclide from catchments. The prediction of detailed hydrological processes are more relevant to hydrology rather than to radioecology. A retrospective analysis can be helpful for the present assessment. Since the beginning of the sixties, researchers have tried to analyse the quantitative behaviour of radionuclide migration from catchments in a pragmatic way, taking advantage of the available experimental results.

Studies on the transport of radionuclides through runoff were initiated as soon the fallout from nuclear weapon tests in atmosphere became a significant source of environmental contamination (Menzel, 1960; Yamagata et al., 1963). Helton et al.

(1985) reviewed the parameter values used in models for predicting the migration of radiocaesium, radiostrontium and plutonium from catchments. These reviews accounted for the research carried out before the Chernobyl accident. The assessed parameter values refer to the model structure described, for instance, by Carlsson (1978). It was assumed that an initial fraction $k_1D(t)$ of radionuclide deposited per second and per square metre (D(t), Bq m^{-2} s^{-1}) was instantaneously transferred to the water body. Thereafter, the remaining part of deposited radionuclide accumulated in compartment S(t), representing the amount of radionuclide in catchment per square metre (the radionuclide inventory at time t, Bq m^{-2}). Radionuclides are, therefore, washed off with a rate constant k_2. Figure 3.1 shows the model structure.

The differential equation controlling S(t) is as follows:

$$\frac{dS(t)}{dt} = -(\lambda + k_2)S(t) + (1 - k_1)D(t) \qquad (3.1)$$

λ is the radioactive decay constant (s^{-1}) and k_2(s^{-1}) is the rate of removal by runoff of the radionuclide in S(t)..

The radionuclide flux per square metre Φ(t) is, therefore:

$$\Phi(t) = k_1D(t) + k_2S(t) \qquad (3.2)$$

The evaluations of the parameters of the above model for radionuclides introduced in the environment following the nuclear weapon tests into the atmosphere were obtained by many workers. The parameteres were obtained by experimental assessments carried out at both regional and experimental plot scales, The results of the reviews can be summarised as follows: k_1 values range from 0.5×10^{-2} to 12.2×10^{-2} and from 0.1×10^{-2} to 1.9×10^{-2} for ^{90}Sr and ^{137}Cs respectively. k_2 values range from 2.2×10^{-11} s^{-1} to 1.0×10^{-9} (s^{-1}) for ^{90}Sr and from 2.1×10^{-12} s^{-1} to 1.8×10^{-10} s^{-1} for ^{137}Cs. For plutonium isotopes fewer data were available indicating that the order of magnitude of k_2 is 10^{-11} s^{-1} (Table 3.1).

The total deposit S(t) of a radionuclide following a single pulse deposition is an exponential function of time as seen from equation 3.1. The effective decay of the deposition is therefore λ + k_2. The radionuclide flux shows a similar exponential decay (equation 3.2), following the deposition pulse, $k_1D(t)=0$. The concentration of radionuclide in runoff water can be calculated by dividing the radionuclide flux per square metre by the runoff water flux per square metre. As consequences, radionuclide concentration in runoff water is an exponential function of time with effective decay constant λ + k_2.

The above data suggest that the range of the values of removal rate (k_2) for strontium is significantly higher that the corresponding value range for caesium. Therefore, the decline of the concentration of radiostrontium in runoff water is expected to be faster than the concentration of radiocaesium.

Before the Chernobyl accident Helton (1985) gave an excellent analysis of the state-of-the-art models for predicting radionuclide migration from catchments. The analysis was done by accounting for extensive investigations in a number of catchments in Europe, North America and Japan. As equation (3.1) shows, the assessment of the radionuclide migrating from a catchment was made hypothesising that the radionuclide removal rate (k_2) is constant over time.

Model (3.1) can be derived accounting for the role that the partition coefficient k_d has in the long term migration of radionuclides through a catchment (Joshi & Shukla ,1991).In this model the fluvial removal F_{ir} (Bq m^{-2} s^{-1}) is assumed to be proportional to the radionuclide inventory in the watershed S(t) at instant t (Bq m^{-2}).

$$F_{ir} = k_2 S(t) \tag{3.3}$$

where, as usual, k_2 is the removal rate (s^{-1}).

Multiplying both sides by the area of the watershed A, we get

$$F_r(t) = k_2 S(t) A \tag{3.4}$$

where $F_r(t)$ is the flux of radionuclide (Bq s^{-1}).

The radionuclide inventory can be calculated according to the following equations:

$$\frac{dS(t)}{dt} = D(t) - (\lambda + k_2) S(t) \tag{3.5}$$

$$k_2 = \frac{V_{wi}(t)}{V_{si}(t) k_{di}}$$

where D(t) is the time dependent deposition rate of radionuclide in the watershed (Bq m^{-2} s^{-1}), $V_{wi}(t)$ is the rate of rainfall (m s^{-1}), $V_{si}(t)$ is the water penetration depth (m), λ is the radioactive decay constant, and k_{di} is the dimensionless partition coefficient ($k_{di} = \rho k_d$, ρ = soil density in kg m^{-3}, k_d = soil-water soil partition coefficient in m^3 kg^{-1}).

S(t) depends on the time behaviour of $V_{si}(t)$ and $V_{wi}(t)$. Hypothesising that the ratio $V_{si}(t)/V_{wi}(t) = \xi$ is constant with time the solution of equation (3.5) for a pulse deposition is

$$S(t) = S(0) e^{-\left(\lambda + \frac{1}{\xi k_{di}}\right) t} \tag{3.5}$$

The radionuclide flux is

$$F_r(t) = \frac{A}{\xi k_{di}} S(0) e^{-\left(\lambda + \frac{1}{\xi k_{di}}\right) t} \tag{3.7}$$

The model is based on the correlation of the effective decay constant $\left(\lambda+\frac{1}{\xi k_{di}}\right)$ with the radionuclide partition coefficient, k_d. It accounts for this correlation by means of an inverse function: as k_d increases the effective decay constant decreases. This result would seem to support the previously described experimental observations. Indeed the experimental long-term effective decay constant for ^{90}Sr, a radionuclide characterised by a low value of k_d, is higher than the corresponding parameters for ^{137}Cs (high k_d radionuclide) as shown in table 3.1.

The above quantitative evaluations were prevailingly carried out by assessing the behaviour of radionuclide concentrations in run-off water following the nuclear explosion tests in the atmosphere. A major problem with the above approach was due to the non-pulse character of the radionuclide fallout. This prevented an accurate evaluation of the time behaviour (and consequently of the effective decay constants) of radionuclides in water. Moreover, these quantitative assessments were carried out assuming that radionuclides accumulated in the catchment storage compartments S(t) were fully available to the migration. This hypothesis implies a significant underestimate of k_2 when such a parameter is assessed by accounting, solely, for the radionuclide balance in the catchment in terms of total deposit and radionuclide removal by runoff waters.

In principle, more compartments than in Figure 3.1 can be hypothesised for the assessment of migration of radionuclides from catchments. Unfortunately, for such more complicated models less experimental parameter values are available from the literature (Helton, 1985).

The model developed by Linsley & Dionian (1983) offers an example of a box model that can be derived from the above experimental evidence. This model was used to predict the transfer of radionuclides from catchment areas to lakes. It was based on two compartments for Sr and only one compartment for Cs. The model structure is reported in figure 3.3. The values of model rates and parameters are reported in table 3.2. A previous review of models for predicting the migration of radionuclides from catchments was carried out by Monte (1996).

A typical multi-compartment model was proposed by Korhonen (1990). Soil in the drainage area was subdivided into layers of various thicknesses. The migration of radionuclides from one layer to another was evaluated accounting for the water fluxes. The model hypothesizes constant rates of water infiltration. The last layer is a sink compartment and only the first layer contributes to the runoff. The differential equations that can be used to calculate the concentration in each layer are :

$$\frac{dCtot_i}{dt} = k_{i-1,i}Cs_{i-1}/h_i - (k_{i,i-1} + k_{i,i+1})Cs_i/h_i + k_{i+1,i}Cs_{i+1}/h_i - \lambda Ctot_i \qquad (3.8)$$

$$Ctot_i = Cs_i(\theta + \rho k_d)$$

where

$$(\theta + \rho k_d) = R \qquad (3.9)$$

$k_{i,j}$ represents the water flux, per square metre, from layer i to layer j measured in m s^{-1}; h_i is the thickness of layer i; Cs_i is the concentration of dissolved radionuclide in layer i; $Ctot_i$ is the total concentration of radionuclide in layer i; θ is the volumetric water content of the soil; ρ is the density of the soil; and k_d is the radionuclide soil-water partition coefficient.

The equation for the first layer is:

$$\frac{dCtot_1}{dt} = \frac{D(t)}{h_1} - (k_{1,2} + k_{1,6} + k^{s}_{1,6} k_d) Cs_1 / h_1 + k_{2,1} Cs_2 / h_1 - \lambda Ctot_1 \quad (3.10)$$

where D(t) is the deposition rate, $k_{1,6}$ is the water run-off (m s^{-1}) from the first layer and $k^{s}_{1,6}$ is the erosion measured as kg m^{-2} s^{-1}. The radionuclide flux due to the runoff is

$$\Phi_r(t) = S\, k_{1,6}\, Cs_1 \quad \text{(dissolved component)} \qquad (3.11)$$

Dividing both members of equations (3.8) and (3.10) by R it is possible to obtain a set of differential equations for Cs_i. The parameter values used in the model are as follows:

$k_{1,2}$ = 1.59 10^{-8} m s^{-1}, $k_{2,1}$= 1.27 10^{-8} m s^{-1}, $k_{2,3}$ = 1.59 10^{-8} m s^{-1}, $k_{3,2}$ = 1.27 10^{-8} m s^{-1}, $k_{3,4}$ = 1.59 10^{-8} m s^{-1}, $k_{4,3}$ = 1.27 10^{-8} m s^{-1}, $k_{4,5}$ = 3.17 10^{-9} m s^{-1}, $k_{1,6}$ = 7.93 10^{-9} m s^{-1}, $k^{s}_{1,6}$ = 2.54 10^{-9}kg m^{-2} s^{-1}, k_d=3 m^3 kg^{-1}, h_1 = 1 cm, h_2= 4 cm, h_3 = 10 cm, h_4 = 15 cm.

Following a single pulse of deposition of radioactivity, the concentration of radionuclide in run-of water is the sum of four exponential function of time with effective decay constants $k_i + \lambda$. k_i may be evaluated after tedious but standard calculation:

$$k_1 = \frac{3.333 \cdot 10^{-6}}{R}; k_2 = \frac{6.564 \cdot 10^{-7}}{R}; k_3 = \frac{2.299 \cdot 10^{-7}}{R}; k_4 = \frac{2.448 \cdot 10^{-8}}{R} \quad s^{-1} \qquad (3.12)$$

Using R= 3000, a value obtained supposing the density of soil equal to be 1 kg dm^{-3} and k_d=3000 dm^3kg^{-1} (Korhonen 1990), we get

$$k_1 = 1.1 \cdot 10^{-9};\ k_2 = 2.2 \cdot 10^{-10};\ k_3 = 7.7 \cdot 10^{-11};\ k_4 = 8.2 \cdot 10^{-12} \quad s^{-1} \qquad (3.13)$$

In the previous model, lower values of k_d imply higher values of decay constants (3.12). Therefore, as for any model based on the assessment of radionuclide mobility from partition coefficient values, the predicted effective decay rates of ^{90}Sr concentration in water are higher than for ^{137}Cs.

Results following the Chernobyl accident

The Chernobyl accident represents a line of demarcation between research carried out following the environmental contamination due to the nuclear weapon tests in atmosphere and new results from such an accidental pulse contamination event.

Following the Chernobyl accident a variety of studies focused on the evaluation of the quantitative behaviour of radionuclide transport through catchments. Some of the results are summarised below. Monte (1995) analysed data collected by various European laboratories, and was able to fit the experimental dissolved radionuclide flux in some rivers, which drain large catchments, to the following function (radionuclide Transfer Function).

$$\Phi_r(t) = \varepsilon D \sum_i \Phi^{\alpha_i}(t)\beta_i A_i e^{-(\lambda_r+\lambda_i)t} \tag{3.14}$$

$$\sum_i A_i = 1 \tag{3.15}$$

The symbols used are as follows:

$\Phi_r(t)$ is the radionuclide flux from catchment (Bq s^{-1})

ε is the radionuclide transfer coefficient from the catchment (m^{-1})

D is the pulse deposition (Bq m^{-2})

$\Phi(t)$ is the water flux from the catchment (m^3 s^{-1})

A_i is the weight of the ith component (dimensionless)

λ_i are empirical parameters controlling the decay of radionuclide concentration in water due to environmental effects (s^{-1})

λ is the radioactive decay constant (s^{-1}),

The terms $\beta_i \Phi^{\alpha_i}(t)$ in equation (3.14) account for possible non-linearity effects of radionuclide flux (concentration in run-off water) as function of the water flux.

β_i are "normalisation" coefficients. A possible choice of β_i, is as follows: $\beta_i = \Phi(0)^{1-\alpha_i}$.$\Phi_r(t)$ is the radionuclide flux (Bq s^{-1}) following a single pulse of radionuclide deposition.

The radionuclide migration from catchment has been the object of many studies (Hilton et al., 1993; Santschi et al., 1990). Monte (1995) evaluated the experimental transfer functions using contamination data collected by some European Laboratories following the Chernobyl accident (Kaniviets & Voitcekhovich,1992; Mundschenk, 1992; Maringer, 1994).

Exponents α_i were introduced into equation (3.14) to account for the possible non-linearity of the radionuclide migrating from the catchment as a function of the water flux. When $\alpha_I = 1$, the Transfer Function fits the radionuclide average flux disregarding the effects due to the seasonal variations of the water flow. In such a case, dividing both components of equation (3.14) by the water flux and accounting for the simple formula:

$$C_w(t) = \frac{\Phi_r(t)}{\Phi(t)} \tag{3.16}$$

we get

$$C_w(t) = \varepsilon D \sum_i A_i e^{-(\lambda+\lambda_i)t} \tag{3.17}$$

As seen from equation (3.17) the yearly average concentration in water comprises two factors:

- A multiplicative "scaling factor" ε; and
- The expression:

$$\sum_i A_i e^{-(\lambda+\lambda_i)t} \tag{3.18}$$

It is quite obvious that, multiplying ε by any factor K and dividing A_i by the same factor, the transfer function does not change. Therefore it is ever possible to choose A_i according to equation (3.15) (i.e. the sum of A_i is normalised to 1).

Function (3.17) is therefore comprised of: a) $\sum_i A_i e^{-(\lambda+\lambda_i)t}$ that represents the "shape" of the curve (the time behaviour); and b) a scaling factor ε that represents the "position" of the curve in relation to the y axis of the graphic "concentration versus time" and is the ratio between the initial concentration of radionuclide in water and the total deposition.

From the experimental data available it was possible to identify two main exponential components:

a) a short-term component over a period of few months after the accident;

b) a long-term component over a period of some years after the accident.

The component a) is influenced by short-term processes occurring in a catchment such as the vegetation wash-out.

Some evaluations of the effective decay constant and of the exponent α_i are reported in Table 3.3.

Table 3.4 shows the values of some measured parameters of TF for particulate Cs.

The values of α_2 are larger than 1 for particulate caesium. Indeed, the amount of suspended matter and, consequently, of particulate radionuclide, in the examined rivers, increases with the water flux.

As discussed in a previous paper (Monte, 1997), it is possible to derive from the transfer function a simple compartment model for predicting the time behaviour of the radionuclides in river water

$$\Phi_r(t) = \varepsilon \sum_i \Phi^{\alpha_i}(t) \beta_i S_i \tag{3.19}$$

where S_i are solutions of the following system of differential equations:

$$\frac{dS_i}{dt} = -(\lambda_i + \lambda_r) S_i + A_i D(t) \tag{3.20}$$

Such a model may be used to assess the radionuclide migration following time-dependent deposition of radionuclides onto the catchment. S_i are the radionuclide storage compartments that may be schematically regarded as the various soil layers and the vegetation cover in the catchment (Figure 3.14).

The previous discussion clearly shows that many experimental evaluations of the effective decay rates and of the weights of the exponential components of the TF were obtained. However, comparatively few experimental assessments are available for the transfer coefficients from catchment to water bodies.

Parameter k_1 in the Helton assessment can be related to the parameters in transfer function (3.14) according to the following formula:

$$\varepsilon A_1 \approx \frac{k_1 \lambda_1}{R} \tag{3.21}$$

where R is the water runoff for unit surface ($m^3\ m^{-2}\ s^{-1}$). Using data from Helton, (1985) and supposing $R=0.5\ m^3\ m^{-2}\ y^{-1}$ and $\lambda_1 \sim 5.x10^{-7}\ s^{-1}$ we obtain that, for caesium, εA_1 ranges from 0.03 to 0.6 m^{-1}. Smith et al., (2002) has related the values of εA_2 and εA_3 to the fraction of organic soil in the catchment according to the following formulae

$$\begin{aligned} \varepsilon A_2 &= a(1 - f_{org}) + b f_{org} \\ \varepsilon A_3 &= c(1 - f_{org}) + d f_{org} \end{aligned} \tag{3.22}$$

The suggested values for the parameters in the previous formulae were $a=3x10^{-3}$, $b=5x10^{-2}$, $c=2x10^{-4}$ $d=2x10^{-3} \cdot m^{-1}$. The above evaluations were obtained by assessing experimental concentrations of ^{137}Cs from catchments of many European lakes following the Chernobyl accident. Similar assessments for ^{90}Sr suggest that εA_1 ranges from 0.2 to 4. m^{-1} and that estimates of εA_2 and εA_3 obtained by fitting equation (3.17) to measurements from several catchments in Europe are as follows:

$\varepsilon A_2 = 2x10^{-2} \cdot m^{-1}$ (organic soils) and $5x10^{-3} \cdot m^{-1}$ (mineral soils)

$\varepsilon A_3 = 5x10^{-3} \cdot m^{-1}$ (organic soils) and $3x10^{-3} \cdot m^{-1}$ (mineral soils).

In a study of ^{90}Sr concentration in 11 rivers in Italy Monte (1997) observed an average value of $\varepsilon A_2 = 9x10^{-3} \cdot m^{-1}$ with a range from $6x10^{-3} \cdot m^{-1}$ to $1.6x10^{-2} \cdot m^{-1}$ and suggested a value of $\varepsilon A_3 = 4x10^{-3} \cdot m^{-1}$.

More recent studies by Smith et al. (2003) suggest the following experimental evaluation of the parameters in equation (3.17):

A_1= 0,905, A_2= 0,09, A_3= 0,005

for caesium and

A_1= 0,984, A_2= 0,012, A_3= 0,004

Assessed values of ε are as follows:

0,0106(%inland water)+0,063 m^{-1} (caesium)

0,146(%inland water)+0,528 m^{-1} (strontium)

It seems clear that, from the above formulae, the migration of strontium is one order of magnitude larger that the caesium. Such a result is supported by considerable experimental evidence.

We have emphasised that the transfer function can be turned into compartment models. Such an approach was used to develop the sub-model of river catchment in model MARTE (Monte, 2001). In addition to the described empirical approach, attempts to assess the role that different components of a catchment can play in relation to the pollutant migration mechanisms were also carried out.

The "mechanistic" model ECOPRAQ (Håkanson et al., 2002),that is implemented in the MOIRA Decision Support System (Monte et al, 2000), comprises two main compartments for predicting the radionuclide inflow to a lake from its catchment (figure 3.15):

$$\begin{aligned}\frac{dMIA}{dt} &= -(\lambda+k_1+k_{12})MIA+D_{mia}(t)\\ \frac{dMOA}{dt} &= -(\lambda+k_2)MOA+k_{12}MIA+D_{moa}(t)\end{aligned} \qquad (3.23)$$

where

$$\begin{aligned}k_1 &= R_{IA}(1-D_{OAW})\\ k_{12} &= R_{IA}D_{OAW}\\ k_2 &= R_{OA}\end{aligned} \qquad (3.24)$$

the above terms are as follows:

MIA: (≈ dry land) is the so called inflow area dominated by vertical transport processes, through the soil horizons, the ground water transport and, finally, the tributary transport to the lake;

MOA: (≈ wetlands) is the so called outflow area dominated by a fast turnover of substances and horizontal transport processes;

D_{mia} and D_{moa} are, respectively, the fallout intercepted by the inflow and outflow areas;

λ is the radioactive decay constant;

D_{oaw} is a distribution coefficient partitioning the flow from inflow area either to outflow area or directly to the lake;

R_{IA} and R_{OA} are, respectively, the migration rate from the inflow area and the outflow area.

Following a single pulse of deposition corresponding to an initial amount MIA(0) and MOA(0) in the two catchment compartments the solutions of equation (3.23) are as follows:

$$\begin{aligned} \mathrm{MIA}(t) &= \mathrm{MIA}(0)\,e^{-(k_1+k_{12}+\lambda)t} \\ \mathrm{MOA}(t) &= \left(\mathrm{MOA}(0)+\frac{k_{12}\mathrm{MIA}(0)}{k_1+k_{12}-k_2}\right)e^{-(k_2+\lambda)t}-\frac{k_{12}\mathrm{MIA}(0)}{k_1+k_{12}-k_2}\,e^{-(k_1+k_{12}+\lambda)t} \end{aligned} \qquad (3.25)$$

consequently the flux from the catchment is

$$\mathrm{TF}(t)=\mathrm{MIA}(0)\left(k_1-\frac{k_2k_{12}}{k_1+k_{12}-k_2}\right)e^{-(k_1+k_{12}+\lambda)t}+k_2\left(\mathrm{MOA}(0)+\frac{k_{12}\mathrm{MIA}(0)}{k_1+k_{12}-k_2}\right)e^{-(k_2+\lambda)t} \qquad (3.26)$$

The model is structurally similar to the models derived from the Transfer Function approach when MOA(0)=0. Therefore, the models can be easily harmonised by tuning the parameters in equations (3.23) with the parameters of the TF (3.17).

The ECOPRAQ model includes sub-models that relate the values of the above parameters to certain prevailingly environmental and seasonal conditions such as precipitation and soil characteristics in the catchment and to the radionuclide properties such as the fixation to soil.

As seen in the previous paragraph, the models based on the assessment of radionuclide mobility from partition coefficient predict higher effective decay rates of ^{90}Sr concentration in water than for ^{137}Cs. This is in contrast to experimental results. Such a difference may be explained supposing that the interaction of radiocaesium with soil particles in the catchment is, at least partially, a non-reversible process. This implies that the concentration of radiocaesium in runoff water declines more quickly than the radiostrontium concentration. Indeed, the amount of radionuclide irreversibly fixed to the soil particle that is not available to the migration increases in the long term. At any rate, it is also surprising that, despite the large differences between the ranges of values of partition coefficients for radiocaesium and radiostrontium, the effective decay rates (λ_i) of those radionuclides (see table 3.3) are not so dramatically different. Moreover such effective decay constants are of the same order of magnitude of 1/T where T is the centroid of the time interval during which the relevant exponential component in the Transfer Function is the most significant. Such a result can be also explained by a statistical assessment of radionuclide contributions accounting for the large number of sub-catchments constituting the catchment that have differing properties (see Appendix). This can be useful to construct models for predicting the migration of contaminants from catchments. It suggests, moreover, that the transfer factor ε, rather than the effective decay rates λ_I, is the main factor influencing the uncertainty of model predictions.

Unfortunately, the assessed models do not account for the important seasonal effects related to the ice and snow melting in the catchment. These processes can be of significant importance in high mountain catchments such as those located in the Alpine region. It is well known that radionuclides stored in the snow pack or in glaciers become available to the migration during the melting season. As Chernobyl accident happened at the end of April when the melting process was occurring, the estimated transfer functions TFs (3.14) and the derived models (3.20) do not account for the effects that a delayed ice and snow melting may have had on the radionuclide migration.In any case, such an effect can be, at least in principle, easily modelled by including a radionuclide storage compartment whose content become available to the migration when ice and snow melt.

Empirical/statistical models and environmental properties

It is evident that many factors and processes can influence the variability in radionuclide concentrations in water and biota within and among aquatic systems. But they cannot all be of equal importance for the predictions of the target y-variable. Statistical methods can be used to provide a ranking of different x-variables influencing a target y-variable. Table 3.5 gives (based on data from 14 Swedish lakes; see Andersson et al., 1991; Håkanson, 1991; Håkanson and Andersson, 1992) an r-rank table (based on linear correlation coefficients of absolute values) for the concentration of radiocesium in pike (Cs_{pi88}) in 1988 (i.e., 2 year after fallout) in relation to different parameters describing the catchment area, Rock% is the percentage of bare rocks in the catchment area, ADA = the area of the drainage area in m^2, RDA = the relief of the catchment area, Open land% is the percentage of open (= cultivated land).

All catchment parameters could, potentially, influence the runoff of cesium from land to water and hence also cesium levels in fish. It should be noted that some of the potential factors appear with higher r-values vs Cs_{pi88}, like Rock% ($r = 0.40$), and some with very low r-values (e.g, relief and Open land%). One must also note that many of the catchment variables are related to one another, so it is not easy to make mechanistic interpretations of the correlations given in table XA.

Note also that there exist great differences in the representativeness and reliability of empirical data. All water chemical variables vary with time and sampling location. Characteristic CV-values (coefficient of variation, CV = MV/SD, MV = mean value, SD = the standard deviation) for many important variables for this radiocesium model, like radiocesium concentrations in fish, water and sediments and many water chemical variables have been listed by Håkanson (2000). Catchment area parameters can often be determined very accurately ($CV \approx 0.01$ to 0.05); some model variables, like rates and distributions coefficients, on the other hand, cannot be empirically determined at all for real ecosystems, but have to be estimated from laboratory tests or theoretical derivations. This means that the values used for such model variables are often very uncertain.

The highest reference r^2, r_r^2, (see Håkanson, 1999 for further information) may be used as a simple, general tool in modelling to obtain a reference r^2 related to the variability/uncertainty in the target y-variable (for within system variations), where:

$$r_r^2 = 1 - 0.66 \cdot CV^2 \qquad (3.27)$$

The practical use of r_r^2 is illustrated below using characteristic CV-values for actual values (and not transformed, e.g., logarithmic values) of radiocesium concentrations in lake water, fish and sediment:

Variable	CV	r_r^2
Cs-concentration in fish	0.22	0.97
Cs-concentration in water	0.30	0.94
Cs-concentration in sediments	0.60	0.76

Table 3.5 gives a statistical model using Cs_{pi88} as target y-variable and catchment area, lake morphometric and water variables as x-variables. This is also a ranking of how the different x-variables influence the y-variable. Note that the concentration of ^{137}Cs in water in 1987 is the most important x-variable. This variable explains statistically approximately 78% ($r^2 = 0.78$) of the variability in the y-variable (Cs_{pi88}) among these 14 Swedish lakes. The next factor is the potassium concentration of the lake water (the mean annual K-value for 1987 is used). At the second step, the r^2-value has increased to 0.89. The third x-variable is the Open land percentage (Ol%, a measure of the cultivated land) of the catchment. Accounting for Ol% increases r^2 to 0.92. The fourth and last x-variable is lake total-P concentration (mean value for 1987). It increases r^2 to 0.93, which is close to the theoretically highest r^2 for lake fish of 0.97.

These are statistical results, and a central part in the derivation of the lake model used in this work was to account for mechanistic principles expressed by the empirical results given in table 3.5. The empirical model is static, i.e., it is only valid for the Cs-concentration in pike caught in 1988 two years after the Chernobyl fallout. Most model in radioecology are dynamic, i.e., they provide time-dependent predictions not just for pike, but for many species of fish with different feeding habits, for many different types of lakes and for different fallout scenarios.

There is a basic approaches to transform a statistical approach into a dynamic approach (see Håkanson, 1991). They, we have:

$$C_X(t) = C_X(t0) \cdot EXP(-k \cdot t) \qquad (3.28)$$

where the coefficient k may be calculated as function of catchment area features (CAF) using statistical methods, i.e., $k = f(CAF_1, CAF_2, CAF_3,....CAF_n)$. This approach has been elaborated by Håkanson (1991) and the aim of the following section is to give a brief outline of that approach. $C_X(t)$ is the concentration of the substance X in water at time t.

Using data from Håkanson (1991), table 3.5 presents some new results to illustrate the approach. The target y-variable is empirical Cs-concentrations in lakes in 1987 (Cs_{wa87} in Bq/l; there are data from 15 Swedish lakes). Table X2A gives a "ladder" (from stepwise multiple regressions) ranking the catchment area features influencing the variability among these lakes in Cs_{wa87}. One can note that fallout (Cs_{soil} in Bq/m^2) can statistically explain 59% of the variability in the target y-variable. This is easy to understand. The next most important factor (the tested ones are listed at the bottom of table X"), is the percentage of fine sediments in the catchment area (FS%) - the more fine sediments in the catchment, the greater the fixation and the lower the transport from land to water. The third factor is the percentage of upstream lakes (Lake%), a major component of the outflow areas - the more upstream lakes, the quicker the transport of cesium deposited in the catchment upstream the given lake. These results are all logical and can be interpreted in a mechanistic manner, but they are basically statistical.

Table 3.5 gives an r-ranking (using liner correlation coefficients, r) to see which catchment area features correlate to the constant k in eq. z2. One can note that the highest r-value appears for the percentage of basic rocks, but that the r-value is rather low (0.4; $r^2 = 0.16$) and that all other correlations are weak. So, with this data-set (n = 15), it was not possible to derive any statistically significant regression model for k based on the tested catchment area features. However, when tested against all empirical data on $Cs_W(t)$ for these 15 lakes, the k-value = -0.095 gave the best fit. This means that eq. 6 may be written as:

$$C_X(t) = (Cs_{soil}/D_m)\cdot EXP(-0.095\cdot t) \qquad (3.29)$$

where Cs_{soil} is the fallout (Bq/m^2) and D_m is the lake mean depth (volume/area in m). This gives $C_X(t)$ in Bq/m^3. When tested, one ne can note that this is a very simple statistical approach and it will also fail to give good predictions in many lakes. An important reason for this failure is that this eq. z3 does not account for catchment area conditions, only fallout and lake mean depth.

Aspects of spatial variation and scale

Radionuclide migration from catchments can be studied and modelled at various spatial scales ranging from the large continental scale down to the small scale of an experimental plot. To simulate radionuclide migration at all these scales, it is essential to understand and quantify the nature of the major hydrologic pathways (e.g. length, tortuosity, and flow rates), and mixing and retention (sorption, deposition, and decay) along these pathways. The spatial variation of the driving forces within the extent of the model area may be taken into account, depending on the purpose of the model. In spatially distributed models, the model input and output are defined at a resolution ranging from tens of square metres to several square kilometres, whilst in lumped models the model resolution equals the size of the model area. In most cases, the model parameter values are scale-dependent, which means that they vary with model resolution. The physical size to which a parameter value refers is often termed support (Bierkens et al., 2001). Thus, the model parameter values for lumped models are different from those for spatially distributed, which, in turn, are different from the values derived from field or laboratory measurements and in most cases they do not equal the spatial mean value. This can be elucidated by means of figure ? that represents different spatial distributions of radionuclide activity concentrations in the topsoil layer of a hypothetical catchment. Nevertheless, the spatially averaged value of the activity concentration is the same for the four situations. Assuming equilibrium between the activity concentrations in the topsoil and runoff water, the activity concentration in the runoff water can be estimated by:

$$C_w = \frac{C_s}{Kd} \tag{3.30}$$

where C_w = radionuclide activity concentration in the dissolved phase (Bq l^{-1}), C_s = radionuclide activity concentration in the topsoil layer (Bq m^{-3}), and *Kd* = distribution coefficient (l kg^{-1}). However, the spatially averaged activity concentration in water is not equal to the mean activity concentration in the topsoil divided by the mean *Kd* value:

$$\overline{C}_w = \frac{\overline{C}_s}{\overline{Kd}} \tag{3.31}$$

Thus, an appropriate scaling of the *Kd* value is indispensable. This can be achieved by geostatistical upscaling methods from the measurement support to the model support or by calibration of the *Kd* value at the model scale.

In some cases, the spatial variation of the processes within the model elements, which control the transport of radionuclide through catchments and river networks, becomes so large that it may be inappropriate to represent these processes by single model parameters and variables. This may become apparent in a one-dimensional river model in which the radionuclide activity concentration in the river water is a state variable depending on the exchange with the dissolved phase and deposition of suspended matter and sediment-associated radionuclides. The hydraulic part of these one-dimensional models commonly calculates the cross-sectional averaged flow velocity and water depth. The deposition rate of suspended matter depends on the shear stress, which in turn, depends on the water flow velocity. Because the flow velocities and water depths are much smaller in the floodplains away from the main river channel than in the river channel itself, it is very likely that processes and environmental conditions in the floodplains are, on balance, more important controls for the migration of radionuclides through the river system than those in the river channel. However, the processes and environmental conditions in the floodplains are generally poorly represented by the cross sectional averaged model parameters.

The model approaches used in the MARTE and ECOPRAQ models described above consider only long-term migration of radionuclides in the dissolved phase. The proportion of dissolved transport relative to the total radionuclide transport can be estimated from:

$$\alpha = \frac{1}{Kd\ SS + 1} \tag{3.32}$$

where α = proportion of dissolved radionuclide transport [-], Kd = distribution coefficient [$L^3\ M^{-1}$], SS suspended sediment concentration in water [$M\ L^{-3}$]. From this equation it appears that particulate becomes important with increasing suspended sediment concentration. For example, given a Kd of 8 kg l^{-1}, radionuclide transport occurs predominantly in particulate form if the suspended sediment concentration in water is greater than 125 mg l^{-1}. In rivers, such suspended sediment concentrations arise frequently during flood events. Consequently, particulate radionuclide transport may especially be important in small catchments where flood events contribute substantially to total runoff. However, Van der Perk and Slávik (2003) demonstrated that the transfer of particulate matter from hillslopes to the river network is particularly difficult to predict, because this transfer often occurs only a limited number of sites and depends on local-scale topographical features, such as for example small embankments, roads, hedges, and puddles.

In general, models to simulate radionuclide migration through and from catchments are available. However, the major bottleneck is the lack of appropriate model input data at the appropriate scale. Default parameter values can often be derived from the literature, but their relation to the model scale remains obscure.

Conclusions

The migration of toxic substances from terrestrial environments to surface waters involves many complex processes of hydrological, physical and geochemical nature. Modelling the transfer of contaminant from catchments to water bodies is therefore a major challenge for modellers.

Models based on a detailed assessment of the above processes come across many difficulties related to imprecise and limited knowledge of phenomena occurring at site-specific level and to the uncertainty of the quantities that parameterise these phenomena. It is therefore essential to develop approaches that allow one to develop simplified and generic models characterised by reasonable accuracy.

Such approaches were implemented by many modellers taking advantage from the experimental evidences following the introduction into the environment of radionuclides from the nuclear explosion in atmosphere of past decades and the Chernobyl accident . The main idea was based on the identification of short- and long-term migration processes that can be modelled by first order compartment systems. The developed models were composed of two or three compartments. Many studies were carried out for assessing the values of the migration parameters in these models. Following the Chernobyl accident more accurate estimates of these parameters become available and general methodologies for their assessment were proposed.

The "holistic" approaches to model the radionuclide migration from catchment described in the present report gave encouraging outcomes for many gamma-emitting radionuclides and for ^{90}Sr. The usefulness of the application of "Reductionistic" models seems questionable, also in view of the results of validation exercises (BIOMOVS II 1996).

As the developed models show similar structures it seems reasonable to undertake their harmonisation and rationalisation.

Many important lessons can be learnt from the above model assessment. First of all, wise application and use of predictive environmental models require that users must be fully aware of the model performances mainly in relation to the output uncertainties and how these are reflected in the decision making process.

It is unwise and dangerous to inspire in the potential users expectations on the accuracy and completeness of model output that are not supported by the experience gained during model testing and validation. During the last decades model exercises and applications to ecosystems contaminated by radionuclides introduced in the environment following the major nuclear accidents have significantly contributed to increase the expertise of modellers. Such experiences are essential for the proper use of models to solve practical problems of environmental management.

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APPENDIX TO SECTION 3

Let be L an elementary component of a catchment (figure A1). Let us suppose that the soil in L shows homogeneous characteristics and, moreover, that the contaminant migrating through the catchment due to the surface water transport (surface runoff) is, prevailingly, confined in the upper layer of soil of thickness ζ. Such a hypothesis is true when the contaminant is characterised by high values of the partition coefficient (k_d). The distribution coefficient may be used as a first approach to evaluate the behaviour of pollutants, like radionuclides and heavy metals, in the system water-soil. We define:

Γ the area of L (m^2);

I(t) the pollutant inventory, at time t, in the soil upper layer of thickness ζ ($g\ m^{-2}$ or $Bq\ m^{-2}$ in case of radioactive substances);

Φ the average water flux per square metre flowing through the catchment ($m^3\ s^{-1}\ m^{-2}$);

ρ the soil density ($kg\ m^{-3}$);

ζ the thickness of the soil contaminated layer (m);

k_d the partition coefficient ($m^3\ kg^{-1}$);

C_w the concentration of the contaminant in the interstitial water ($Bq\ m^{-3}$ or $g\ m^{-3}$);

C_s the concentration of the contaminant attached to the soil particles ($Bq\ kg^{-1}$ or $g\ kg^{-1}$);

ω the volumetric content of water in L ($m^3\ m^{-3}$).

The inventory may be calculated as function of the concentration in the interstitial water:

$$I(t) = C_w \zeta \omega + C_s \zeta \rho = C_w \zeta (\omega + \rho k_d) \qquad \text{(A1)}$$

The contaminant flux, F ($g\ s^{-1}$ or $Bq\ s^{-1}$) , from the element L is

$$F = \Gamma \Phi C_w \qquad \text{(A2)}$$

The inventory is then controlled by the following first order differential equation:

$$\frac{dI(t)}{dt} = -\Phi \frac{I(t)}{\zeta(\omega + \rho k_d)} \qquad \text{(A3)}$$

If $k_d\rho >> \omega$ and I(0) is the initial inventory, which corresponds to the initial deposition, the contaminant flux from L is:

$$TF(t) = \frac{\Gamma\Phi}{\zeta\rho k_d} I(0) \exp(-\frac{\Phi}{\zeta\rho k_d} t) \qquad (A4)$$

Putting $\xi = \frac{\zeta}{\Phi}$ we get, in case of an unitary initial deposit,

$$TF(t) = \frac{\Gamma}{\xi\rho k_d} \exp(-\frac{t}{\xi\rho k_d}) \qquad (A5)$$

Equation (A5) is similar to the formula used by Joshi & Shukla (1991).

A large catchment is composed of an "ensemble" of sub-catchments characterised by different values of ξ, ρ and k_d. If A is the area of the catchment and $f(\xi\rho k_d)$ is the distribution function of $\xi\rho k_d$ in the catchment, the total flux of the contaminant becomes

$$TF(t) = A\int_0^\infty \frac{f(\xi\rho k_d)}{\xi\rho k_d} \exp(-\frac{t}{\xi\rho k_d}) d(\xi\rho k_d) \qquad (A6)$$

The previous formula shows that the TF is composed of an infinite number of infinitesimal exponential terms.

Putting $\xi\rho k_d = \frac{1}{\theta}$, equation (A6) may be written as follows:

$$TF(t) = A\int_0^\infty \frac{1}{\theta} f(\frac{1}{\theta}) \exp(-t\theta) d\theta \qquad (A7)$$

The (modelled) effective removal rate, $\lambda(t)$, of pollutant at time t is:

$$\lambda = -\frac{1}{TF(t)} \frac{dTF(t)}{dt} \qquad (A8)$$

After simple calculations, we get:

$$\lambda = \frac{1}{t} + \frac{1}{t}\frac{\int_0^\infty \theta g'(\theta)\exp(-t\theta)d\theta}{\int_0^\infty g(\theta)\exp(-t\theta)d\theta} \qquad \text{(A9)}$$

where $g(\theta) = \frac{1}{\theta} f(\frac{1}{\theta})$. The second term in the right hand side of the previous equation will scarcely affect the order of magnitude of λ, due to the presence of g'(θ) in the integral at numerator. Such derivative reaches, indeed, both positive and negative values that may mutually compensate when the function is integrated over (0, ∞), whereas g(θ) is a non-negative function.

Evaluations of λ from some distribution functions supply examples of applications of the described model (Monte, 1997; Monte, 1998).

It is quite obvious that a similar analysis can be carried out on the general hypothesis of a stochastic distribution of removal rates and that the initial concentration of radionuclide is proportional to such rates. This can be directly applied to the eroded soil particles from a catchment.

Table 3.1 Ranges of parameter values in the assessment of Helton et al. (1985)

Radionuclide	k_1	k_2 (s^{-1})
^{137}Cs	$0.1x10^{-2} – 1.9x10^{-2}$	$2.1x10^{-12} – 1.8x10^{-10}$
^{90}Sr	$0.5x10^{-2} – 12.2x10^{-2}$	$2.2x10^{-11} – 1.0x10^{-9}$
^{239,240}Pu	-	10^{-11} (few data available)

Table 3.2 Values of parameters of the model of Linsley & Dionian (1983)

	x(%)	y(%)	λ_1 (s^{-1})	λ_2 (s^{-1})
Sr	10	90	$1.6x10^{-8}$	$3.2x10^{-10}$
Cs	100	-	$3.2x10^{-11}$	
I	5		(assumed instantaneous)	

Table 3.3 - Review of measured values of TF parameters.

River	radionuclide	ε (m^{-1}) (order of magnitude)	A_2 (dimensionless)	α_2 (dimensionless)	standard deviation of α_2	$\lambda_1+\lambda$ (s^{-1})	standard deviation of $\lambda_1+\lambda$	$\lambda_2+\lambda$ (s^{-1})	standard deviation of $\lambda_2+\lambda$	reference
Po (a)	^{137}Cs	10^{-3} - 10^{-2}				2.3 x 10^{-7}	5.5x10^{-8}			Monte (1995) (c)
Rhine (a)	^{137}Cs	10^{-2} - 10^{-1}	0.052	0.53	0.3	6.5 x 10^{-7}	1.3x10^{-7}	2.7 10^{-8}	0.6 10^{-8}	Monte (1995)
Prypiat (a)	^{137}Cs	10^{-2} - 10^{-1}	0.035	1.08	0.06	5.2 x 10^{-7}	6.5x10^{-7}	1.8 10^{-8}	0.7 10^{-9}	Monte (1995)
Dnieper (a)	^{137}Cs	10^{-2} - 10^{-1}	0.028	0.86	0.06	8.8 x 10^{-7}	1.1x10^{-7}	1.1 10^{-8}	0.7 10^{-9}	Monte (1995)
Teterev (a)	^{137}Cs			0.96	0.15			8.2 10^{-9}	2. 10^{-9}	Monte (1995)
Uzh (a)	^{137}Cs			1.02	0.1			1.5 10^{-8}	1.8 10^{-9}	Monte (1995)
Inlets of Devoke Water(b)	^{137}Cs			1.0-1.3				1.2 10^{-8}		Hilton et al. (1993)
Inlets of lakes Hillesjön and Salgsjön (b)	^{137}Cs					.6 x10^{-7}- 1.5x10^{-7}	7.x10^{-9}- 2.x10^{-8}			Sundblad et al. (1991)
Po (a)	^{131}I					1.1 10^{-6}	6.5 10^{-8}			Monte (1995) (c)
Po (a)	^{103}Ru					4.7 10^{-7}	4. 0 10^{-8}			Monte (1995) (c)
Prypiat	^{90}Sr		0.048	1.41	0.08	9.0 10^{-7}	1.1 10^{-7}	4.9 10^{-9}	0.9 10^{-9}	Monte (1995)
Dnieper	^{90}Sr		0.166	1.4	0.08	5.2 10^{-7}	1.5 10^{-7}	5.5 10^{-9}	0.9 10^{-9}	Monte (1995)
Teterev	^{90}Sr			1.12	0.14			3.6 10^{-9}	2.1 10^{-9}	Monte (1995)
Uzh	^{90}Sr			1.31	0.09			5.9 10^{-9}	1.8 10^{-9}	Monte (1995)
Irpen	^{90}Sr							1.6 10^{-9}	-	Smith et al. (2002)
Ilya	^{90}Sr							2.7 10^{-9}	-	Smith et al. (2002)
Sakhan	^{90}Sr							3.8 10^{-9}	-	Smith et al. (2002)
Glinitsa	^{90}Sr							1.9 10^{-9}	-	Smith et al. (2002)

(a) dissolved radionuclide; (b) total ^{137}Cs (particulate+dissolved); (c) primary data used for fitting from Queirazza & Martinotti (1987):data fitted to a single exponential function.

Table 3.4 - Measured values of some parameters of TF (particulate caesium)

River	α_2 (dimensionless)	95% confidence limit (up) of α_2	95% confidence limit (down) of α_2	$\lambda_2+\lambda_r$ (s^{-1})	95% confidence limit (up) of $\lambda_2+\lambda_r$	95% confidence limit (down) of $\lambda_2+\lambda_r$
Danube	2.44	2.98	1.90	$1.4x10^{-8}$	$2.2x10^{-8}$	$6.7x10^{-9}$
Uzh	1.02	1.39	0.65	$1.1x10^{-8}$	$1.8x10^{-8}$	$4.0x10^{-9}$
Teterev	1.34	1.77	0.97	$1.2x10^{-8}$	$1.8x10^{-8}$	$6.0x10^{-9}$
Prypiat	1.52	1.70	1.34	$1.4x10^{-8}$	$1.6x10^{-8}$	$1.3x10^{-8}$
Dnieper	1.24	1.37	1.00	$1.2x10^{-8}$	$1.4x10^{-8}$	$1.1x10^{-8}$
Desna	1.11	1.39	0.83	$8.9x10^{-9}$	$1.3x10^{-8}$	$4.7x10^{-9}$
Rhine	1.12	1.97	0.27	$1.7x10^{-8}$	$2.4x10^{-8}$	$1.0x10^{-8}$
Geometric mean	1.34			$1.2x10^{-8}$		

Table 3.5. A. r-rank table (showing linear correlation coefficients, r); data from 14 lakes on cesium in pike 1988 (Cs_{pi88} in Bq/kg ww) versus different catchment variables.
B. "Ladder" from stepwise multiple regression using cesium in pike 1988 (Cs_{pi88} in Bq/kg ww) as target y-variable and testing different catchment area, lake morphometric and lake water variables to statistically explain the variability among 14 lakes in Cs_{pi88}-values. From Håkanson (1991).

A. r-rank; n = 14	Cs_{pi88}
Rock%	0.40
ADA	0.37
RDA	0.12
Open land%	-0.11

B. Ladder; $y=Cs_{pi88}$; n = 14

Step	Variable	r^2-value	Model
1	Cs_{wa87}	0.78	y=9479·x1+769
2	K	0.89	y=9559·x1-170.6·x2+2524
3	Open land%	0.92	y=9685·x1-249.5·x2+172·x3+2804
4	total-P	0.93	y=9259·x1-226.4·x2+191.6·x3-224.6·x4+4939

Rock% = percentage of rocks in the catchment; ADA = area of drainage area; RDA = relief of catchment area; Open land in % of ADA (= Ol%); Cs_{wa87} = total concentration of ^{137}Cs in lake water (Bq/l); K-concentration in lake water (μeq/l); total-P concentration in lake water (μg/l).

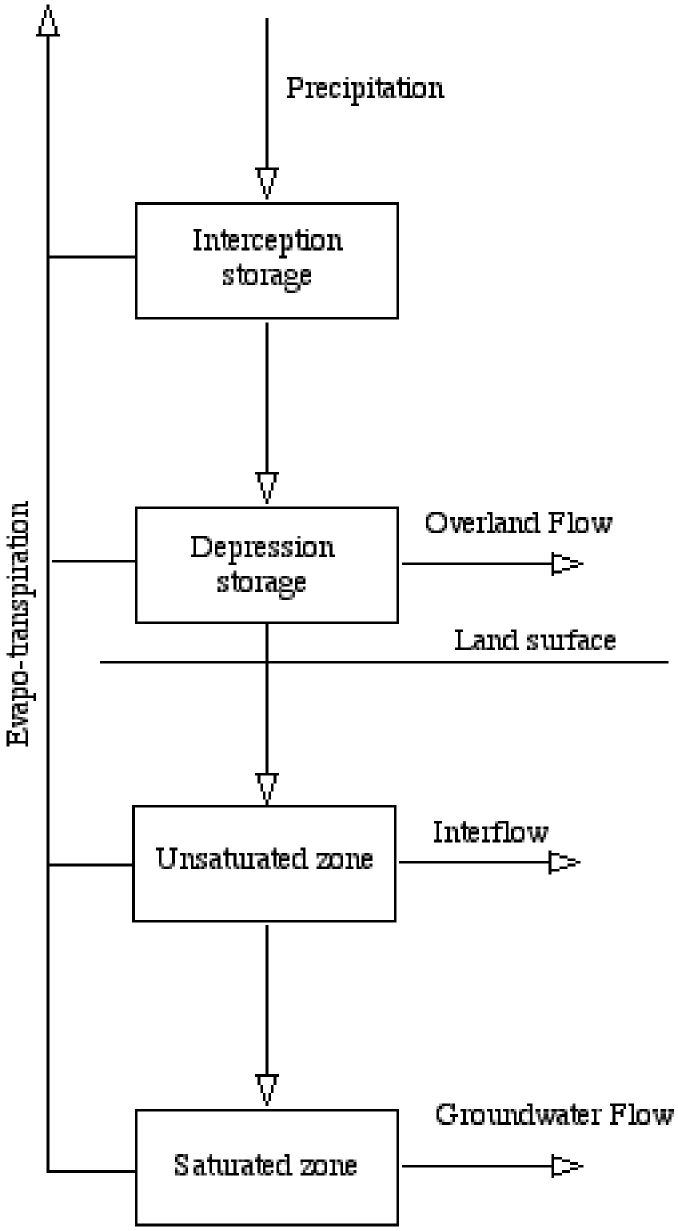

Figure 3.1 Main hydrological processes of water transport and balance that control the migration of radionuclides from a catchment (Kivva & Zheleznyak, 2000).

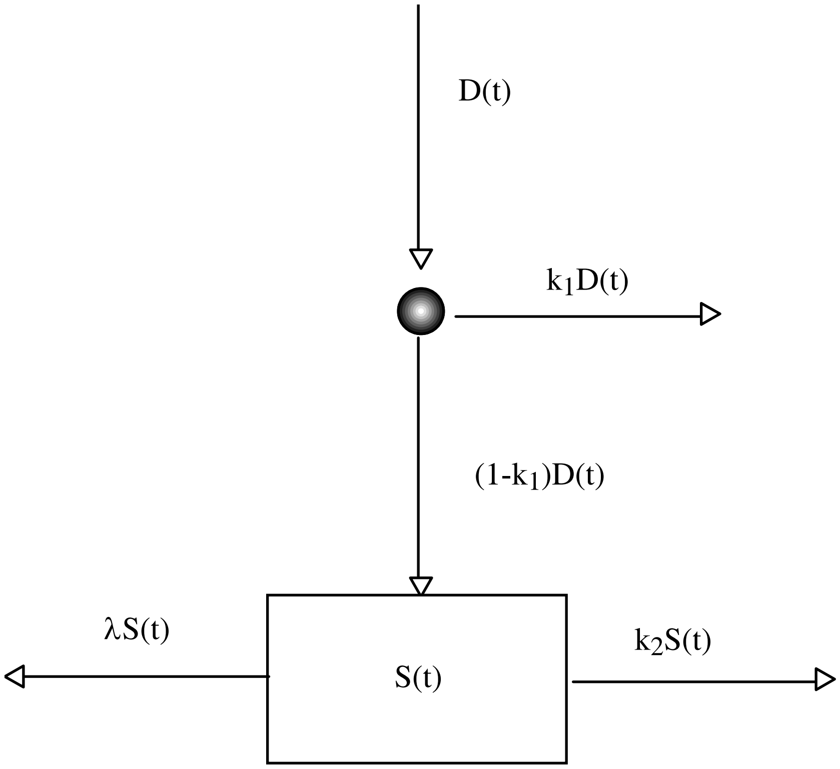

Figure 3.2 General structure of models for predicting the migration of radionuclides from catchments to water bodies following the assessment of data from nuclear weapon test fallout.

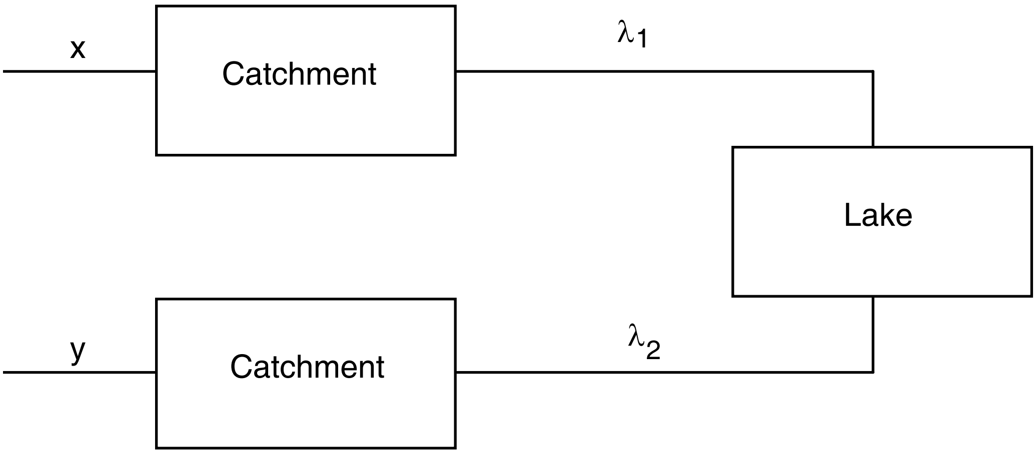

Figure 3.3 Box model of models for predicting Sr and cs migration from catchment. (Linsley & Dionian, 1983)

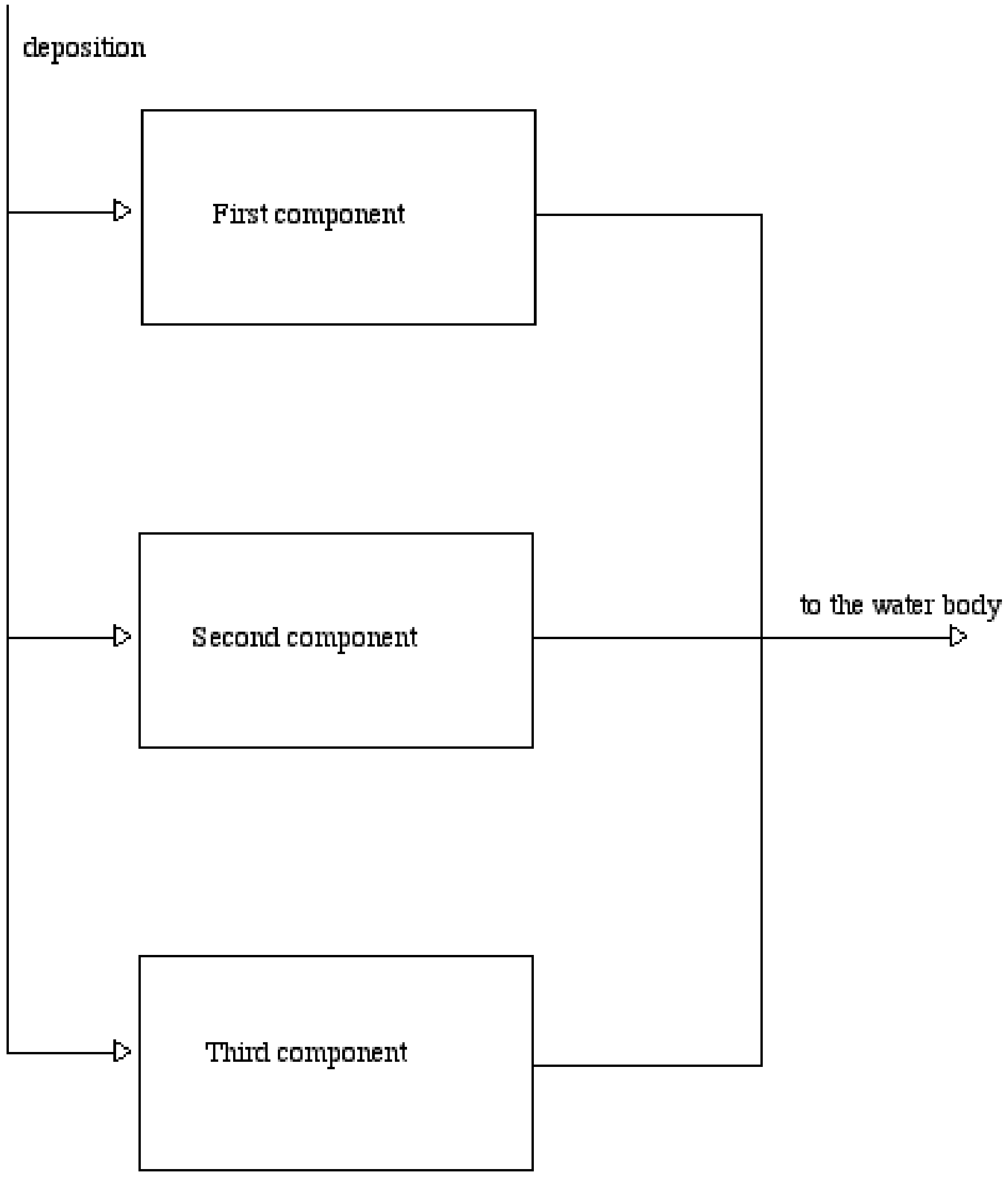

Figure 3.4 catchment sub-model in model MARTE (Monte, 2001)

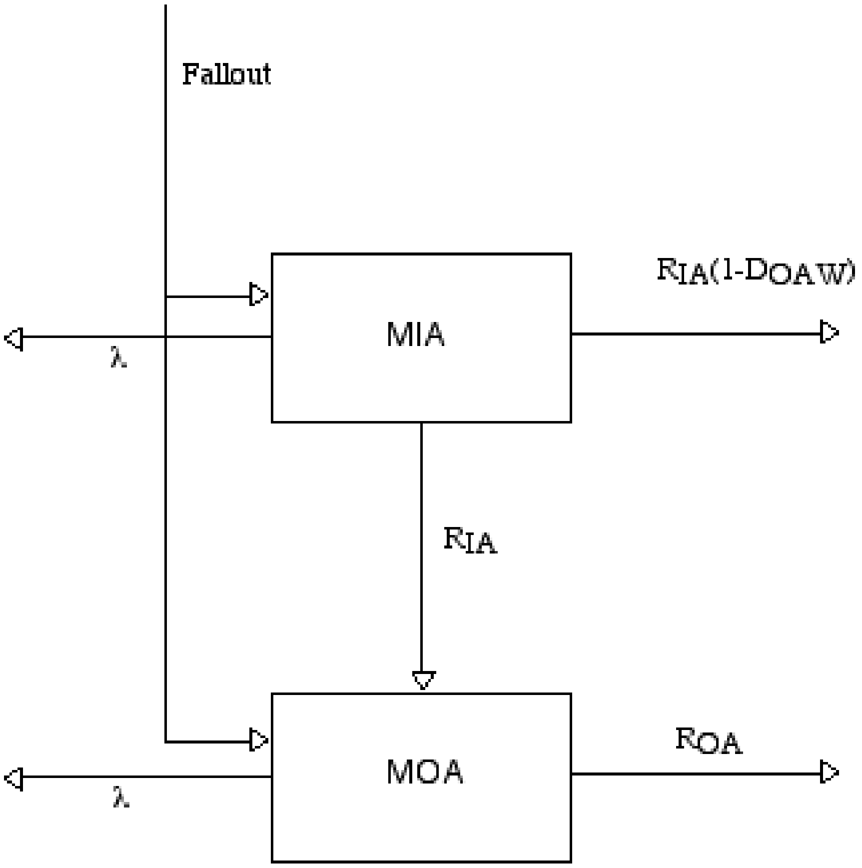

Figure 3.5 ECOPRAQ-MOIRA model for catchment (Håkanson et al., 2002)

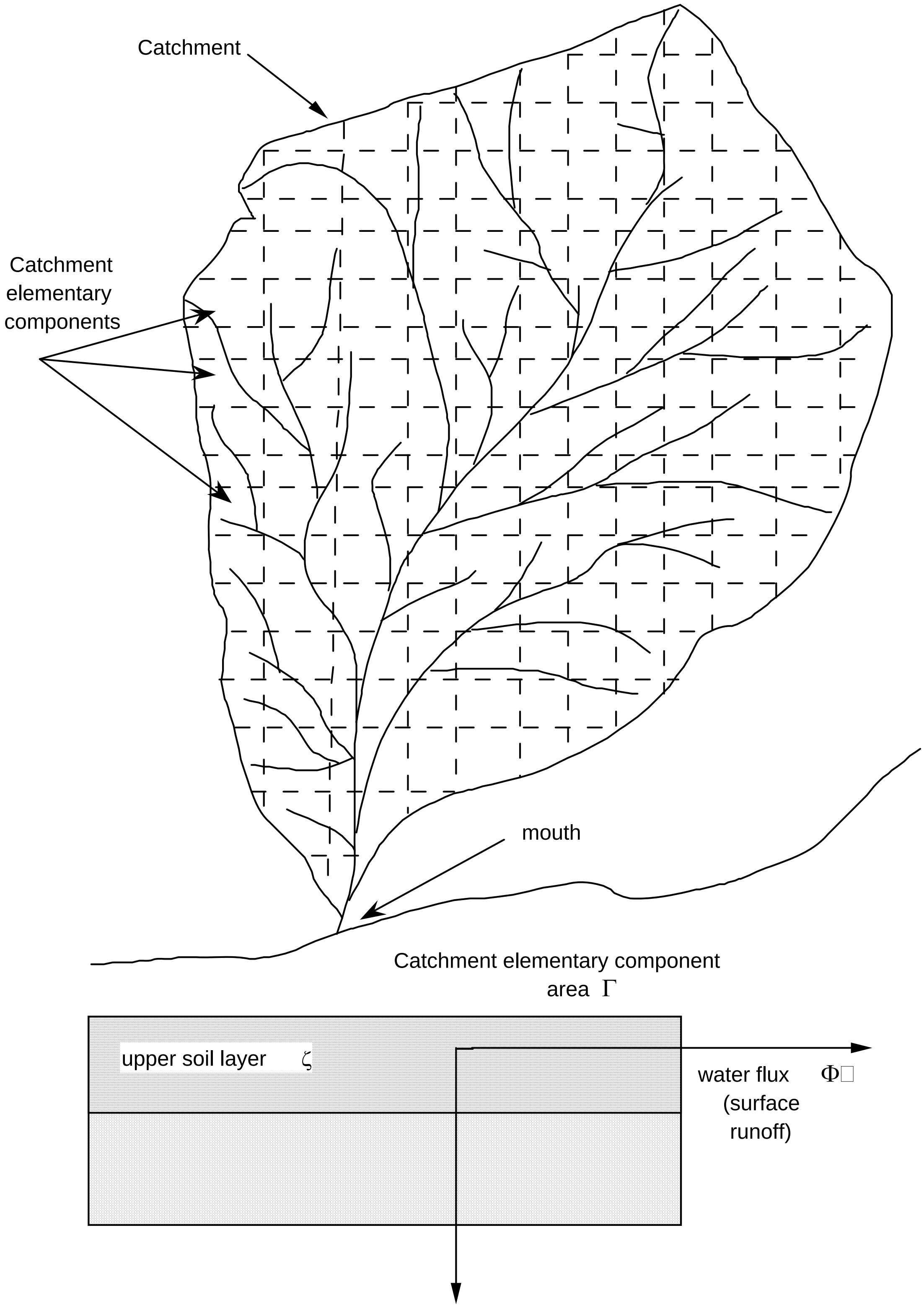

Figure A1 – A catchment is considered as composed of a set of sub-catchment of area Γ each showing specific characteristics.

SECTION 4: RIVERS

REVIEW AND ASSESSMENT OF MODELS FOR PREDICTING THE MIGRATION OF RADIONUCLIDES THROUGH RIVERS

Introduction

Rivers are complex ecosystems of significant economic, social and environmental value. Models for predicting the behaviour of pollutants in rivers are of paramount importance for the management of such water bodies in a suitable environmental perspective. On the other hand, the development of these models is a challenge for the modellers owing to the complicated web of interacting processes that control the migration of toxic substances in lotic ecosystems.

Modelling the behaviour, the consequences and the effects of contaminants in rivers requires, in principle, the quantitative assessment of phenomena of hydraulic, geo-chemical, sedimentological, ecological and anthropogenic nature.

The overall structure of such models comprises the following sub-models:

a) modules for predicting the hydrological, the hydraulics and the biotic processes that occur in the river ecosystem (such as water fluxes and current velocities, erosion-sedimentation processes and suspended matter in the water column, growth rate of organisms and species, etc.) and that are supposed to influence the contaminant migration;

b) modules for predicting the radionuclide transfer:

  a. to the river from its catchment;
  b. through the abiotic components of the river;
  c. from the abiotic components to the biota.

c) modules for predicting doses to man and the impact of contamination (and, eventually, of countermeasures actions) on the river ecosystem.

Hydraulics processes are mainly responsible of the transport and the diffusion of toxic substance through the water, whereas geo-chemical processes influence the interaction of dissolved radionuclide with suspended matter and bottom sediments. Sedimentation and resuspension are of important for controlling the two-ways migration of radionuclide from the water column to the bottom sediments and vice-versa. Models for predicting the migration of radionuclides through the food web are based on general approaches and methodologies that are, in principle, similar to the ones used for predicting the behaviour of radionuclides in the biotic compartments of lacustrine ecosystems.

The aim of the present report is the assessment of models aimed at evaluating the contamination levels of river ecosystem componentss. The assessed models, AQUASCOPE (Smith et al., 2000), MOIRA-MARTE (Monte, 2001), RIVTOX (Zheleznyak et al., 1992), CASTEAUR (Duschesne et al., 2003), RIPARIA (Lepicard, 2001), AQUASTAR (Smith et al.,2003), U.U. (Håkanson, 2003) and their main features are listed in Table 4.1 and are described in the annex 1: “EVANET-HYDRA network – Description of the assessed river models”.

The above models are state-of-the-art products reflecting the level of development of the specific sector not only in Europe but in a worldwide perspective as well. For instance model RIVTOX was the result of a collaboration between the Ukrainian Institute of Mathematical Machines and System Problems and the Pacific Nortwest Laboratoty (USA).

Overview of the basic migration processes and relevant modelling approaches

The migration of contaminants in rivers is controlled by three main processes:

1) Diffusion of the dissolved pollutant within the water due to chaotic molecular movements and to the turbulent motion of water;
2) Transport caused by the water current;
3) Interaction of pollutant with sediments and suspended matter and consequent transport.

These processes are modelled by well-known equations. In addition, the migration from the river catchment is an important source of contamination following the deposition of radionuclides over large areas. Finally, the contamination of the abiotic components of a river ecosystem implies the pollution of biota and the consequent transfer to man through the human food chain in addition to direct transfer via drinking water.

Diffusion

The pollutant flux, F (Bq m^{-2} s^{-1}), due to molecular and to water turbulent motion (eddy diffusion) can be related to the concentration gradient from equation (4.1) corresponding to the Fick's first law for the molecular diffusion and to an analogical form for the eddy diffusion:

$$F = -K^{*}\frac{\partial C}{\partial x} \qquad (4.1)$$

The constant K* is called the diffusion (dispersion) coefficient (m^2 s^{-1}). C is the concentration (Bq m^{-3}) and x is the distance (m). The sign "-" in equation (4.1) implies that the pollutant flux is always directed to the region of low contaminant concentration. In principle, diffusion process is due to the thermal motion of the molecules. Nevertheless, diffusion of pollutant due to turbulent motion of water is modelled by equation (4.1) as well. The order of magnitude of coefficient K* ranges, ordinarily, from 10^{-10} to 10^{-8} m^2 s^{-1}. Turbulent motion of water is responsible for apparently higher values of K*. Indeed the turbulent-diffusion coefficient is many orders of magnitude larger than the molecular-diffusion coefficient.

Equation (4.1) can be generalised accounting for anisotropic processes of diffusion in the three dimensions. In such a case K* is a 3x3 component symmetric tensor (the diffusion tensor). Anisotropic diffusion can be important in very deep and large water bodies. Such a process is modelled in different ways by the assessed models. Along the river, different simplifications are possible according the hydraulic conditions. Spatial simplifications are possible in function of the mixing conditions. These conditions are related to the geometrical and flow characteristics of the river. If we admit that the width (distance between the banks) is one hundred times the depth, the vertical mixing is fairly complete before the transversal one. This last, is faster than the longitudinal one. So, for a given release, it is possible to identify different mixing areas. Some meters near the emission, the mixing process is three-dimensional and no spatial simplifications are possible. After about ten to hundred meters, it is possible to admit that the vertical mixing is complete. After about hundred to thousands meter, the transversal mixing is also complete. Mono-dimensional models can be applied in the mixing area, where the vertical and the lateral gradients of concentration are negligible. Finally, box models hypothesise a complete dilution in a reach of the river. In that case, the fluxes by diffusion are not considered because the gradients of concentration are supposed negligible. These models are associated with the hypothesis of equilibrium or semi-equilibrium conditions and their time step have to be coherent with the necessary dilution time according the hydraulics conditions and the box size.

The choice of the model type depends on the domain of applicability of the model. For instance, model WATOX (an hydrodynamic sub-model implemented in RODOS Computerised Decision Support System) makes use of the generalised transport-diffusion equation based on the diffusion tensor. AQUASTAR calculates the transverse dispersion in large river by introducing a “transverse dispersion” coefficient that is related to the longitudinal dispersion coefficient by a suitable semi-empirical relationship.

Values of the diffusion coefficients for many rivers in North America are reported in IAEA, 2001. These values were obtained by semi-empirical formulae accounting for river width, flow velocity, water depth and the so-called “shear velocity”. The suggested values of the longitudinal diffusion coefficient range from $7.6\text{x}10^{-1}$ to $1.5\text{x}10^{3}$ m^2 s^{-1}, whereas the lateral dispersion coefficient ranges from $5.\text{x}10^{-3}$ to 1.1 m^2 s^{-1} depending on the river characteristics. AQUASTAR makes use of values of the longitudinal dispersion coefficient that, in river Thames, range from 1 to 26.3 m^2 s^{-1} according to a site-specific experimental-based assessment, whereas, dispersion coefficients in other rivers are estimated by an empirical model (Won Seo et al. 1998) which is based on US dye tracer measurements. The corresponding values of K range up to 1486.45 m^2 s^{-1}.

Transport

The pollutant flux due to water transport is related to the concentration C and to the water velocity U (m s^{-1}) by the following equation:

$$F = U \cdot C \tag{4.2}$$

Formula (2) was obtained by dividing the total amount of substance flowing, per unit time, through a surface S by the surface area.

As for the diffusion, equation (4.2) can be generalised to three-dimensional, time dependent transport processes. Simplifications are possible according different hypothesis on the hydraulics conditions: homogeneous hypothesis (the current velocity does not depend on the spatial co-ordinates); permanent hypothesis (the velocity is constant with time); bi-dimensional and mono-dimensional approaches; box approach. As for the diffusion, the selection of the more appropriate simplification depends on the applicability domain of the model.

The equations for the diffusion and the transport fluxes are used to assess the spatial distribution of radionuclides.

Some models, like MOIRA and RIPARIA, which are aimed at evaluating the average concentration of radionuclide within each reach of the watercourse, do not simulate the diffusion processes. They model the water transport process by the assessment of the input-output balance of water flowing to and from each reach hypothesising a homogeneous distribution of pollutant within each box.

The aim of MOIRA is to predict the medium and long-term transport process within the river ecosystem. The river model model subdivides the river in 20 reaches. To estimate the effect of diffusion on the distribution of a pollutant in a reach the diffusion coefficient can be determined by means of some empirical formulae suggested by IAEA, 2001:

$$\begin{aligned} K &= \frac{U \cdot W^2}{3 \cdot h} \\ h &= 0.163 \cdot q^{0.447} \\ W &= 10 \cdot q^{0.460} \\ U &= \frac{q}{h \cdot W} \end{aligned} \qquad (4.3)$$

U is the water velocity (m s^{-1}), W the river width (m), h the river depth (m) and q the water flux (m^3 s^{-1}). From formulae (3) we obtain:

$$K = 125 \cdot q^{0,566} \qquad (4.4)$$

From the solution of the diffusion equation, we get that, at time t, 95% ($\pm 2\sigma$) of pollutant is confined within a river reach of length

$$L = 4 \cdot \sqrt{2 \cdot K \cdot t} \qquad (4.5)$$

For instance supposing a river length of 1000 km and a water flux of 1000 m^3 s^{-1}, L is, approximately, 400 km at time t=10 days. As the average length of each compartment of MOIRA, in the present example, is 50 km (1/20 of the river length), the hypothesis of homogeneous distribution of pollutant within each compartment can be assumed to be reasonable for medium and long-term predictions also in view of the overall uncertainty of the model output.

Migration to bottom sediments

The process of pollutant migration to bottom sediment is due to the sedimentation of suspended matter in water and to radionuclide diffusion through the sediment.

The process of interaction of dissolved radionuclides in water with suspended solids has been investigated by many researchers. It is usually modelled according to the well-know "k_d concept" (k_d = partition coefficient "particulate form/dissolved form") based on the hypothesis of a reversible and rapid equilibrium between the dissolved (C_w, Bq m^{-3}) and the adsorbed phases (C_s, Bq kg^{-1}) of radionuclide

$$\frac{C_s}{C_w} = k_d \tag{4.6}$$

Of course the above hypotheses are not generally and rigorously true for every contaminant substance. The equilibrium between the concentrations of the dissolved and the attached phases is also not instantaneously achieved. Moreover, the adsorption-desorption processes are not generally reversible.

The models CASTEAUR and RIVTOX simulate the time behaviour of the radionuclide absorption on suspended matter and on sediments according to first order kinetics:

$$\frac{dC_s}{dt} = b(k_d C_w - C_s) \tag{4.7}$$

where b is the radionuclide dynamic rate (s^{-1}) of sorption-desorption between the attached and the dissolved phases. If b is very large, the equilibrium condition is rapidely attained. Generally, these rates are significantly larger than time constants of other processes. Consequently, the process is negligible in relation to the expected time resolution of migration models. For instance, for several radionuclides (cobalt, americium, caesium, manganese, ruthenium), CASTEAUR makes use of a value of the order of 10^{-4} s^{-1} (the equilibrium is completely attained in few hours).

Many authors have discussed and analysed the dynamic behaviour of sorption-desorption processes of dissolved pollutants with sediments and suspended matter. Several models accounting for complex sorption-desorption kinetics and non-reversible interaction processes have been developed. It is worthwhile to notice that the processes of interaction of radionuclides with particulate matter can be very complicated. Neither equation (4.6) nor equation (4.7) exhaustively approach such a very complex problem (Delle Site, 2000).

The flux of radionuclide migrating to sediment due to the sedimentation is

$$F = S_r C_s \tag{4.8}$$

where S_r is the net sedimentation rate (kg m^{-2} s^{-1}) that accounts for the dynamic balance of the particle settling to bottom sediment and of the particle resuspension from sediment to water.

In many models these two last processes are calculated separately in terms of sedimentation and resuspension.

From equation (4.6) it follows:

$$F = S_r k_d C_w \tag{4.9}$$

$v_s = S_r k_d$ has the dimension of a velocity.

The radionuclide resuspension flux is related to the radionuclide deposit in the sediment by a multiplication factor (radionuclide resuspension rate). It is quite obvious that the radionuclide sedimentation sub-model can be appropriately modified to account for the adsorption dynamics modelled by equation (7) as in RIVTOX. Nevertheless, as previously stated, the complicated interaction of radionuclides with particulate matter makes it hard to develop an exhaustive sub-model of such a very complex process. Moreover, the benefit from a detailed mathematical description of this process is questionable in view of the uncertainty of the whole model.

Diffusion through bottom sediments

The migration of a radionuclide through sediments may be modelled, in principle, by the diffusion equation. Assuming that the bottom sediments are sub-divided into a set of layers of thickness dx. From the balance of radionuclides in each layer we get:

$$\begin{aligned} & dxS\frac{\partial}{\partial t}\left(q_w C_w(x,t) + k_d r C_w(x,t)\right) = SK^*\frac{\partial}{\partial x} q_w C_w(x+dx,t) + \\ & -SK^*\frac{\partial}{\partial x} q_w C_w(x,t) - \lambda dxS\left(q_w C_w(x,t) + k_d r C_w(x,t)\right) \end{aligned} \tag{4.10}$$

where K* is the diffusion coefficient, $C_W(x,t)$ is the concentration of the contaminant in sediment interstitial water at time t and at depth x from the sediment surface□□□□is the sediment density (kg m^{-3}), □$_w$ is the sediment water content (m^3 m^{-3}) and λ is the radioactive decay constant. Equation (4.10) expresses the time behaviour of the total amount of radionuclide in a sediment layer of thickness dx and surface area S. The first two terms on the right side of the above equation are the fluxes of radionuclide to and from the contiguous sediment layers. The last term accounts for radioactive decay.

After simple algebraic calculations, assuming that □□ □$_w$ and k_d are independent of x, we get the well-known diffusion equation for a pollutant in porous media (dx tends to 0):

$$\frac{\partial}{\partial t}C_W(x,t) = K\frac{\partial^2}{\partial x^2}C_W(x,t) - \lambda C_W(x,t) \tag{4.11}$$

K, the effective diffusion coefficient, is related to K* by the following formula

$$K = \frac{K^*}{R} \tag{4.12}$$

R (dimensionless) is the so called retardation factor:

$$R = 1 + \frac{K_d r}{q_w} \tag{4.13}$$

Unfortunately, the situation is more complicated. Indeed, all the above quantities r□ □$_w$ and k$_d$ may differ spatially (due to the variability of sediment characteristics) and on time (seasonal conditions may, in principle, influence the characteristics of the upper sediment layers). Obviously from the mathematical point of view it is possible to obtain a more general equation by a similar assessment of the contaminant balance in the sediment layers. Nevertheless, the need for such a large number of environmental variables makes the use of equation (4.11) impossible for practical applications.

In principle, equation (4.11) can be linked, through appropriate boundary conditions, to radionuclide sedimentation and to the radionuclide absorption rates on upper sediment layer.

In spite of this more or less rigorous mathematical technique, the totality of the assessed models wisely approach such a difficult problem by accounting, in a mere pragmatic way, for three main “aggregated” radionuclide fluxes from water and a couple of sediment compartments:

a) Radionuclide flux from water to sediment due to the sedimentation and to the direct interaction of radionuclide in water with the bottom sediment,

b) Radionuclide flux from sediment to water due to sediment resuspension and direct exchange of radionuclide from bottom sediment to water,

c) Radionuclide burial (or any other kind of irreversible process responsible for definitive removal of radionuclides from the water column).

Radionuclide migration from catchment

In case of contamination of a large area, the migration of radionuclide from catchment is one of the most important factors controlling the concentration of radionuclides in river water.

Indeed, the importance of the pollutant contribution from the catchment is strictly related to the mean water retention time of the considered water body. We can see this by using a simple example.

Let

Fiw = the water flux from the catchment to the water body ($m^3\ s^{-1}$);

Fow = the water flux from the water body ($m^3\ s^{-1}$);

Crw = the pollutant concentration in the runoff water from the catchment ($Bq\ m^{-3}$);

Cw = the pollutant concentration in the water body ($Bq\ m^{-3}$);

V = the volume of the water body (m^3);

Frws = the pollutant flux from the water column to the bottom sediment ($Bq\ s^{-1}$);

Frsw = the pollutant flux from the bottom sediment to the water column ($Bq\ s^{-1}$).

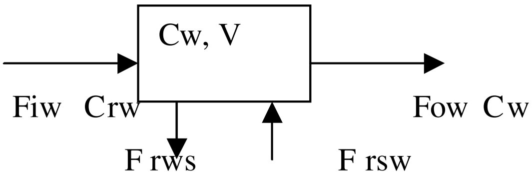

Figure 4.1. Main fluxes of a pollutant in a water body.

The balance of the substance in the water body is controlled by the following equation

$$\frac{dVCw}{dt} = CrwFiw - CwFow + Frws - Frsw - Dp \tag{4.14}$$

where Dp represent the effect of any degradation processes. VCw is the total amount of radionuclide in water. In case of a radionuclide Dp=-λCwV where λ is the radioactive decay constant.

Equation (4.14) may be rewritten as follows:

$$\frac{dCw}{dt} = Crw\frac{Fiw}{V} - Cw\frac{Fow}{V} + \frac{Frws - Frsw - Dp}{V} \tag{4.15}$$

The ratio Fow/V is the inverse of the so called mean water retention time of the water body. If the mean water retention time is very short, Fow/V will be very high. Moreover, in such a case if the pollutant has a low degradation rate or a low radioactive decay constant (long-lived radionuclide, such as ^{90}Sr and ^{137}Cs) the terms Frws/V, Frsw/V and Dp/V are negligible compared with the other terms in the right-hand side of equation (4.15). It is then possible to assume that $Fiw \approx Fow$ (indeed, the effect of evaporation can be considered negligible when the mean water retention time is sufficiently short), therefore we get:

$$\frac{dCw}{dt} = Crw\frac{Fow}{V} - Cw\frac{Fow}{V} \tag{4.16}$$

The solution of equation (4.16) is:

$$Cw = \int_0^t Crw\frac{Fow}{V} e^{-\frac{Fow}{V}(t-\tau)} d\tau + Cw(0)e^{-\frac{Fow}{V}t} \tag{4.17}$$

where Cw(0) is the initial contamination of the water body (concentration in water at time 0).

Following simple calculations, equation (4.17) becomes:

$$Cw = Crw - Crw\,e^{-\frac{Fow}{V}t} + Cw(0)e^{-\frac{Fow}{V}t} \tag{4.18}$$

It is quite obvious that, if the mean water retention time is very short, the ratio Fow/V is very high and therefore the last two terms in the right side of the previous equation approach rapidly 0, then

$$Cw \approx Crw \tag{4.19}$$

We can conclude that the concentration in the water body, based on the above hypotheses, approaches the values of the concentration of water flowing from "its" catchment (notice that, for a river reach, the catchment must include the entire upstream part of the river). The described example was aimed at illustrating, in a simple way and without claming to give a general demonstration, the complex relation existing between the time behaviour of radionuclide concentrations in the water body and in its catchment.

The characteristics of the catchment sub-model strongly influence the features and the uncertainty of the whole river model. Therefore, reliable models for predicting radionuclide migration from the catchment are essential for improving the performance of river models. Such models were the object of a detailed assessment in a previous phases of the network EVANET-HYDRA (summaries of activities and achievements for the period 1/November/2002- 30/April/2003) (Monte et al., 2003a).

Migration to biota.

The models for assessing the migration of radionuclides from the abiotic to the biotic components of the river ecosystem are essentially similar to the models used for lakes. For instance AQUASTAR makes use of the biota contamination sub-model implemented in AQUASCOPE that utilises a single compartment to assess the contamination of edible part of fish. CASTEAUR accounts for the complex web of processes occurring in the fish food web: structure of the food chain (phytoplankton, zooplankton, macrobenthos, planktivorous and omnivorous fish species) and transfer processes such as ingestion, filtration, etc.

Therefore the conclusions relevant to such a particular aspects of the river models are basically the same that were derived for lake models (Monte et al., 2003).

A review of the concentration factors of several radionuclides in whole fish is reported by Smith et al., 2003.

Attempts were carried out to assess the effects that fish movements (for instance of migratory species) may have on the contamination levels in heterogeneously polluted large watercourses. This seems a particular problem that can be of some importance only for specific circumstances such as the migration of salmons. The solutions proposed by Monte, (2002) are, at present, mainly of academic interest.

Analysis of the overall structure of the models

The assessed models show different "horizons" of application. Some of them (RIVTOX, CASTEAUR) make use of suitable sub-models to evaluate the river water flow and the suspended sediment transport in terms of hydraulic equations and quantities (e.g. the equation of motion based on Newton's second law, semi-empirical relations like the Manning-Stricker equations, the vertical and longitudinal turbulent diffusion coefficients, the hydraulic radius, etc.). In contrast, other models (MOIRA, AQUASCOPE, AQUASTAR) make use of empirical values of hydrological quantities averaged at different temporal and spatial scales (for instance, average monthly run off from catchment, average rain rates, average water fluxes, average contents of suspended matter in the water column).

It is outside of the scope of the present assessment to analyse the fluid dynamics sub-models implemented in some of the assessed models. Our main concern is limited to the assessment of the radioecological modules of the models.

It is interesting to notice that modules for predicting the radionuclide transfer through the abiotic components of the river within the sub-system "water column – bed sediments" are basically similar to the corresponding models for lakes. The modules for predicting the transfer of radionuclides to biota are also similar to the analogous modules used for the lacustrine environment although they account for thespecific hydrological and ecological characteristics of the lotic habitats.

We now compare, in detail, the mathematical expressions used by the models considered here to evaluate the various radionuclide fluxes from the water column to bottom sediment and vice-versa (paragraphs a), b) and c) of section 2.4). The assessment of these specific aspects is particularly interesting in view of the evaluation of the radioecological features of environmental models.

Applications of the modelling approaches to the models

Diffusion

AQUASTAR

This model, in principle, is based on the “non-hysotropic” form of the diffusion equation considering both longitudinal (y) and transverse diffusion (x):

$$\vec{F}(x,y,t) = -K_x \cdot \frac{\partial C(x,y,t)}{\partial x}\vec{i} - K_y \cdot \frac{\partial C(x,y,t)}{\partial y}\vec{j}$$

(4.20)

Nevertheless, the transverse diffusion is modelled by a multiplicative correction factor. The transfer diffusion coefficient is related to the longitudinal diffusion coefficient by an empirical sub-model accounting for the water flow and the water body average depth and width.

The value of the transverse dispersion coefficient, D_t may be estimated, with some minor changes for correcting what seem typographical errors, using the empirical model of Gharbi & Verrette (1998) which relates the transverse dispersion coefficient to the coefficient of longitudinal dispersion, D:

$$D_t = 0.00035 \left[\frac{(Q/d)^{1.75}(W/d)^{0.25}}{D^{0.75}}\right] + 0.0005 \tag{4.21}$$

where Q is the volumetric flow rate ($m^3 s^{-1}$), d is the average depth (m), W is the average width (m).

The longitudinal diffusion coefficient is evaluated by a 2nd degree polynomial of the water flux Q, $K_x = a \cdot Q^2 + b \cdot Q$, obtained by site-specific dye-tracer experiments in river Thames. More generally AQUASTAR make use of an empirical formulae from Won Seo et al., 1998 to estimate the longitudinal dispersion coefficient:

$$D = 5.915 d U_* \left(\frac{W}{d}\right)^{0.62} \left(\frac{U}{U_*}\right)^{1.428} \tag{4.22}$$

where W is the river width, d is the mean depth, U is the mean flow velocity and U_* is the shear velocity which may be estimated using:

$$U_* = \sqrt{g.d.s} \tag{4.23}$$

where g ($m\ s^{-2}$) is the acceleration due to gravity and s ($m\ m^{-1}$) is the slope.

CASTEAUR

$$F(x,t) = -K \cdot \frac{\partial C(x,t)}{\partial x} \qquad (4.24)$$

where K is the global coefficient of diffusion ($m^2.s^{-1}$), C the radionuclide activity per unite volume ($Bq.m^{-3}$) and x the distance along the river (m). For the assessment of K CASTEAUR makes use of an approach similar to AQUASTAR.

RIVTOX

It is essentially a one-dimensional model making use of the diffusion equation. Nevertheless the set of models implemented in RODOS account for “non-hysotropic” diffusion by the diffusion tensor.

Transport

CASTEAUR

$$F(x,t) = -U \cdot C(x,t) \qquad (4.25)$$

where U is the average speed of the flow ($m.s^{-1}$), C the radionuclide activity per unite volume ($Bq.m^{-3}$).

Similar equations are used by AQUASTAR and RIVTOX. AQUASTAR relates the water velocity to the water flux. CASTEAUR and RIVTOX calculate the water velocity by sub-models showing different degree of complexity. CASTEAUR makes use of the Manning-Stricker formula accounting for the hydraulic radius and the river slope. RIVTOX is based on a more complex hydrodynamic approach. It makes use of Saint-Venant’s and adversion dispersion equations to simulate water fluxes, suspended sediments and, finally, the migration of radionuclides.

Migration to bottom sediments

The MOIRA model calculates the radionuclide flux to bottom sediment by multiplying the concentration of dissolved radionuclide by the migration velocity and the sedimentation velocity:

$$\mathrm{Flux}\left[Bq\,m^{-2}s^{-1}\right] = (v + v_s)C_w \qquad (4.26)$$

The above flux can be related to dissolved, suspended and total form of radionuclide in water. Obviously, formula (26) should be modified accordingly by accounting for the fractions of each form of radionuclide. To be more specific, for the purposes of the present assessment, we make use of formula (26) where C_w is the concentration of dissolved radionuclide in water. The flux is expressed in Bq m^{-2} s^{-1}. The velocities v and v_s (m s^{-1}) were introduced to evaluate the transport to sediment due to direct process of interaction of the dissolved radionuclide with bottom sediment particles (v) and the removal of radionuclide from the water column due to the process of sedimentation (v_s).

It can be easily seen that the equations used by the other models can be reduced to a mathematical form equivalent to equation (4.26). The difference resides in the way the values of v and v_s are predicted (in MARTE they are generic values obtained from experimental evaluations for radiocaesium and radiostrontium). The following values of v_s were calculated supposing that the equilibrium condition between the suspended and the dissolved radionuclide phases is quickly attained. It is important to notice that both models RIVTOX and CASTEAUR account for the interaction of the dissolved radionuclide with the suspended matter and the bottom sediment by a first order kinetics model. More generally, according to the hypotheses of these model the formulae for calculating v_s should be substituted by the expression "$\text{Flux of deposited radionuclide} = R_s C_s$" where C_s is the concentration of radionuclide adsorbed onto suspended matter (Bq kg^{-1}).

AQUASTAR

$$v_s = SM \cdot v_p \cdot k_d = R_s \cdot k_d \tag{4.27}$$

where SM is the suspended matter per unit volume of water, v_p is the particulate settling velocity and R_s is the sedimentation rate (kg m^{-2} s^{-1})

RIVTOX

$$\begin{aligned} v &= r(1-e)\, a_{ws}\, d\, k_d \\ v_s &= R_s k_d \end{aligned} \tag{4.28}$$

where r is the sediment density, e is the sediment porosity, d is the "effective thickness of the contaminated upper layer of bottom sediment, a_{ws} is the rate of radionuclide exchange "water-bottom sediment", k_d is the radionuclide partition coefficient and R_s is the sedimentation rate.

RIPARIA

$$v + v_s = \text{sedimentation} + \text{diffusion} + \text{bioturbation}$$
$$\text{sedimentation} = k_d R_s$$
$$\text{diffusion} = \frac{D}{Rd}(1 + k_d SM) \qquad (4.29)$$
$$\text{bioturbation} = \frac{R-1}{R}\frac{B}{d}(1 + k_d SM)$$

where

$$R = 1 + (1-e)\frac{r}{e}\cdot K_d \qquad (4.30)$$

In equations (29) and (30) SM is the suspended matter (in kg.m^{-3}), D is the diffusion coefficient (in m^2.s^{-1}) and B is bioturbation coefficient (in m^2.s^{-1}).

CASTEAUR

$$v = r \cdot a_{ws} \cdot d \cdot k_d$$
$$v_s = R_s \cdot k_d \qquad (4.31)$$

Uppsala University model relates v_s to suspended matter, water velocity, particle resuspended fraction and k_d by semi-empirical formulae aimed at evaluating the sedimentation velocity of the carrier particles for radionuclides. The approach is similar to formulae used by other models that calculate v_s as the product of the sedimentation rate by the radionuclide partition coefficient. The model makes use of an explicit formula for relating such a rate to the prevailing above mentioned characteristics of the water body.

Migration from sediment to water (resuspension)

The radionuclide flux from sediment to water (often called resuspension) can be calculated according to the following formula

$$F_{sw}\left[Bq\, m^{-2} s^{-1}\right] = K_{sw} \cdot D_{ep} \qquad (4.32)$$

where F_{sw} is the radionuclide flux per square metre and per second to from sediment to water, K_{sw} is the rate of migration (s^{-1}) and Dep is the radionuclide deposit (Bq m^{-2}). The above formula is used by MOIRA. A similar formula is used by the other models.

RIVTOX

$$K_{sw} = a_{ws} + \frac{R_r}{d \cdot r \cdot (1-e)} \tag{4.33}$$

where a_{ws} is the rate of water-bottom exchange and R_r is the resuspension rate.

RIPARIA

$$\begin{aligned} K_{sw} &= \text{Diffusion} + \text{Bioturbation} \\ \text{Diffusion} &= \frac{D}{R \cdot d^2} \\ \text{Bioturbation} &= \frac{(R-1) \cdot B}{R \cdot d^2} \end{aligned} \tag{4.34}$$

CASTEAUR makes use of a formalisation similar to MOIRA.

Uppsala University model

$$\begin{aligned} K_{sw} &= a_T \cdot T && \text{(from the sediment accumulation area)} \\ K_{sw} &= f(V_{rw}) && \text{(from the sediment erosion area)} \end{aligned} \tag{4.35}$$

where $f(V_{rw}) = aV_{rw}+b$ if V_{rw} , the velocity of the river water that is supposed > 0.1 ms^{-1}, is lower than 1.1 ms^{-1} . If V_{rw} > 1.1 ms^{-1}, K_{sw} reaches the limit value $3.9\text{x}10^{-7}$ s^{-1}. T is the temperature of bottom water in °C. The model developed by the Uppsala University is structured like model ECOPRAQ that was assessed in detail in the previous report on lake models.

Migration from bottom to deep sediment

MARTE and University of Uppsala models account for non-reversible process of radionuclide interaction with bottom sediment that prevent radionuclide resupension to water.

Such a process is simply modelled by an equation similar to formula (22):

$$F_{sw}\left[Bq\,m^{-2}s^{-1}\right]=K_{ds}\cdot D_{ep} \qquad (4.36)$$

where K_{ds} is a rate constant (s^{-1}). The values of K_{ds} used by the two models are of the order of magnitude $10^{-8} – 10^{-9}\ s^{-1}$). Due to the very small mean water retention time typical of river reaches, differences in K_{ds} do not influence significantly the predicted values of radionuclide concentration in water. Indeed, in principle, these non-reversible processes can be of importance on the medium and long term when the contribution of radionuclide from catchment is the prevailing contamination source of the river water. On the other hand, for direct releases of contaminant in water the migration to deep sediment becomes of importance for the assessment of water contamination when the rate of radionuclide introduction in the river becomes negligible. In that case, the small mean water retention time implies a significant decrease of water contamination. Generally, in such a circumstance, although, in principle, models become less reliable, the urge of accurate results is less crucial. Obviously, the above discussion remains valid for those models that do not account for this specific process.

Table 2 shows values of some parameters used in the models.

Discussion

The analysis of radionuclide fluxes carried out in sub-sections 3.2, 3.3 and 3.4 clearly shows that the structures of the assessed sub-models for predicting the migration of radionuclides through the system “water column – bed sediments” are basically equivalent.

The evaluated models are characterised by different degrees of sophistication ranging from box models to models based on the diffusion-transport equations. In relation to several specific features of the models, it is possible to repeat many of the conclusions that we have already achieved for lake and catchment models. Therefore, it seems not necessary to replicate the statement of concepts and conclusions that were thoroughly discussed in the previous sections.

Among the models assessed, AQUASCOPE is the only one that makes use of a simple “response function” approach to evaluate radionuclide concentration in water from the deposition of radioactive substance over the whole river catchment. In contrast, the other models make distintions between the processes of migration from the river catchment and the processes occurring in the river.

Figure 4.2 shows the results of an intercomparison exercise among the models in the present assessment. The results of this exercise are described, in detail, in the EVANET-HYDRA report “Model Intercomparison Exercise” Annex II. The hypothesised scenario of contamination involved a pulse deposition of a certain amount of radiocaesium over a river catchment. The models AQUASCOPE, MOIRA and the model developed by the Uppsala University (U.U.) show levels of complexity that are significantly different. They range from the two compartments of AQUASCOPE to the 120 compartments of MOIRA that are spatially distributed over the various sub-catchments and reaches of the river system. Nevertheless, the results in Figure 4.2 show similar time behaviours. An appropriate “model tuning”, based on a suitable choice of values of the model parameters, is therefore possible among the different models. Consequently they may be considered conceptually equivalent for practical applications. Of course the models are characterised by different possibilities of application to various environmental contamination scenarios in order to solve different problems of environmental management. For instance MOIRA allows one to assess, by a single run, the levels of contamination at different points of the watercourse for radionuclide deposition heterogeneously distributed over a large catchment. Moreover MOIRA is also able to assess the effect of countermeasures based on water flux control and isolation of the river from polluted sub-catchment areas. Obviously, such differences are only relevant to the model usage and they do not pertain to the general, conceptual approaches of the models.

The results of the models (concentration of total radiocaesium in water) varied within a factor 3 over a period of 2 years. The models clearly show two exponential components (short and medium terms). The applications of AQUASCOPE and MOIRA to the present exercise are aimed at assessing the average concentration of radionuclides in water over time (although, in principle, they are structured to account for the influence that seasonal variation of water flux may have on the radionuclide concentrations). In contrast, U.U. model accounts for these effects as shown by the fluctuations of radionuclide concentrations around an average value decaying according to two exponential components.

Figure 4.3 reports the results of the intercomparison of the output (radiocaesium concentrations in predatory fish species) of the models AQUASTAR, MOIRA and CASTEAUR applied to the contamination of a river following the introduction of radiocaesium into water from a point source. The figure shows the effect of using different size of the river reaches in compartment model MOIRA. It must be noticed that MOIRA, being a compartment model, in principle, is inappropriate to predict the concentration of radionuclides in river ecosystems for very short-term periods (hours) unless the compartment size is suitably chosen.

According to the results of a previous assessment (summaries of activities and achievements of EVANET-HYDRA for the period 1/November/2002- 30/April/2003) (Monte et al., 2003a), the migration of radionuclides from catchments is one of the most important factors influencing the uncertainty of models aimed at evaluating the behaviour of pollutants within river ecosystems. Indeed, as demonstrated in section 2.5, pollutant contribution from catchment is of paramount importance for the balance of radionuclide in rivers.

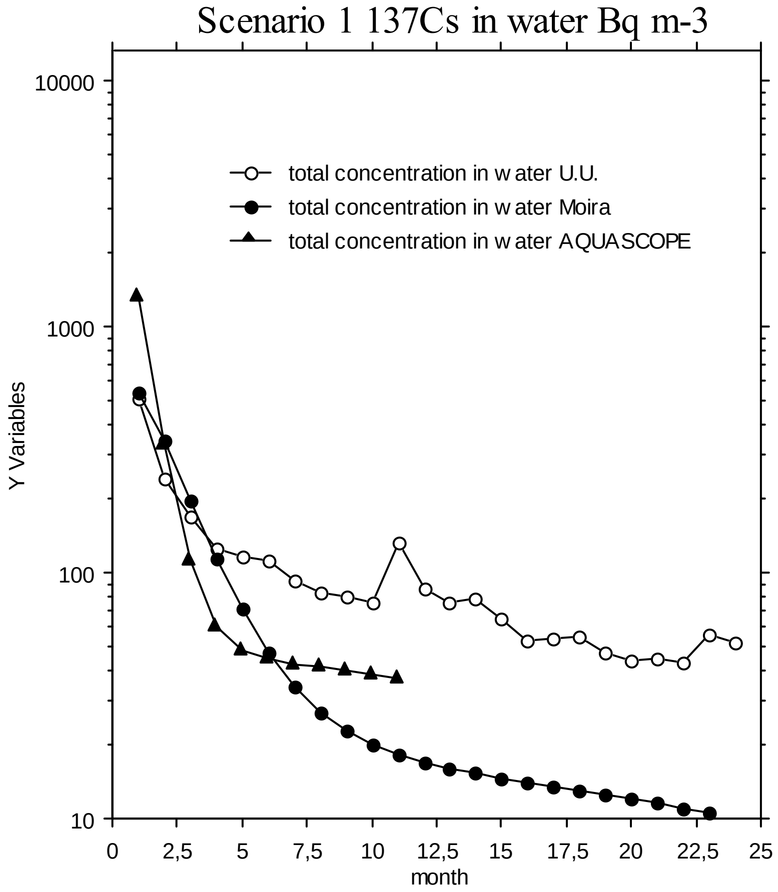

Figure 4.2. Results of a model intercomparison exercise. The scenario of contamination assumes a pulse deposition of ^{137}Cs on the catchment of a hypothetical river.

It is interesting to compare the features of the AQUASTAR and CASTEAUR models. Such models are based on transport-diffusion equations for predicting the radionuclide concentrations in water. They comprise sub-models for predicting the behaviour of radionuclides in biota that are characterised by very different degrees of complexity. As it was noticed for the comparison of AQUASCOPE and MOIRA, the model results show similar shapes in spite of their different position on the x-y plane. We can restate that an appropriate choice of the values of the model parameters can allow one to “tune” the model outputs.

The assessment of the behaviour of the prediction of radionuclide in fishes at distance 1 km from the source point is in agreement with the conclusions that can be derived from the analysis of the predictions at point 100 km.

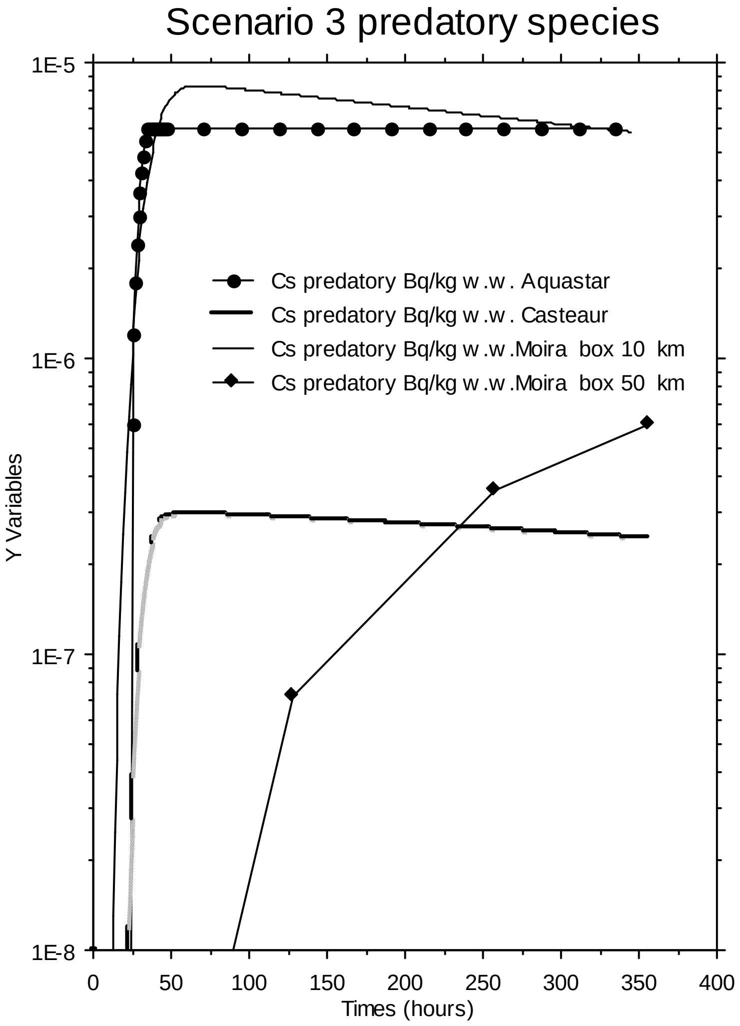

Figure 4.3. Comparison of the models AQUASTAR, CASTEAUR and MOIRA for a scenario of contamination involving a pulse release of ^{137}Cs into river water. The output is the concentration of radionuclide in predatory fish species 100 km downstream the release point.

As previously stated, the results of the model intercomparison exercise are described, in detail, in a special report of EVANET-HYDRA network. The above quoted examples are only aimed at illustrating the variability of the results among the models object of the assessment. Such a variability cannot be attributed to the imprecision or to the inaccuracy of some of the evaluated models. It is, to some extent, the consequence of the incomplete knowledge of complex environmental processes and of the ambiguity and uncertainty of many data and information. This situation is strictly related to the present "state-of-the-art" of radioecological modelling, in paricukar to the available knowledge about the systemic behaviour of radioactive substances in the complex fresh water ecosystem.

As an example, Figure 4.4 shows the results of some models compared with experimental data obtained in conditions that are somewhat similar to the hypothetical scenario for the model intercomparison exercise (contamination of catchment of river Po in northern Italy following the Chernobyl accident). It is quite obvious that the experimental data themselves are affected by a significant variability caused by environmental processes that are difficult to predict. Similar conclusions can be achieved by comparing the predictions of fish contamination with experimental data (Figure 4.5).

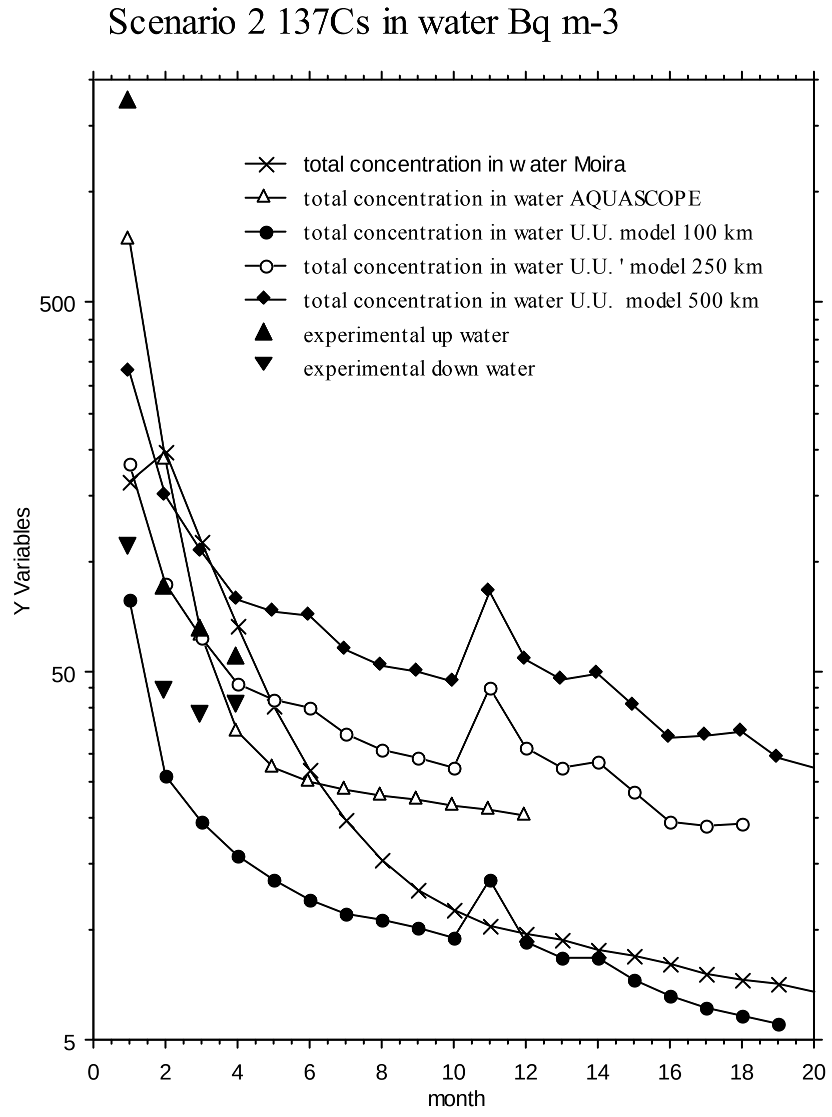

Figure 4.4. The figure shows the results of models MARTE, AQUASCOPE and U.U. follwing a single pulse of ^{137}Cs deposition (5000 Bq m-2) on the whole catchment of a hypothetical river. The model results are compared with some empirical measurements of radiocaesium concentration in river Po following the Chernobyl accident.

The range of variability of the measured values of radionuclide concentrations in fish is one order of magnitude. The model uncertainty is the result of a complex combination of environmental and biological variability, lacking of data and information, incomplete knowledge. State-of-the-art models are the results of decades of studies and researches and represent what the scientific communities (the experts) could produce by synthesising the inheritance of acquired experience and knowledge. Model uncertainty is due to the factual limitation of available information (in the broader meaning) and to the variability and complexity of processes in the biosphere; on the contrary, it is not the consequence of the failure of modellers. This consideration can lead to an appropriate attempt for overcoming the dilemma "true-false" when assessing model performances. Recently, indeed, within the perspectives of the *Expert System Theory*, a more realistic (and quite obvious) point of view has gained ground: any kind of statement (therefore the model output too, that are, for instance, statements affirming something about the concentration of contaminant in certain environmental components) does not tell anything that "objectively pertains to the external real world"; at best it inform us about the beliefs of the expert who asserts the statement itself (Giles, 1981). It does not matter if, in principle, it is assumed that an improvement "ad libitum" of knowledge and process understanding is ever possible to reach a definitive comprehension of the external world: the actual, limited knowledge within the frame of a specific scientific sector is the only basis on which it is possible to construct models of natural systems.

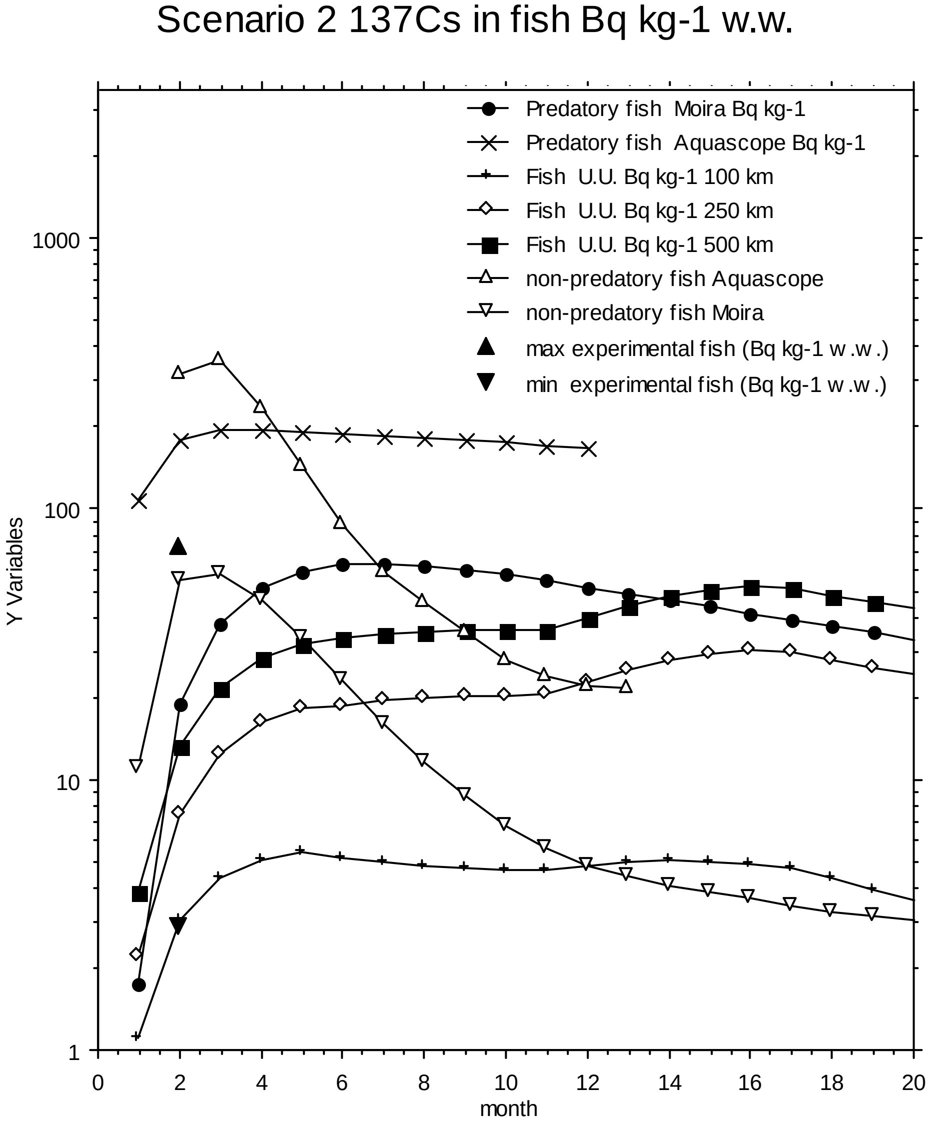

Figure 4.5. The results of the intercomparison of the predicted concentrations of radiocaesium in biota suggest conclusions that are coherent with the comments done for the assessment of model predictions in water.

Conclusions

We have noticed that river models are structured as follows:

Application of the diffusion-transport equation to the movement through river water of contaminants whose behaviour is controlled by migration processes occurring in the "water column-river bed sediment" system.

Such a structure is not only characteristic for radio-ecological models but is also widely applicable for predicting the behaviour of any kind of toxicant in water systems. The assessed models, in general, comply with the main principles for predicting the migration of radionuclides in water bodies that were reported in IAEA (1985) a document describing state-of-the-art models developed several decades ago. Nevertheless, it seems that, at present, although the structures of the models have not been subject to significant revisions, the perspective of model application has changed considerably. First of all, having a look to previous scientific literature, it was almost impossible, before the experience recently gained, to find experimentally based assessment of the values of some transfer parameters and rates used by the models. For instance, a previous state-of-the-art publication of IAEA "Handbook of Parameters Values for the Prediction of Radionuclide Transfer in Temperate Environments" (IAEA, 1994), listed solely values of water/sediment partition coefficients and concentration factors for edible portions of fishes. The copious experimental data available, at an environmental systemic level, following the Chernobyl accident and other severe accidents like Kyshtym offered the opportunity of evaluating transfer parameters for radionuclides in large, complex water bodies. Values of migration rates from water to sediment, from sediment to water and of irreversible fixation rates to buried sediments of radiostrontium and radiocaesium were measured. These evaluation were of importance in view of the different characteristics of interaction with sediment particles of the above radionuclides that represent a wide range of behaviours that can be considered pertinent to the migration properties of many different radioactive substances. In past decades, compartment models for predicting the migration of radionuclides through the "water column bed sediments" were considered as mere approximation of more complex, reliable models based, for instance, on the solution of diffusion equations of radionuclide through bottom sediment and of transport equation from water to sediment of settling pollutant. At present, it seems more reasonable to deem the simple compartment models practical tools based on those aggregated processes that occurr at a systemic level and that can be quantified, parameterised and measured. the so-called emerging processes.

The migration processes that are the object of the present assessment are modelled according to principles traditionally used for the lacustrine environment. It is obvious that the conclusions achieved for the assessment of lake and catchment models are valid for the river models too (Monte et al., 2003).

The models show different "horizons" of application. The most general, such as RIVTOX, make use of hydrodynamical sub-models for assessing water fluxes, suspended sediment transport, etc. in a "reductionistic" perspective. Other models, like MOIRA, make use of experimental time and space-averaged evaluations of the above quantities. To increase the "horizon" of a model can imply higher levels of uncertainty of the model output. For instance, it is obvious that the assessment of water fluxes by hydrodynamical models can cause an increase of the uncertainty of short term outputs due to the difficulties in predicting some meteorological events.

It is encouraging that many models show relatively simple structures in view of the possibility of the application of data assimilation procedures. This can significantly improve the reliability of the models by tuning the output to experimental data of contamination that can be acquired in case of accidents. On the contrary, the model intercomparison exercises demonstrated that complex models can be, in some circumstances, difficult to use and apply in view of the great deal of input data they need.

It seems quite clear that much of the uncertainty of models reflects the state-of-the-art of the experimental knowledge. In turn, this is associated with some inherent uncertainties that are mainly caused by the intrinsic variability of the environmental and biological processes. Such variability cannot be predicted with sufficient accuracy due to the lack of information and data.

The results of the state-of-the-art models are therefore influenced by the incompleteness and the uncertainty of the actual knowledge that has been derived from a limited experimental basis (the accidents causing significant contamination of the environment at a regional scale). This is not unique to radioecology, but is a fairly common problem in environmental modelling.

It is difficult or even impossible to reduce, beneath a certain level, the uncertainty of the predictions relevant to certain processes (mainly of biological nature) that are significantly influenced by the above-mentioned intrinsic environmental and biological variability. Indeed, such a variability produces fluctuations of radionuclide concentrations in environmental and in biological compartments that cannot be predicted with sufficient accuracy in view of the incompleteness of the available information.

The present analysis and the intercomparison exercise suggest that a profitable strategy for developing models aimed at predicting the migration of pollutants in complex environmental systems reside in identifying emerging processes and in parameterising them according to the specific environmental conditions and situations that influences these processes from a holistic, ecological perspective.

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Table 4.1. Main characteristics of the models object of the present assessment.

Model	Target variables (concentrations)	Aims	Radionuclides	Space horison	Time horizon	Time Resolution Power	Spatial Resolution Power (SRP)	Dimension	Processes	Main characteristics of the method of solution
AQUASCOPE (Smith et al., 2003)	Water, sediment and fish	Long term assessment following deposition on the whole catchment	Sr, Cs and I	Large catchment	Medium and long term	Monthly averages	Entire river	-	Migration from the whole catchment	Transfer function
AQUASTAR (Smith et al., 2002)	Water, sediment and fish	Accidental and routine release in water	Cs, Sr P, I Co, ^{14}C, Pu, U, Zn, Am	River at any space scale	Any timescale	Minutes or hours	In principle punctual predictions	2-dimensional	Transport, transverse dispersion, migration to sediment (particle settling), 1st-order uptake by fish species (prey and predator)	Contaminant input-output balance (Transport downstream, uptake by fish species). Analytical (Transverse dispersion)
CASTEAUR (Duchesne et al., 2003)	Water and fish	Accidental and routine releases in water	Fission products	River at any space scale	Any time scale	Minutes or hours	In principle, punctual predictions	1-dimensional	Transport, diffusion, migration to sediment (particle settling), 1st-order uptake by fish species (prey and predator)	Analytical within a reach. Input-output balance among reaches and for biota
MOIRA (Monte, 2001)	Water, sediment and fish	Medium and long term assessment of contamination and countermeasures effects. Contamination of catchment and direct release in water.	Sr and Cs (high flexible structure, easy to convert for assessment of other radionuclides)	Catchment and river (medium and large size)	Medium and long term	Monthly averages	1/20 of the entire river length	1-dimensional	Migration from river sub-catchments, transport, migration to sediment, resuspension and non-reversible migration to deep sediment (1st-order), 1st-order uptake by fish species (prey and predator), effects of fish movement on their contamination levels , effects of countermeasures on contamination levels.	Contaminant input-output balance and compartment models derived by Radionuclide Transfer Functions
RIPARIA (Lepicard, 2001)	Water, sediment, fish	Accidental and routine release in water	Fission products, 3H, NORM,	River at any space scale	Any time scale	Depends on the compartm	Depends on the compartmen	1-dimensional	Compartment model assuming: a homogeneous distribution of radionuclide	Input-output balance among compartments

						ent size	t size		within a compartment; radionuclide fluxes calculated in terms of annual average transfer of water volumes. Radionuclide migration to sediment and resuspension Radionuclide concentration in fish and water assumed to be in equilibrium.	
RIVTOX (Zheleznyak et al., 1992)	Water, sediment, fish	Accidental and routine release in water. Contamination of catchment (Connected to RETRACE model, Popov et al., 1996)	Fission products, NORM, 3H	River at any space scale	Any time scale	Days	In principle, punctual predictions	1-dimensional	Diffusion-transport equation, radionuclide migration to sediment and resuspension.	Numerical/analytical . In principle, the model equations are derived by averaging 1-dimensional equations over depthand width
Uppsal University (Håkanson, 2003)	Water, sediment, fish	Accidental and routine release in water.	Fission products	Large catchment	Medium and long term	Monthly averages	Entire river	-	Migration from river sub-catchments, transport, migration to sediment, resuspension and non-reversible migration to deep sediment. Migration to biota. Migration processes preeicted by accounting for the prevailing environmental characteristics and conditions	Contaminant input-output balance and compartment models

Table 4.2. Examples of values of radiocaesium and radiostrontium transfer parameters through the water column.

Models	$v+v_s$ (m s^{-1}) ^{137}Cs	$v+v_s$ (m s^{-1}) ^{90}Sr	K_{sw} (s^{-1}) ^{137}Cs	K_{sw} (s^{-1}) ^{90}Sr
RIPARIA	$3.17x10^{-7}$	$3.2x10^{-9}$	$3.x10^{-11}$	$1.7x10^{-10}$
MOIRA	$1,1x10^{-6}$	$3.5x10^{-7}$	$3.x10^{-8}$	$5.6x10^{-9}$
CASTEAUR	10^{-6} (Order of magnitude of v)	-	$3.2x10^{-8}$	-

APPENDIX A TO SECTION 4

Descriptions of the assessed river models

AQUASCOPE

Jim T. Smith, CEH (UK)

AQUASCOPE river model:

Average deposition to the catchment:	5.00E+03	Bq/sqm
Areal fraction of organic boggy soils, forg:	0.05	*Default: 0.05 for most areas, 0.2 for organic, boggy catchments*
lambda, radioactive decay constant	0.023	y^ -1
Potassium conc of river water	61.4	uM l^-1
Wet weight of fish (default, 1.0kg)	1	kg

Brief description of model.

The AQUASCOPE river model predicts radiocaesium, radiostrontium and ^{131}I in rivers following an atmospheric deposition of radionuclides to the catchment and river surface. The models are designed to be simple in structure and are implemented in EXCEL spreadsheets.

The models used to predict time changes in radionuclide runoff are based on those described in Monte (1995) and Smith et al. (2000a). The radionuclide concentration in runoff or river water, C_R (Bq m^{-3}), is given by:

$$C_R(t) = D_c.(\alpha.e^{-(\lambda+k_1)t} + \beta.e^{-(\lambda+k_2)t} + \gamma.e^{-(\lambda+k_3)t}) \tag{1}$$

where λ (y^{-1}) is the decay constant of the radionuclide and D_c is the radionuclide deposition to the catchment (Bq.m^{-2}). α, β, γ (m^{-1}) and k_1, k_2, k_3 (y^{-1}) are empirically determined (radionuclide-specific) constants. The k values may be expressed as effective ecological half-lives, T_{eff}, where $T_{eff} \approx \ln 2/(k+\lambda)$. The three exponential terms in equation (1) represent, respectively: a fast "flush" of activity as a result of rapid washoff processes; a slow decline as a result of soil fixation and redistribution processes; and the very long term "equilibrium" situation.

Estimation of runoff parameter values for Cs-137, Cs-134

Measurements of the change in ^{137}Cs activity concentrations as a function of time after fallout from Chernobyl were obtained for four European rivers (Voitsekhovitch et al. 1991; Monte 1995). These give a mean value of $k_1 = 13.2$ y^{-1} for the initial rate of decline in radiocaesium concentrations in rivers.

The values of the decay constants, k_2, k_3 are estimated from studies of the time dependence of radiocaesium activity concentrations in many European rivers after both weapons testing and Chernobyl (Smith et al. 1999; 2000a; 2000b). Estimated values are: $k_2 = 0.41$ y^{-1} and $k_3 = 0.02$ y^{-1}.

Data in the review of Helton et al. (1985) gives estimates of α in the range 0.013 - 0.26 m^{-1}. A slightly conservative value of $\alpha = 0.3$ m^{-1} will be chosen for the model.

Work has shown (Hilton et al. 1993) that high long term runoff rates of radiocaesium (i.e. high β ,γ values) are related to boggy peat soils in the catchment. It is therefore proposed that models for the estimation of these parameters be based on the percentage coverage of the catchment by these boggy, organic soils (Hilton et al. 1993; Smith et al. 1998). The following linear relations have been used in the model:

$$\beta = \beta_1.(f_{\min}) + \beta_2.(f_{org}) \tag{2}$$

$$\gamma = \gamma_1.(f_{\min}) + \gamma_2(f_{org}) \tag{3}$$

where $\beta_{1,2}$ and $\gamma_{1,2}$ are empirically determined constants, f_{org} is the fraction (by area) of the catchment which is covered by boggy, organic soils and f_{min} (= 1 $-f_{org}$) is the fraction not covered by boggy, organic soils.

The values of β and γ have been determined by fitting equation (1) to measurements of radiocaesium runoff in various catchments of different coverage by organic boggy soils. Equation (1) was fitted to measurements of ^{137}Cs activity concentration in water, C_R, draining each of the catchments, after normalisation to unit fallout (by dividing C_R by deposition, D_c). The fit is shown in Figure 1.1 and gives the following estimated parameters for ^{137}Cs runoff:

$$\beta = 0.003(f_{\min}) + 0.05(f_{org}) \tag{4}$$

$$\gamma = 0.0002(f_{\min}) + 0.002(f_{org}) \tag{5}$$

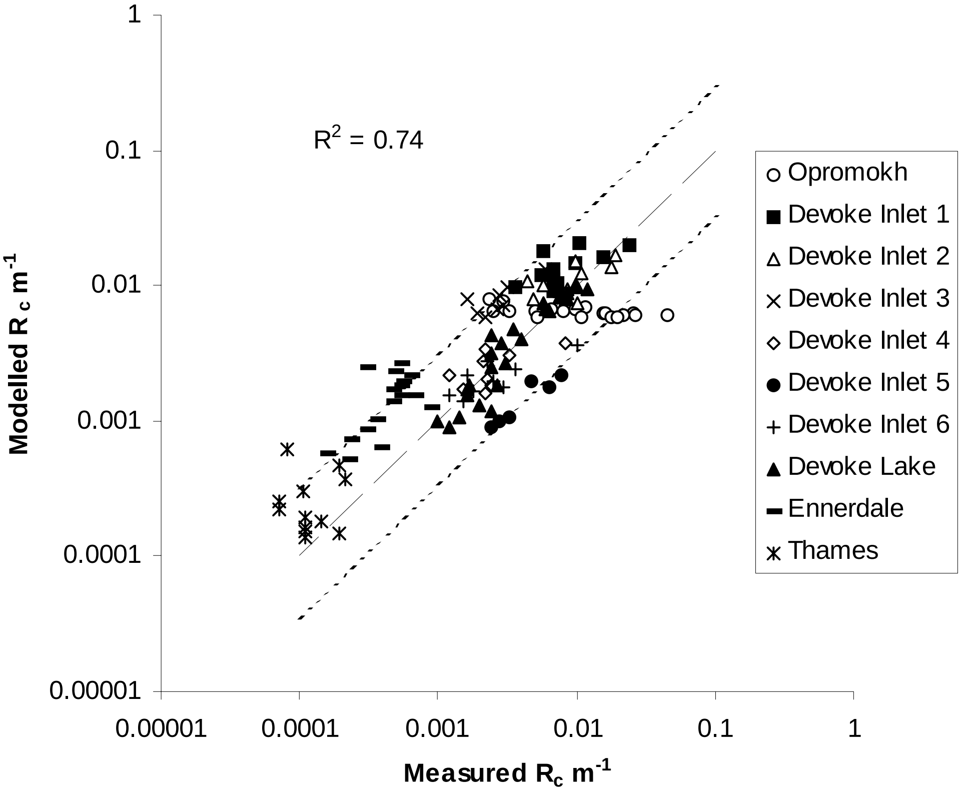

Figure 1.1 Measured radiocaeisum runoff coefficient in lakes and rivers with different amounts of organic peat bog in their catchment vs fitted values. The dashed line shows the line of 1:1 correspondence and the dotted lines show a factor of 3 error in the model.

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AQUASTAR

Jim T. Smith, CEH (UK)

AQUASTAR is an advection-dispersion model developed to predict the concentrations of radionuclides in the river environment, ie in river water, river bed sediment and in predatory fish. Uptake of radionuclides to fish is modelled by estimating rates of uptake of radionuclides via the aquatic food chain or across the gill, as appropriate. The model can be used to predict the concentrations of the radionuclides in rivers as a result of short duration discharges. The extent of cross-sectional mixing of a release plume may be estimated using simple empiricalrelationships (Gharbi & Verette, 1998)
Application to scenario 3.
10 hours release of 100 kBq of Cs-137, Sr-90, at the top of reach 8 from a pipeline at the right hand side of the river. Date: January 1st.

Calculate:
At 1 km, 10 km, 100 km downstream of the release.

Estimations:

Volumetric flow rate for reaches:
0-1 km 380.5 m^3 s^{-1};
0-10 km 380.5 m^3 s^{-1};
0-100 km 397.6 m^3 s^{-1}.
Mean depth: 2.4 m
Mean velocity: 1.04 m s^{-1}
River width: 155 m.
Dispersion coefficient (longitudinal) predicted 512 m^2 s^{-1}
Assume water temperature of 7 C.
Assume fp = 0.1, Cs in water, fp = 0.95, Cs in sediment.
Assume fp = 0.0, Sr in water, fp = 0.05, Sr in sediment.

Fish uptake and excretion rates as in Table below.

Comparison of USGS dispersion model with “plug-flow” dilution model.

Distance: 100 km from release.

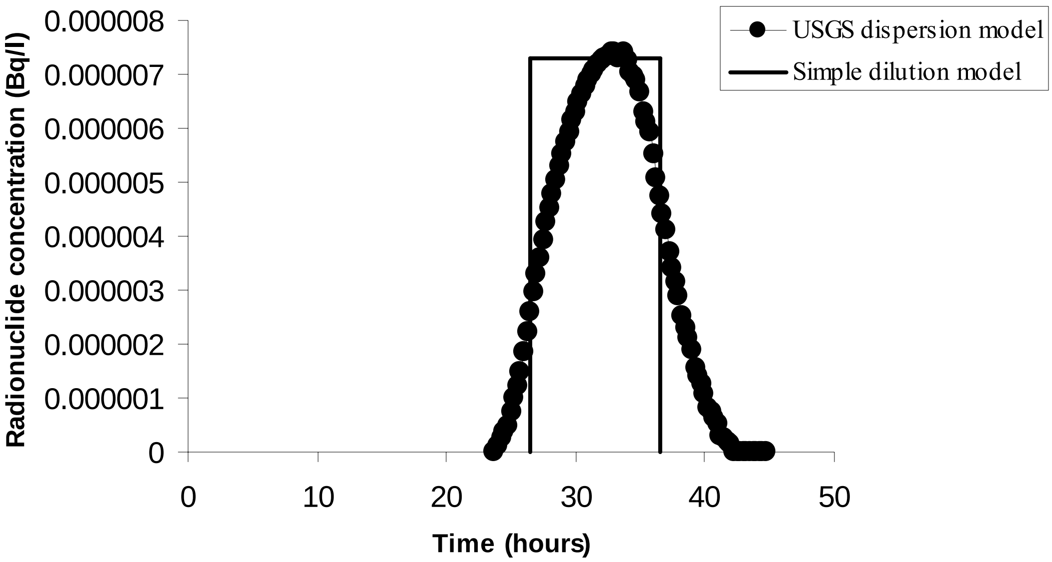

Figure 2.1 Comparison of predictions of diffusion model and simple dispersion model

Table 2.1. Estimated uptake and excretion rates of radionuclides in fish at 7 ^{o}C. Cs is assimilated via the food pathway and for strontium uptake via the gills is modelled.

Element	Pathway	Relevant water chemistry	*CF(fish)* l kg^{-1}	*CF(food)* l kg^{-1}	Assimilation efficiency, α	Feeding rate, w.w. g dy^{-1} @ 7 ^{o}C	Uptake rate k_f l kg^{-1} d^{-1} @ 7 ^{o}C	Excretion rate, k_b d^{-1} @ 7 ^{o}C
^{137}Cs	Food	[K] 2.4 mg l^{-1} *s* = 102 mg l^{-1}	IAEA: expected 2×10^3, range: 3×10^1 - 3×10^3 Smith 2×10^3	= *CF(fish)/2*	0.44	5.0	2.20	0.0011
^{90}Sr	Water	[Ca] 57.5 mg l^{-1} = 1438 uM l^{-1} pH 7.8	IAEA: expected 60, range:1-10^3	N/A	N/A	N/A	0.39	0.0065

Transverse dispersion of the plume

D(longitudinal) = 511.7 m^2 s^{-1} (Won Seo et al. 1998)
D(transverse) = 0.066 m^2 s^{-1} (Gharbi & Verette, 1998)
Value of D_tt at 1 km = 66.5 m^2
Value of D_tt at 10 km = 665 m^2

Expect incomplete cross section mixing at 1 km, but almost complete by 10 km. Potentially around 5 x higher than average cross sectional concentrations at the right hand bank at 1 km distance.

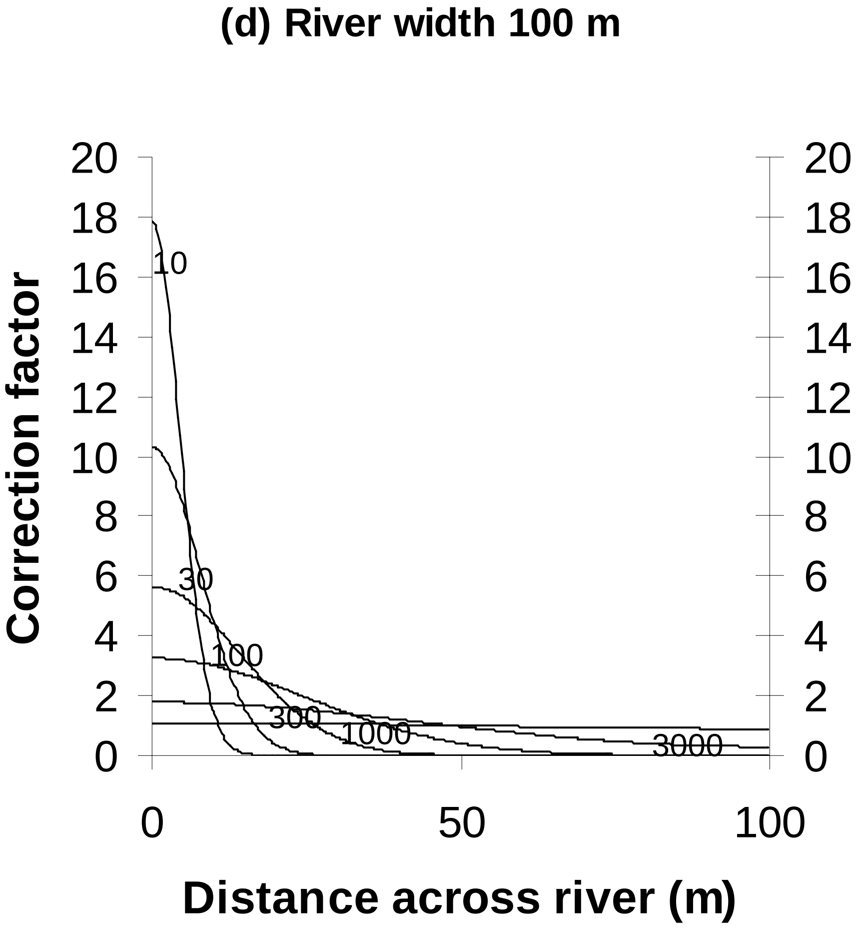

Figure 2.2 Correction factor as function of the distance across the river

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Gharbi S and Verrette J-L (1998) *Relation between longitudinal and transversal mixing coefficients in natural streams.* Journal of Hydraulic Research, 38 43-53 (in French).

Jobson H E (1997) *Predicting travel time and dispersion in rivers and streams.* J. Hydraulic Engineering, Vol. 123, 971-978.

Smith, J. T., Bowes, M. & Denison, F. H. 2003. Modelling the dispersion of Radionuclides following Short Duration Releases to Rivers. R&D Technical Report P3-074/TR. Environmental Agensy R&D Dissemination Centre, Wrc, Frankland Road, Swindon, Wilts, SN5 8YF.

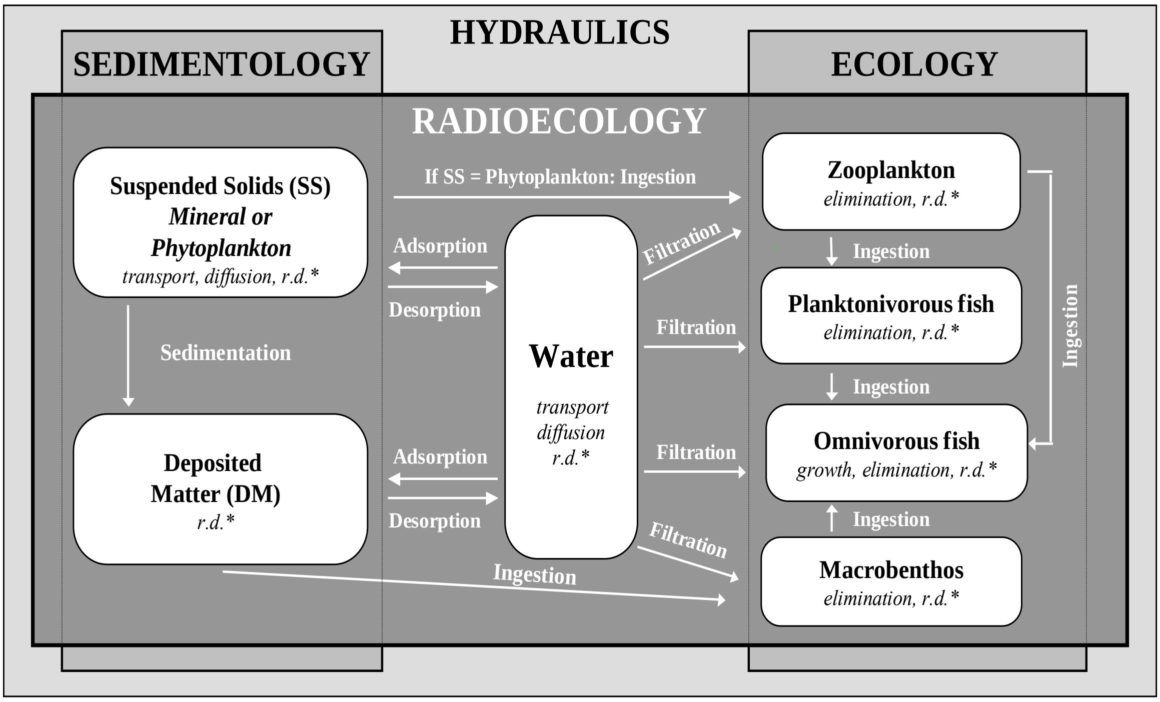
Won Seo I., Asce M. and Sung Cheong T (1998) *Predicting longitudinal dispersion coefficient in natural streams.* Journal of Hydraulic Engineering, 124 No. 1, 25-32.

CASTEAUR

Patrick Boyer, IRSN (France)

Brief description of model

CASTEAUR (French acronym of "Simplified Computation of Radionuclides Transfers in Receiving Waterways", homonym of "beaver") belongs to the category of operational tools that aim to assess the radioecological impact of radionuclides discharged in fluvial rivers, either during accidental or scheduled releases for middle scales, about one kilometre, several hours to several days. Its main is to compute spatial and temporal distributions of radionuclides in the following components of a fluvial hydrosystem: water, suspended solids (either mineral or phytoplankton), deposited matter, zooplankton, macrobenthos, planktonivorous fish and omnivorous fish. These transfers are evaluated using a radioecological model associated to three sub-models: 1) a hydraulic model, 2) a sedimentary dynamic model and 3) a food chain model. The general approach is one-dimensional: all computed values are assumed to be constant over the transversal sections perpendicular to the main flow direction. Rivers are represented in the model as linear successions of trapezoidal reaches. On each of these reaches, all hydraulic parameters and variables remain constant during the whole simulation period. All these assumptions limit the CASTEAUR domain of application, in space to the effluent well-mixing zone, and in time to a hydrological season. Four kind of pollutant sources (punctual permanent release, punctual pulse release, punctual sequential release and linear sequential release), each of them being composed of several radioactive nuclides and located everywhere on the river are available. The radionuclides inserts today in the code are: ^{110m}Ag, ^{241}Am, ^{58}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn, ^{103}Ru and ^{106}Ru. The prototype is developed under Visual Basic for Excel.



Hydrographic model

The river is described by a succession of reaches, constituting a hydrographic network. Each reach represents a homogeneous part of the river, for all its characteristics. It is defined by its length, L_r (m), its slope, I_r ($m \cdot m^{-1}$) and an isosceles trapezium bathymetric section form.

Hydraulics model

The flow conditions are supposed fluvial and permanent. The hydraulics model applied the Manning - Strickler relations, using the flow, the average velocity, the Strickler coefficient and the geometrical parameters, such as the hydraulics radius and the wet cross section, which are deduced from the water column height, the bottom width and the bank angle of each reach.

Sedimentary model

Under hypothesis of permanent conditions, the matter dynamics are mathematically formulated as a function of the (suspended and deposited) matters concentrations, the global longitudinal diffusion coefficient and the rate of deposit. Only the deposited matters represent the first layer of the bottom sediment, because they are considered similar to the suspended one. A single kind of matter is considered per run, mineral or phytoplanktonic. Considering that the cohesive matters (diameter < 64 mm) are more reactive with radioactive nuclides, the deposit rate is determined by the relation of Krone [4], taken into account the settling velocity, the deposit critical shear stress of the matter and the flow shear stress.

Food chain model

Three trophic levels are considered: plankton (both zoo- and phyto-), macrobenthos and fish. Mainly pelagic, the food chain is linked to the superficial bottom sediment through the macrobenthos. From it to fish, the trophic net is linear. Indeed, a realistic choice conduces to divide the fish compartment into juveniles and adults, whose diet includes the three inferior links of the food chain. The case of the phytoplankton is particular, as it is modeled as suspended matters. At each trophic level, the biological relations quantify the exchange rates of an average individual with the other levels and with the environment (alimentation, ingestion, filtration). Theoretically, these physiological parameters are space and time dependent. In a way consistent with the physical approach, they are taken to be constant per reach, and the temporal validity of CASTEAUR is thus limited to a season.

Radioecological models

The radioecological model computes the radionuclide transfers between the different components of the hydrosystem. Radionuclides exchanges between all CASTEAUR compartments are computed using kinetic models. Elimination of radionuclides by biotic components is supposed not to alter the radioactivity in water.

For the abiotic components, the basic equations take into account source terms, dispersion of radionuclides in water and of radionuclides associated with suspended matter, exchanges between compartments and radioactive decay.

References

Duchesne, S., Boyer, P. & Beaugelin-Seiller K. 2003. Sensitivity and uncertainty analysis of a model computing radionuclides transfers in fluvial ecosystems (CASTEAUR) application to ^{137}Cs accumulation in chubs. Ecological modelling, 166: 257-276

Casteaur parameters for the ^{137}Cs part of scenario 3

Only the three last reach of the river have to be considered for this scenario. In the framework of this exercice, the following paragraphs present the parameters considered for the different sub-model of Casteaur.

The colours gives the nature of the parameters:

■	Data given by the scenario
▒	Expert values not given by the scenario
□	Parameters calculated from the model

Geometrical and hydraulics parameters

Reach	**Length** (km)	**Width** (m)	**Bank angle** (°)	**Slope** (m/m)	**Strickler** ($m^{0.33}/s$)	**Q** (m3/s)	**H** (m)	**U** (m/s)	**S** (m2)	**R** (m)	**τ** (N/m^2)	**Kx** (m^2/s)
8	50	149.8	45	0.00011	50	374	2.55	0.96	389.36	2.48	2.67	1844
9	50	155.4	45	0.000108	50	405	2.63	0.97	416.74	2.55	2.70	1957
10	50	159.6	45	0.00014	50	427	2.47	1.06	401.54	2.41	3.30	2365

- The value given to the Strickler coefficient corresponds to an average for natural river.
- The bank angle is the default value proposed by CASTEAUR.
- The slopes are calibrated according the Strickler coefficient, the water flow and the water height.

Sedimentary parameters

Reach	**Vs** ($m.s^{-1}$)	τ_{CD} ($N.m^{-2}$)	q_{SS} ($mg.s^{-1}$)
8	0.0001	3.4	37400
9	0.0001	3.4	3100
10	0.000	3.4	2200

- The value-attributed toVs, the settling velocity, corresponds to suspended particle having an equivalent Stokes diameter equal to 10µm.
- τ_{CD}, the critical shear stress of deposition, is fixed to have an average deposition flux of 50 kg.m^{-2}.year^{-1} for a suspended matter concentration equal to 100mg.l^{-1}.
- Added to the flux of matter coming from the upper reach, this flux correspond to a specific entry associated to a concentration of 100 mg.l^{-1} multiply by the specific discharge added at the entry of each reach to the discharge coming from the upper ones.

Omnivorous fish parameters

Reach	Growth rate (j^{-1})	Feeding ratio $(kg.kg^{-1}.j^{-1})$	Diet zooplancton (%)	Diet macrobenthos (%)	Diet planktonivorous (%)
8	0.002	0.005	33	33	33
9	0.002	0.005	33	33	33
10	0.002	0.005	33	33	33

- These values are the default values given by CASTEAUR. In practice, they have to be adjusted for particular fish specie.

Abiotic radiological parameters for ^{137}Cs

Radioactive decay (s^{-1})	**Kd** $(m^3.kg^{-1})$	**Desorption kinetic suspended matter** (s^{-1})	**Desorption kinetic deposit matter** (s^{-1})
7.29007E-10	1	0.00053	3.21E-08

- The desorption kinetic for deposit matter is adjusted to verify equilibrium on one year between sedimentation and erosion fluxes.

Biotic radiological parameters for ^{137}Cs

Zooplancton

Filtration $(ml.g^{-1}.j^{-1})$	**Filtration elimination** (s^{-1})	Phytoplancton ingestion $(g.g^{-1}.j^{-1})$	**Phytoplancton elimination** (s^{-1})
60.5	2.16	1.81	0.58

Macrobenthos

Filtration ($ml.g^{-1}.j^{-1}$)	Filtration elimination (s^{-1})	Deposit matter ingestion ($g.g^{-1}.j^{-1}$)	Deposit matter elimination (s^{-1})
2.07	0.17	0.00004	1.04

Planktonivorous fish

Filtration ($ml.g^{-1}.j^{-1}$)	Filtration elimination (s^{-1})	Zoolancton ingestion ($g.g^{-1}.j^{-1}$)	Zooplancton elimination (s^{-1})
0.19	0.008	0.004	0.01

For the three previous biotic components:

- The accumulation parameters are aggregated radionuclide accumulation rate taking into account the efficiency of accumulation, the alimentation or filtration rate and the alimentary diet of the organism for the considered pathway..
- The elimination parameters are aggregated radionuclide elimination rate taking into account the increase in size, and the biologic excretion for the considered pathway.

Omnivorous fish

Filtration (-)	Filtration elimination (s^{-1})	Zoo ingestion (-)	Zoo elimination (s^{-1})	Benthos ingestion (-)	Benthos elimination (s^{-1})	Planktoniv. ingestion (-)	Planktoniv. elimination (s^{-1})
0.11	0.018	0.15	0.01	0.25	0.08	0.022	0.0007

For the omnivorous fish:

- The accumulation parameters are the radionuclide assimilation efficiency for the considered pathway.
- The elimination parameters are the kinetics of elimination for the considered pathway.

Release parameters

Receptor reach	Release position in the reach (m)	Release duration (h)	Release discharge ($Bq.s^{-1}$)
8	0	10	2.7

Initial conditions

- The activities are initially nulls in all the compartments and everywhere along the river.

MARTE (MOIRA sub-code)

L. Monte, ENEA (Italy)

MARTE (**M**odel for **A**ssessing **R**adionuclide **T**ransport and countermeasure **E**ffects in complex catchments - **MARTE**) is a model for predicting the effects of countermeasures aimed to restore radionuclide polluted fresh water systems The model, is included in the MOIRA software. It provides assessments of radionuclide behaviour in water systems comprised of rivers, lakes and reservoirs. It makes use of aggregate, "collective" parameters which summarise the overall effects of competing migration processes occurring in fresh water bodies. The model accounts for the radionuclide fluxes from the water column to the sediment and vice-versa, for the radionuclide migration from the catchment and for the transport of contaminated matter through the water body. The model can predict the effects of the following countermeasures: a) Sediment removal; b) Diversion of water from sub-catchments; and c) Decontamination of sub-catchments. The results of the sensitivity and uncertainty analyses are described. Some examples of countermeasure applications are described and discussed.

MARTE is a box model that supplies predictions averaged over a spatially defined part of the water system (for instance a small lake or a part of a river).

The model includes:

- A radionuclide migration sub-model;
- A simple hydrological sub-model for the approximate evaluation of the water balance and the water fluxes;
- A sub-model for predicting the effects of countermeasures.

The model is basically composed of "elementary boxes" (EB). An EB is any part of a water body and of its catchment. A lake (or a part of it), a part of a river are examples of elementary boxes. A complex catchment is assumed to be composed of a chain of interconnected EBs.

Each EB is comprised of

- The water column;
- An upper sediment layer strongly interacting with water ("interface layer);
- An intermediate sediment layer below the "interface layer" ("bottom sediment");
- A sink sediment layer below the "bottom sediment";
- The right and left sub-catchments of the EB.

The models for predicting the radionuclide behaviour in each EB and the radionuclide migration from the catchment have been extensively described in previous papers.

The radionuclide fluxes within each EB are due to the following processes:

- Sedimentation;
- Radionuclide removal due to water withdrawal;
- Radionuclide migration from water to sediment (diffusion component);
- Radionuclide migration from sediment to water (resuspension);
- Radionuclide migration from catchment;
- Radionuclide transport through the EB chain.

REFERENCE

Monte, L. 2001. A generic model for assessing the effects of countermeasures to reduce the radionuclide contamination levels in abiotic components of fresh water systems and complex catchments. Environmental Modelling and Software, 16: 669-690

UPPSALA UNIVERSITY MODEL

Lars Håkanson, Unppsala University (Sweden)

This section presents very briefly a new general, mechnistically-based river model for substances such as radionuclides, metals, organics and nutrients from single pulse fallouts. The model has been critically tested using data from 13 European rivers contaminated by radiocesium from the Chernobyl accident. This modelling approach gives radionuclide concentrations in water (total, dissolved and particulate phases; and also concentrations in sediments and fish) at defined river sites. The model is based on processes in the upstream river stretch and in the upstream right and left side catchment area (see fig. 5.1). The catchment area is differentiated into (1) inflow ($\approx$ dry land) areas with a dominant horizontal transport of radionuclides and water and (2) outflow ($\approx$ wetland) areas with a dominant vertical transport of matter (see fig. 5.2). The upstream river stretch is differentiated into (1) areas where erosion and transport (ET-areas) processes for fine materials settling according to Stokes's law dominate the bottom dynamic conditions and (2) accumulation areas (A-areas) with continuous sedimentation of fine sediments, such as in topographically sheltered areas and in macrophyte beds (see fig. 5.3). All basic equations are compiled in table 5.1. The model also accounts for time-dependent fixation of substances in the catchment. The catchment area sub-model is based on a previous catchment model, which has been tested with very good results for radiocesium, radiostrontium and Ca-concentrations (from liming operations; see Håkanson et al., 2002).

The model is simple to apply in practice since all driving variables may be readily accessed from maps an standard monitoring programs. The driving variables are: latitude, altitude, continentality, catchment area, mean annual precipitation, soil type (percentages or organic and sandy soils), fallout and month of fallout. Modelled values have been compared to independent empirical data from 10 rivers sites (91 data on radiocesium in water) covering a wide domain (catchment areas from 4000 to 180000 km^2, precipitation from 500 to 960 mm/yr, and fallout from 1700 to 660000 Bq/m^2). The new model predicts very well - when modelled values are compared to empirical data, the slope is perfect (1.0) and the r^2-value is 0.90. This is good given the fact that there are also uncertainties in the empirical data, which set a limit to the achieved predictive power, as expressed by the r^2-value.

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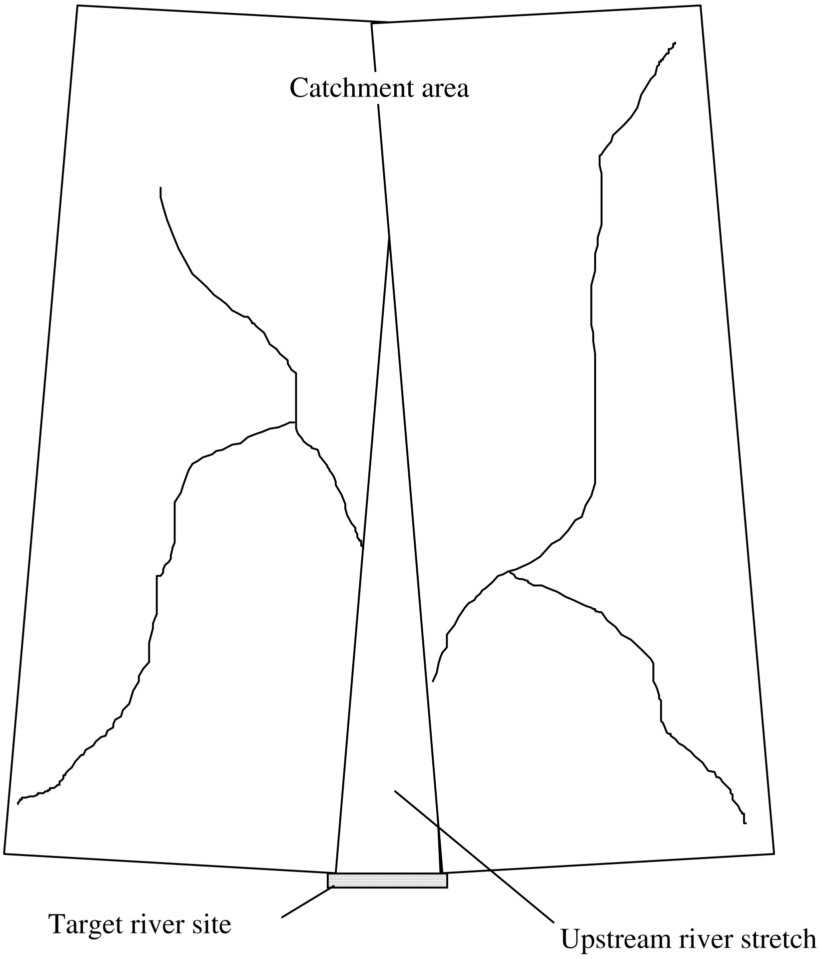


Obligatory driving variables

A. Catchment area

Fallout in Bq/m2 and month of fallout
Catchment area in km2
Soil type (a rule system based on percentages of organic and sandy soils)
Mean annual precipitation in mm/yr
Latitude in °N
Altitude in m.a.s.l.
Continentality in km

B. Upstream river stretch

River length in m
Characteristic K-conc. in water in mg/l
Characteristic TP-conc. in water in µg/l
Characteristic SPM-conc. in water in mg/l

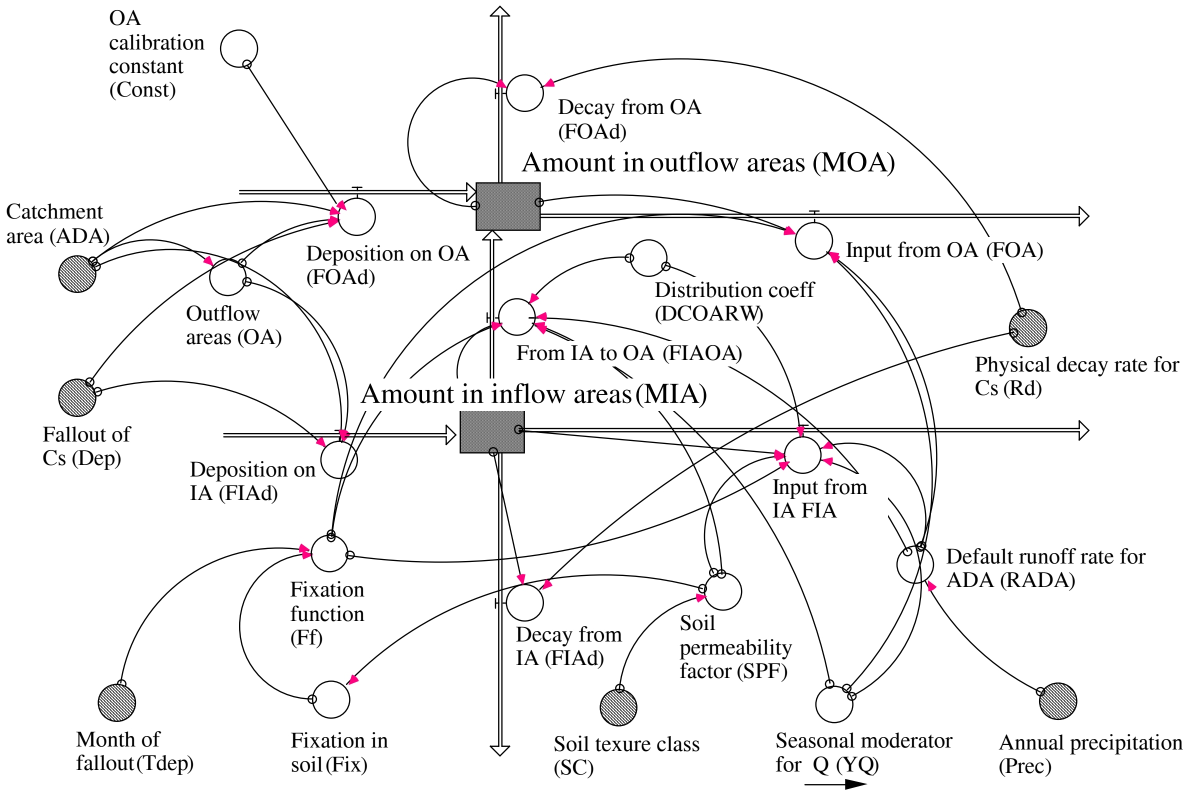
Taget variables for the selected river site:

- Radionuclide concentrations in water (mean monthly values in Bq/m3).
- Radionuclide concentrations in sediments (mean monthly values in Bq/g dw).
- Radionuclide concentrations in fish (mean monthly values in Bq/kg ww).

- The model also includes a sub-model to predict mean monthly water discharge and monthly values of water temperatures from data on latitude, altitude, continentality, river volume and mean annual precipitation.

Fig. 5.1. An outline of the river model. It is based on a sub-model for the river stretch upstream a defined sampling site and a corresponding catchment area sub-model. The figure also lists the obligatory driving variables, the target variables and the fact that the river model also includes sub-models to predict water discharge and water temperature based on readily accessible data.

Catchment area sub-model



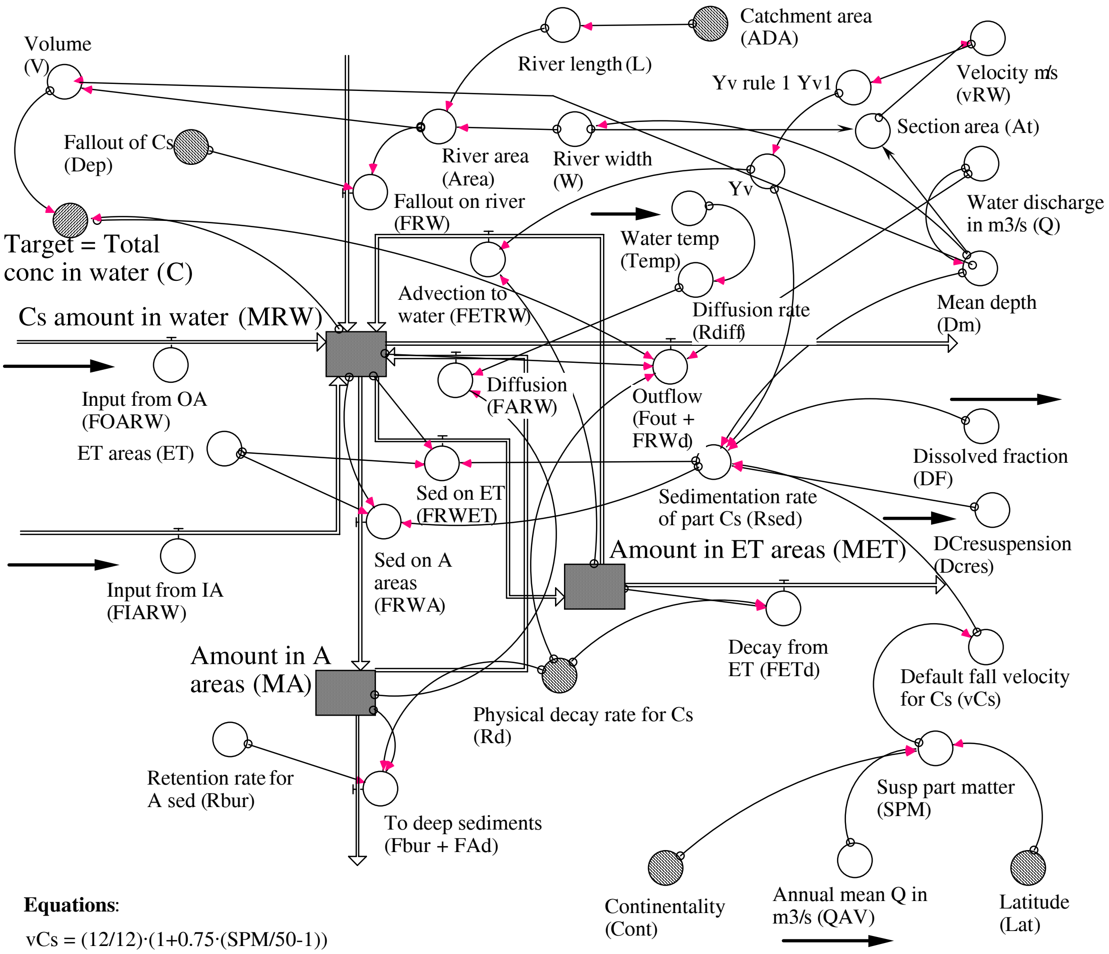
Equations:
RADA = 0.04·(Prec/650)^2
DCOARW = 0.5
If (TIME-Tdep) < 1 then Ff = (1/(1)^Fix) else Ff = (1/(TIME-Tdep)^Fix)
Fix = (SPF)/100
OA = 10^(-0.19·log(ADA/1000000)-0.71)
Rd = 0.693/(30.2·12)
SPF = 40·SC
Rules of catchment area soil factor (SC):
If there is no information on characteristic soil type (ST), use default value SC = 1
If Sandy soils dominate (Soil%) > 50% then SC = 1
else if organic soils dominate (Org%) > 50% then SC = 0.25
else if Sand% or Org% < 50% then
if Sand%+Org% < 5% then SC = 4
if Sand%+Org% 5-10% then SC = 3
if Sand%+Org% 5 -20 then SC = 2.5
if Sand%+Org% 20-35 then SC = 2
if Sand%+Org% 35-50 then SC = 1.5
if Org% > 25% then SC = 0.5

▨ = Obligatory driving variable

→ = From sub-model

Fig.5. 2. An outline of the catchment area sub-model. The following calibrations focus on the outflow area (OA) calibration constant and the rules regarding the Soil texture class.

Sub-model for upstream river stretches (URS)



Equations:

vCs = (12/12)·(1+0.75·(SPM/50-1))
Rdiff = (0.002/12)·(Temp/4)
DF = If (1/(1+Kd·SPM/1000000)) < 0.1 then DF = 0.1 else DF = (1/(1+Kd·SPM/1000000))
ET = 0.95
Dm = (0.0135+0.159·Q^0.45)
W = (68.2·Dm-3.90)/2
Rd = 0.693/(30.2·12)
Rbur = 48
Area = L·W
L = ADA·10/10^6
Rsed = Yv·((1-DF)·(1-Dcres)·(vCs/Dm)+((1-DF)·Dcres·2·(vCs/Dm))
SPM = 10^((3.44·(90-Lat)/90)+0.24·log(QAM)+0.0066·(Cont)^0.5-0.83)
C = MRW/V
vRW = Q/At
V = Dm·Area
Yv = If Yv1 < 0.001 then Yv = 0.001 else Yv = Yv1
Yv1 = If vRW < 0.1 m/s then 1Yv1 = else Yv1 = (1-0.1·(vRW/0.1-1))

▨ = Obligatory driving variable

→ = From sub-model

Fig. 5.3. The sub-model for upstream river stretches.

Table 5.1. Compilation of the differential equations making up the river model

---

Compartment river water (M_{RW}):

$M_{RW}(t) = M_{RW}(t - dt) + (F_{RW} + F_{OARW} + F_{IARW} + F_{ARW} + F_{ETRW} - F_{out} - F_{RWd} - F_{RWA} - F_{RWET})\cdot dt$

where

Fallout on river water: $F_{RW} = Dep\cdot Area$

Input from outflow areas: $F_{OARW} = (10\cdot R_{ADA}\cdot M_{OA}\cdot Y_Q\cdot Ff)/12$ [OH area calibration constant = 10]

Input from inflow areas: $F_{IARW} = (R_{ADA}\cdot M_{IA}\ (1-DC_{OARW})\cdot Y_Q\cdot Ff)/(12\cdot SPF)$

Diffusion from A-areas to river water: $F_{ARW} = M_A\cdot R_{diff}$

Resuspension from ET-areas to river water: $F_{ETRW} = M_{ET}\cdot(1-Y_v)$

Outflow from river to downstrean river stretch: $F_{out} = Q\cdot C$

Physical decay from river water: $F_{RWd} = M_{RW}\cdot R_d$

Sedimentation from river water to A-areas: $F_{RWA} = M_{RW}\cdot v_{Cs}\cdot(1-ET)$

Sedimentation from river water to ET-areas: $F_{RWET} = M_{RW}\cdot v_{Cs}\cdot ET$

Compartment (sediment) accumultion areas (M_A):

$M_A(t) = M_A(t - dt) + (F_{RWA} - F_{ARW} - F_{bur} - F_{Ad})\cdot dt$

where

Burial (transport from bioactive to biopassive A-sediments): $F_{bur} = M_A\cdot R_{bur}$

Physical decay from A-areas: $F_{Ad} = M_A\cdot R_d$

Compartment (sediment) erosion and transport areas (M_{ET}):

$M_{ET}(t) = M_{ET}(t - dt) + (F_{RWET} - F_{ETRW} - F_{ETd})\cdot dt$

where

Physical decay from ET-areas: $F_{ETd} = M_{ET}\cdot R_d$

Compartment (catchment) outflow areas (M_{OA}):

$M_{OA}(t) = M_{OA}(t - dt) + (F_{OAd} + F_{IAOA} - F_{OA} - F_{OAd})\cdot dt$

where

Deposition on outflow areas: $F_{OAd} = Dep -ADA\cdot OA$

Transport from IA- to OA-areas: $F_{IAOA} = (DC_{OARW}\cdot Ff\cdot M_{IA}\cdot Y_Q\cdot R_{ADA})/(12\cdot SPF)$

Physical decay from OA-areas: $F_{OAd} = M_{OA}\cdot R_d$

Compartment (catchment) inflow areas (M_{IA}):

$M_{IA}(t) = M_{IA}(t - dt) + (F_{IAd} - F_{IA} - F_{IAd} - F_{IAOA})\cdot dt$

where

Deposition on inflow areas: $F_{IAd} = Dep\cdot ADA\cdot(1-OA)$

Decay from IA-areas: $F_{IAd} = M_{IA}\cdot R_d$

1. Sedimentation using the UU River model.

Sedimentation from river water to ET-areas:

$F_{RWET} = M_{RW} \cdot R_{sed} \cdot ET$

Where
M_{RW} = The amount (= mass) of the radionuclide (here radiocesium) in river water (Bq).
R_{sed} = The sedimentation or settling rate of particulate fraction of the radionuclide (1/month); the only fraction subject to gravitational sedthe imentation according to Stokes' law.
ET = The fraction of ET-areas in the upstream river stretch (dim. less); set to 0.95 as a default value.

R_{sed} is given by:

$R_{sed} = Y_v \cdot (PF \cdot v_{Cs}/Dm) \cdot ((1-DC_{res})+DC_{res} \cdot 2)$

Where
Y_V = A dimensionless moderator expressing how river water velocity influences sedimentation and resuspension. If $v_{RW} < 0.1$ (river water velocity in m/sec) then Y_v = 1 else $Y_v = (1-0.1 \cdot (v_{RW}/0.1-1))$; $v_{RW} = Q/At$ (Q = river water discharge in m^3/sec and At = river section area in m^2).
PF = The particulate fraction (dim. less). PF = (1 – DF); DF is the dissolved fraction; for radiocesium $DF = (1/(1+Const \cdot SPM/C_K))$; Const is the Kd constant in mg K/g. C_K is the potassium concentration in the river water in mg K/l and SPM is the concentration of suspended particulate matter in the river water in g/l.
v_{sed} = the settling velocity (m/month) of the carrier particles for the radionuclide; for radiocesium $v_{sed} = 1 \cdot (1+0.75 \cdot (SPM/50-1))$.
Dm = the mean river depth (m).
DC_{res} = the resuspended fraction of the radionuclide in the water mass (dim. less).
2 = The resuspended particles settle 2 times faster than the primary materials; an empirical constant (dim. less).

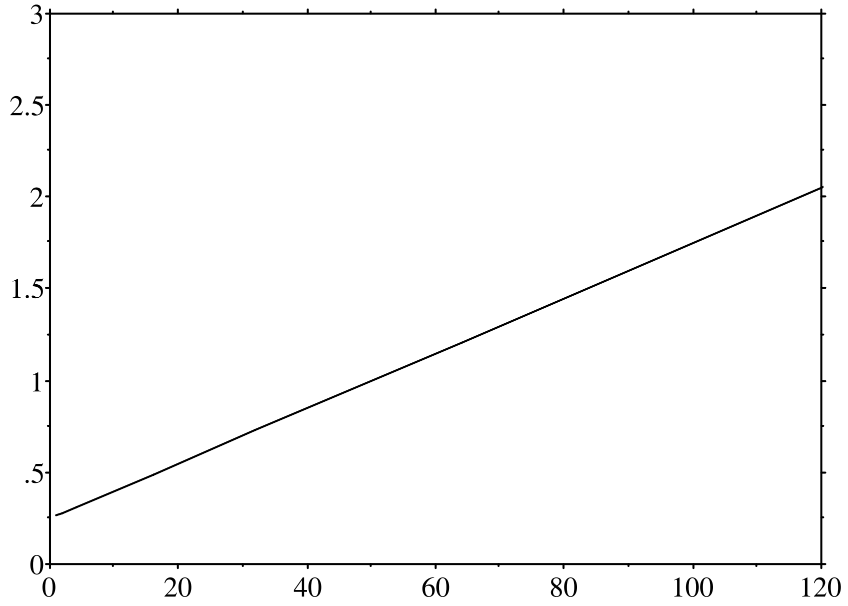


Fig. 2. The model developed by Uppsala University makes use of values of the settling velocity of the particulate fraction of the radionuclide which is a function of the concentration of suspended particulate matter (SPM) in the river water – the higher the SPM-concentration, the higher the flocculation, aggregation and the settling velocity.

2. <u>Resuspension</u>

The resuspension flux of the radionuclide from ET-sediments to river water is given by:

$F_{ETRW} = M_{ET} \cdot R_{res} \cdot (1 - Y_v)$

Where

M_{ET} = Amount (= mass) of radionuclide (here radiocesium) in ET-sediments (Bq).
R_{res} = The resuspension rate of the radionuclide (m/month); this model uses a default value of 1 (1/month) for R_{res}.
Y_V = A dimensionless moderator expressing how river water velocity influences sedimentation and resuspension. Y_V is never permitted to be > 1. If the river water velocity, v_{RW} approaches 100 cm/s, sedimentation approaches zero and the resuspension rate approaches 1.

3. Burial

This is the flux (F_{bur} in Bq/month) from top to deep accumulation area (A = 1 -ET) sediments; by definition there is no burial on ET-areas.

$F_{bur} = M_A \cdot R_{bur}$

Where
M_A = Amount (= mass) of radionuclide (here radiocesium) in the upper (bioactive) A-sediment layer (Bq).
R_{bur} = The burial rate of the radionuclide (1/month); this model uses a default value of 4 years for the age of the radionuclides on A-sediments, so the burial rate is 1/48 (in 1/months).

References

Håkanson, L., Sazykina, T.G., and Kryshev, I.I., 2002 A general approach to transform a lake model for one radionuclide (radiocesium) to another (radiostrontium) and critical model tests using data for four Ural lakes contaminated by the fallout from the Kyshtym accident in 1957. J. Env. Radioactivity, 60:319-350

RIVTOX

Mark Zheleznyak, IMMSP (Ukraine)

RIVTOX is a one-dimensional model describing the cross-sectionally averaged flow in a network of upland channels. The model was obtained by averaging the three-dimensional dispersion equation over the river width and depth.

The water flow, the suspended sediments and the radionuclide transport in both solution and suspended matter are simulated by the Saint-Venant's and the advection-dispersion equations.

RIVTOX includes two hydraulic models:

- RIVTOX-HD: diffusion approximation of Saint-Venant equations
- RIVTOX-HSV: full Sint-Venant equation (for rivers with dams, gates, and other obstacles disturbing water elevation and water discharge).

The sub-model for assessing the suspended sediment transport is based on the advection-diffusion equation with parametrisation of sedimentation/erosion rates.

The model structure is reported in the following picture.

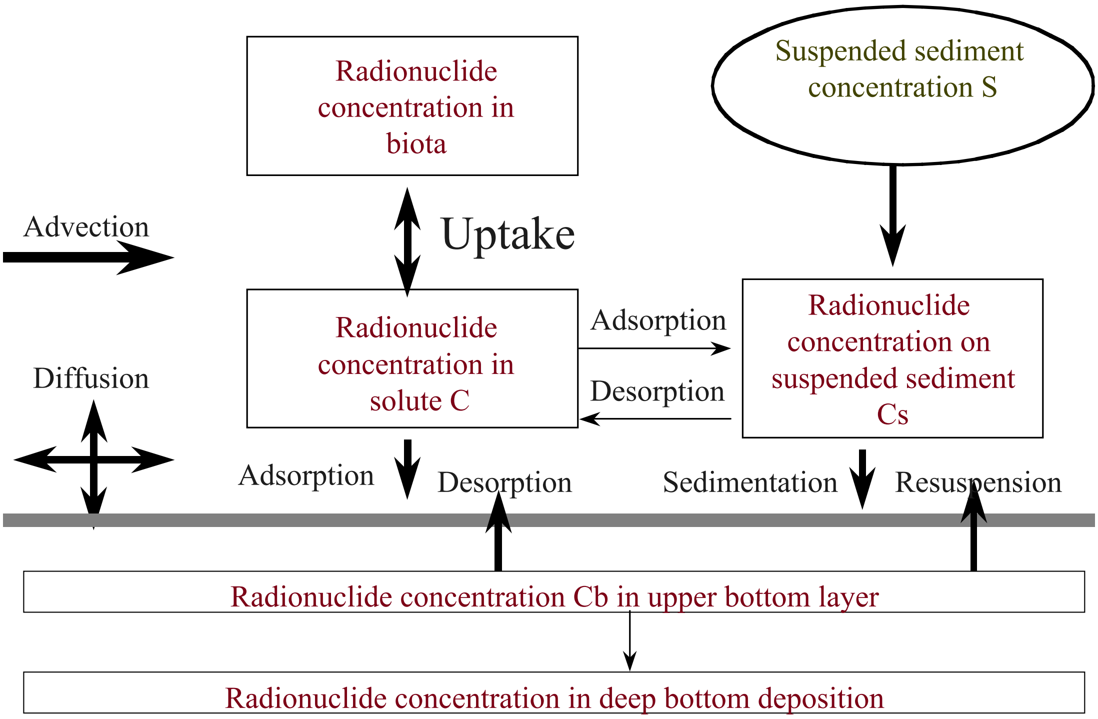


Figure 6.1. Structure of model RIVTOX (processes in the water-sediment subsystem)

RIPARIA

Samuel Lepicard, CEPN (France)

General Presentation of RIPARIA

RIPARIA is a "compartmental-modelling" computer code for assessing the radiological consequences of radioactive releases into rivers [1]. This code was developed and tested by CEPN for the French Rhône river in the framework of the ExternE study [2], and its parameters have been adjusted to the Dnieper cascade in the context of a recent study [3]. In particular the modelling of the sedimentation processes has also been modified, on the basis of the European Methodology report RP72 [4].

The major assumption inherent to this compartmental modelling is the homogeneity of each reservoir with respect to its parameters (i.e. suspended sediment load, sedimentation rate, depth, etc.), and an equal distribution of the activity within the volume of the compartment. Exchanges between compartments are expressed in terms of an average annual transferred volume of water. Seasonal variations (of water flows for example) are not considered in the modelling. The impacts of such seasonal variations of water flows were estimated and considered in the variability study of dose assessment results.

Principles for Radionuclide Dispersion Modelling

Each compartment of the river is modelled as a box made up of different layers. The first layer corresponds to the water column. The processes of dispersion of the radionuclides into the river system refer to mechanisms of transport by water exchanges between each compartments (water outflow). The second layer corresponds to the bed sediments. The sediment processes result from three phenomena: depletion of suspended materials in equilibrium with the water phase activity, diffusion of radioactivity between the water column and the bed sediment layer, and bioturbation, modelled as a diffusive process between layers too.

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[1] RAFFESTIN, D., LEPICARD, S., MICHOU, P., RIPARIA: Logiciel d'évaluation de l'impact radiologique associé au relâchement de matières radioactives en milieu fluvial, Rapport CEPN n° 237, 1995.

[2] M. DREICER, V. TORT, P. MANEN, **Nuclear fuel cycle: estimation of physical impacts and monetary valuation for priority pathways**, Rapport CEPN N°234, 1995.

[3] LEPICARD S., **Chernobyl dyke on the Pripyat river: collective dose reduction and cost-benefit analysis**, Report CEPN n°265, 1999.

[4] EUROPEAN COMMISSION, **Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment**, RP 72, EUR 15760, 1995.

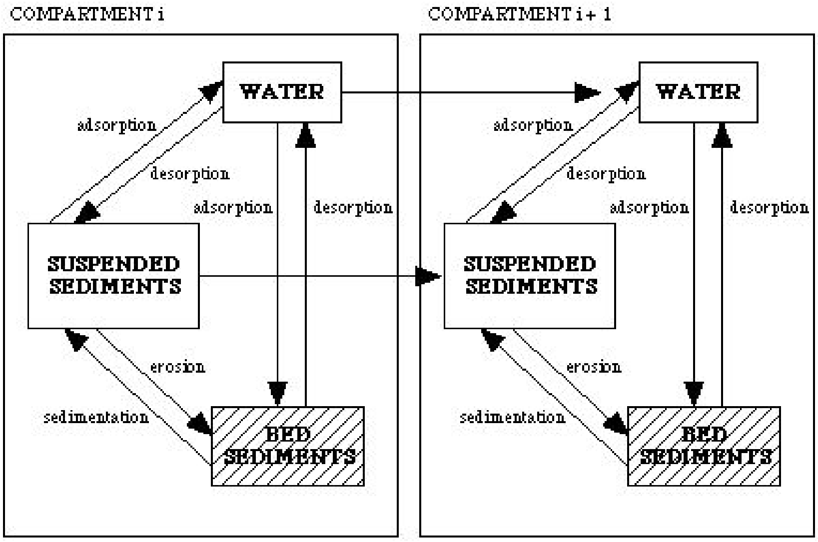

Figure 7.1 **Modelling of the radionuclide dispersion and sedimentation processes**

Each compartment of the river is characterised by a set of parameters: volume, length, width, depth, water outflow and bed sediment depth (the depth of the sediment layer where exchanges of radionuclides – diffusion, bioturbation – are occuring).

The equations of the time evolution of the activity concentration in both water columns and bed sediment layers are written for each compartment i:

$$\frac{dC_{i,w}}{dt} = \frac{k_{i-1,i}}{V_i} \cdot C_{i-1,w} - \frac{k_{i,i+1}}{V_i} \cdot C_{i,w} - (\lambda_1 + \lambda) \cdot C_{i,w} + \lambda_2 \cdot \frac{e_i}{h_i} \cdot C_{i,sed} + Q_w$$

$$\frac{dC_{i,sed}}{dt} = -(\lambda_2 + \lambda) \cdot C_{i,sed} + \lambda_1 \cdot \frac{h_i}{e_i} \cdot C_{i,w} + Q_{sed}$$

where:
$C_{i,w}$: activity concentration in water column (in Bq.m^{-3}) – unfiltered water,
$C_{i,sed}$: activity concentration in bed sediments (in Bq.m^{-3}) – wet sediments,
$K_{i-1,i}$: water flow from compartment i-1 (upstream) to compartment i (in m^3.y^{-1}),
V_i: volume of compartment i (in m^3),
λ: radioactive decay constant (in y^{-1}),
e_i: depth of bed sediment (in m),
h_i: depth of water column (in m),
Q_w: release rate in dissolved form (normalised by the volume of the release compartment – in Bq.m^{-3}.y^{-1}),
Q_{sed}: release rate in adsorbed form (normalised by the volume of the release compartment – in Bq.m^{-3}.y^{-1}).

Activity in the water column is lost to bed sediments through sorption onto suspended particulates which then settle out. The transfer from the water column to the bed sediment layer is given by λ_1 while the return of activity from bed sediments to the water column is given by λ_2.

$$\lambda_1 = \frac{K_d \cdot S}{h(1 + K_d \cdot SS)} + \frac{1}{R} \cdot \frac{D}{h \cdot e} + \frac{(R-1)}{R} \cdot \frac{B}{h \cdot e}$$

$$\lambda_2 = \frac{1}{R} \cdot \frac{D}{e^2} + \frac{(R-1)}{R} \cdot \frac{B}{e^2}$$

with:

$$R = 1 + (1 - \varepsilon)\frac{\rho}{\varepsilon} \cdot K_d$$

where:
K_d: concentration factor for sediments (in Bq.kg^{-1} per Bq.m^{-3}),
S: sedimentation rate (in kg.m^{-2}.y^{-1}),
h: depth of water column (in m),
e: depth of bed sediments (in m),
SS: suspended sediment load (in kg.m^{-3}),
ε: porosity of sediments (dimensionless)
ρ: density of sediments – dry weight (in kg.m^{-3}),
D: diffusion coefficient (in m^2.y^{-1}),
B: bioturbation coefficient (in m^2.y^{-1}).
R: retardation coefficient (dimensionless) which is used to distinguish between activity held on the sediments and activity in the water; R^{-1} is the proportion of activity held in the sediment pore water.

The activity concentrations in filtered water and in dry sediments are given by:

$$C_{i,w}^{filtered} = \frac{1}{1 + K_d \cdot SS} \cdot C_{i,w}$$

$$C_{i,sed}^{dry} = \frac{K_d}{R \cdot \varepsilon} \cdot C_{i,sed}$$

Creation of the "evanet" river test and update of modelling parameters

Calculations presented hereafter were conducted with RIPARIA computer code. The scenario which served as a basis for these calculations was the 3rd scenario (point release).
The "evanet" test river considered for the scenario was introduced in RIPARIA database. All physical parameters necessary for the calculations are presented in Table 7.1 at the end of this document and discussed below. In concrete terms, all parameters necessary for the customisation must have been entered in two corresponding files.

The following parameters have been taken directly from the scenario description:

- Compartments length, width and depth (yearly averages),
- Water flow (yearly average m^3/year),
- Suspended matter (average value 100 g/m^3).

Some parameters given in the scenario description could not have been taken into account, such as:

- Water chemical characteristics,
- Fish speciation,
- Catchment characteristics.

Finally some parameters were required for RIPARIA and not mentioned in the scenario description. Default values have been derived from the literature (past experience):

- Sedimentation rate (0.5 kg/m^2/year),
- Bottom sediment depth, density and porosity (respectively 0.2 m, 2.6 t/m^3 and 0.75),
- Diffusion and bioturbation coefficients (respectively 3.15E-02 m^2/y and 3.6E-05 m^2/year),
- Radionuclide dependent data: it was decided to consider two sets of values for Kd sediment, in order to evaluate the impact on results (mainly on the activity concentrations in bottom sediments).

Radionuclide	Kd sediment (m^3/kg)	Kd fish (m^3/kg)
^{137}Cs	20$^{(1)}$, 1$^{(2)}$	1
^{90}Sr	0.2$^{(1)}$, 1$^{(2)}$	0.03

$^{(1)}$: Default value in RIPARIA; $^{(2)}$: From IAEA Safety Reports Series n°19 (2001)

Definition of the accidental release

This scenario considers a 10 hour release of a total of 10^5 Bq of ^{137}Cs and ^{90}Sr respectively (100% in dissolved form[5]) at the top of compartment n°8 (350 km from the river spring).

Presentation of the results

The activity concentrations of ^{137}Cs and ^{90}Sr in water (resp. total and dissolved form), sediments (bottom) and fish are given at 1 km and 10 km (same compartment n°8) and 100 km (compartment n°9). They are provided for each hour since the beginning of the release until 2 weeks (e.g. during 236 hours).

The format of the results in the database is presented hereafter.

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[5] RIPARIA allows the introduction of radionuclides in the river system into two distinct forms: the first is dissolved form (in water) and the second is adsorbed form (in sediments).

Format of results database

Column of database	**Range of values**
Radionuclide	[CS-137], [SR-90]
Time (hours)	from 1 to 336
Distance	[1 km, 10 km (n°8)], [100 km (n°9)]
Kd Sediment (m3/kg)	[Resp. 20 and 1 for ^{137}Cs] and [0.2 and 1 for ^{90}Sr]
Total activity in water (unfiltered) (Bq/m3)	-
Dissolved activity in water (filtered) (Bq/m3)	-
Total activity in sediments (wet weight) (Bq/m3)	-
Activity in biota (fish) (Bq/kg)	-

Table. 7.1 Characteristics of radionuclides included in RIPARIA

Nuclide	Decay constant (/s)	Kd sediments (m3/kg)	Kd fish (m3/kg)	Fc ingestion (Sv/Bq)	Kd green vegetables (Bq/kg per Bq/m2/y)	Kd root vegetables (Bq/kg per Bq/m2/y)	Kd cereals (Bq/kg per Bq/m2/y)	Kd cow meat (Bq/kg per Bq/m2/y)	Kd cow milk (Bq/kg per Bq/m2/y)
Ag110	3,21E-08	0,2	2,30E-03	2,80E-09	3,71E-03	3,92E-04	2,36E-03	1,33E-03	4,66E-02
C--14	3,84E-12	2	4,5	5,80E-10	2,93E-03	5,86E-03	2,64E-02	8,79E-03	2,93E-03
Co-58	1,13E-07	20	0,3	7,40E-10	2,91E-03	8,13E-06	1,65E-03	2,20E-04	1,63E-03
Co-60	4,18E-09	20	0,3	3,40E-09	3,66E-03	1,63E-04	2,18E-03	9,26E-04	2,25E-03
Cr-51	2,90E-07	20	0,04	3,80E-11	2,21E-03	6,78E-08	1,13E-04	1,57E-03	1,39E-03
Cs134	1,06E-08	20	1	1,90E-08	4,17E-03	3,78E-03	1,54E-02	2,52E-02	5,05E-03
Cs137	7,33E-10	20	1	1,30E-08	4,72E-03	4,42E-03	1,67E-02	2,90E-02	5,67E-03
Fe-55	8,19E-09	10	0,1	3,30E-10	3,47E-03	7,69E-06	2,08E-03	2,33E-04	2,83E-04
Fe-59	1,78E-07	10	0,1	1,80E-09	2,62E-03	1,77E-06	1,43E-03	1,75E-05	2,27E-04
H---3	1,79E-09	3,00E-05	9,00E-04	1,80E-11	7,99E-03	7,10E-03	8,88E-04	6,22E-03	7,99E-03
I-129	1,37E-15	0,3	0,02	1,10E-07	1,05E-02	1,02E-02	2,23E-02	6,75E-03	9,98E-03
I-131	1,00E-06	0,3	0,02	2,20E-08	1,31E-03	2,74E-04	1,34E-03	7,85E-04	1,85E-03
Mn-54	2,57E-08	50	0,1	7,10E-10	3,61E-03	2,50E-04	2,25E-03	6,09E-03	3,98E-03
Ra226	1,37E-11	0,5	0,05	2,80E-07	6,50E-03	3,07E-04	2,42E-03	6,59E-04	5,36E-04
Ru106	2,03E-07	7	0,01	7,00E-09	3,23E-03	2,92E-05	1,94E-04	5,07E-04	9,44E-07
Sb124	1,33E-07	0,5	0,001	2,50E-09	2,82E-03	7,04E-06	1,58E-03	6,06E-04	7,99E-05
Sr-90	7,63E-10	0,2	0,03	2,80E-08	2,39E-02	3,57E-03	1,64E-02	9,65E-04	4,51E-03
U-234	8,96E-14	0,05	0,01	4,90E-08	3,64E-03	3,20E-04	4,94E-04	2,43E-04	7,35E-04
Zn-65	3,29E-08	1	1	3,90E-09	5,20E-03	9,45E-04	3,87E-03	3,49E-03	4,16E-02

Table 7.2. Input parameters for test river “evanet” description

Green cells: data directly taken from scenario description
Red cells: data derived/taken from the literature (past experiences)

n°Comp	Vol(m3)	Flux(m3/y)	Suspended sediments (kg/m3)	Sedimentation Rate(kg/m2/y)	Bottom sediment density (kg/m3)	Bottom sediment porosity	Diffusion coefficient (m2/y)	Bioturbation coefficient (m2/y)	Compartment lenght (m)	Width (m)	Depth (m)	Bottom sediment depth (m)
1	1,17E+06	6,22E+08	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	38,56	0,6	0,2
2	3,83E+06	2,49E+09	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	72,95	1,05	0,2
3	9,04E+06	5,99E+09	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	109	1,66	0,2
4	1,46E+07	1,02E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	139,08	2,1	0,2
5	2,00E+07	1,47E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	162,88	2,45	0,2
6	2,78E+07	2,10E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	192,55	2,88	0,2
7	3,28E+07	2,52E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	209,63	3,13	0,2
8	3,62E+07	2,80E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	220,17	3,29	0,2
9	3,84E+07	2,99E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	226,95	3,38	0,2
10	4,00E+07	3,13E+10	1,00E-01	5,00E-01	2,60E+03	7,50E-01	3,15E-02	3,60E-05	5,00E+04	231,83	3,45	0,2

APPENDIX B TO SECTION 4

Intercomparison exercise of river models

Scenario description

This is a hypothetical scenario aimed at the intercomparison of models for predicting the behaviour of radionuclides in rivers.
The location, the geographical characteristics of catchment, of soil and of rocks, the chemical characteristic of water, the average yearly runoff, the main fish species correspond to real conditions of river Po (north Italy).
Morphometric data are hypothetical but realistic.

River name: Test
Location: 44° -48° North, 8° - 12° East Length: 500 km
Catchment area: 50000 km^2.

Main characteristics of the catchment: high mountains in the northern part (up to 4800 m) with perennial glaciers (Alpine region); plain area: more than 2/3 of the total catchment surface. Alluvial plain.
Main soil characteristics: Lithosol, Rankers, Rendzinas, Rock outcrop, Humic podzols, Dystric cambisol (mountain area); Cambisols. Eutric fluvisols, Fluvio-Eutric Gleysols, Eutric Histosols (Plain). High population density in the plain area with significant agricultural and industrial activities.

Air temperature (yearly average): < 5 °C (mountain area); 12-14 °C on the plain

Chemical characteristics of the water (ranges):
pH 7.6 – 8.
Cond. ($\mu S\ cm^{-1}$) : 300 – 450
Ca ($g\ m^{-3}$): 47 – 68
K ($g\ m^{-3}$): 2 – 2.8
Na ($g\ m^{-3}$): 9.7 –13.9
Mg ($g\ m^{-3}$): 9.3 – 13.8
Suspended matter ($g\ m^{-3}$): 50 - 154

Main fish species:
Barbus b. plebejus
Scardinius erythrophthalmus
Leuciscus c. cabeda
Carassius carassius
Alborella a. alborella
Rutilus erythrophthalmus

Leuciscus s. muticellus
Rutilus pigus
Anguilla anguilla
Cyprinus carpio

We suppose that the river is composed of 10 reaches. The following morphologic data are relevant to these reaches.

Morphologic data of the catchment.

ID number of the river segment	Left sub-catchment area (km^2)	Right sub-catchment area (km^2)	Distance from the source (km)
1	500	500	0-50
2	1500	1500	50-100
3	2500	2500	100-150
4	3000	3000	150-200
5	5500	5500	200-250
6	4500	4500	250-300
7	3000	3000	300-350
8	2000	2000	350-400
9	1500	1500	400-450
10	1000	1000	450-500

Monthly average flux (m^3 month^{-1})

Distance from the source (km)	January	February	March	April	May	June	July	August	September	October	November	December
0-50	2,789E7	3,202E7	2,642E7	3,458E7	7,055E7	5,071E7	2,830E7	4,226E7	8,157E7	9,040E7	9,924E7	3,791E7
50-100	1,116E8	1,281E8	1,057E8	1,383E8	2,821E8	2,028E8	1,132E8	1,690E8	3,261E8	3,615E8	3,968E8	1,516E8
100-150	2,528E8	2,951E8	2,396E8	3,250E8	6,900E8	4,976E8	2,753E8	4,147E8	8,029E8	8,825E8	9,620E8	3,482E8
150-200	4,223E8	4,956E8	4,002E8	5,491E8	1,180E9	8,515E8	4,700E8	7,096E8	1,375E9	1,508E9	1,640E9	5,840E8
200-250	4,656E8	5,956E8	4,421E8	7,221E8	1,809E9	1,322E9	7,079E8	1,102E9	2,156E9	2,297E9	2,438E9	6,895E8
250-300	7,199E8	8,964E8	6,832E8	1,058E9	2,544E9	1,853E9	9,998E8	1,544E9	3,014E9	3,235E9	3,455E9	1,043E9
300-350	8,894E8	1,097E9	8,438E8	1,282E9	3,033E9	2,207E9	1,194E9	1,839E9	3,586E9	3,860E9	4,133E9	1,279E9
350-400	1,002E9	1,231E9	9,510E8	1,432E9	3,360E9	2,442E9	1,324E9	2,035E9	3,968E9	4,277E9	4,585E9	1,436E9
400-450	1,086E9	1,327E9	1,030E9	1,535E9	3,571E9	2,595E9	1,409E9	2,162E9	4,213E9	4,548E9	4,883E9	1,550E9
450-500	1,143E9	1,393E9	1,084E9	1,610E9	3,734E9	2,713E9	1,474E9	2,260E9	4,403E9	4,756E9	5,109E9	1,629E9

Morphologic data: average depth (m)

Distance from the source (km)	January	February	March	April	May	June	July	August	September	October	November	December
0-50	,471	,501	,460	,519	,714	,616	,475	,568	,762	,797	,831	,541
50-100	,876	,932	,855	,964	1,326	1,144	,882	1,055	1,415	1,482	1,545	1,005
100-150	1,263	1,353	1,233	1,413	1,978	1,709	1,312	1,576	2,117	2,208	2,295	1,457
150-200	1,588	1,706	1,551	1,786	2,514	2,173	1,666	2,003	2,692	2,805	2,913	1,836
200-250	1,659	1,852	1,621	2,019	3,044	2,645	2,001	2,438	3,292	3,386	3,478	1,977
250-300	2,016	2,224	1,969	2,395	3,544	3,076	2,335	2,835	3,824	3,946	4,064	2,380
300-350	2,216	2,434	2,164	2,610	3,834	3,326	2,528	3,066	4,133	4,271	4,403	2,607
350-400	2,338	2,562	2,283	2,741	4,014	3,481	2,647	3,208	4,324	4,471	4,612	2,745
400-450	2,423	2,649	2,366	2,828	4,125	3,576	2,722	3,296	4,441	4,596	4,744	2,840
450-500	2,478	2,708	2,421	2,889	4,208	3,648	2,777	3,362	4,530	4,688	4,841	2,904

Morphologic data: average width (m)

Distance from the source (km)	January	February	March	April	May	June	July	August	September	October	November	December
0-50	29,829	31,784	29,093	32,929	45,714	39,270	30,029	36,111	48,867	51,236	53,482	34,353
50-100	56,439	60,137	55,047	62,300	86,482	74,290	56,810	68,314	92,446	96,928	101,179	64,996
100-150	82,230	88,296	80,217	92,302	130,500	112,282	85,521	103,249	139,916	146,132	152,053	95,272
150-200	104,119	112,071	101,576	117,482	167,000	143,751	109,364	132,187	179,200	186,955	194,349	120,862
200-250	108,895	121,960	106,336	133,256	203,328	175,985	132,039	161,828	220,408	226,913	233,206	130,449
250-300	133,067	147,190	129,900	158,870	237,817	205,550	154,770	189,014	257,134	265,616	273,791	157,832
300-350	146,660	161,510	143,155	173,544	257,871	222,760	167,965	204,839	278,531	288,105	297,320	173,345
350-400	154,958	170,284	151,246	182,570	270,283	233,416	176,126	214,638	291,786	302,020	311,863	182,842
400-450	160,779	176,274	156,919	188,539	277,987	239,994	181,233	220,687	299,929	310,685	321,019	189,365
450-500	164,572	180,303	160,618	192,702	283,758	244,951	185,023	225,246	306,099	317,152	327,771	193,721

Pictures reporting the altimetry, the average yearly precipitation (mm year^{-1}), climatic characteristics, the average yearly runoff litre s^{-1} km^{-2} were annexed to the scenario description (Atlante Tematico d'Italia. Touring Club Italiano & Consiglio Nazionale delle Ricerche. Milano, 1989).

1st Scenario

Description

Deposition of ^{137}Cs

January the 1st an average of 100000 Bq m^{-2} were deposited on sub-catchments n° 8 (left and right). Calculate the total concentration in water from km 400 to km 500. Supply monthly predictions for the first 2 years.

2nd Scenario

Description

Deposition of ^{137}Cs

May the 1st an average of 5000 Bq m^{-2} were deposited on the whole catchment. Calculate the total radionuclide concentration in water, the dissolved radionuclide concentration in water, the radionuclide concentration in fish species (see above described scenario) in w.w. at 100, 250 an 500 km. Supply monthly predictions during the first 2 years.

3rd Scenario

This scenario considers the assessment of the short-term impact of direct radionuclide release into the river (the two first weeks after the deposit). A 10 hours release of 100000 Bq (^{90}Sr and ^{137}Cs) at the top of reach 8 (350 km from the river spring) is hypothesised. Date: January the 1°.
Calculate the radionuclide dissolved concentration in water, the radionuclide concentration on suspended matter and bottom sediment and the radionuclide concentration in fish species at 1, 10 and 100 km of distance from the point of release.

Dimension
Concentration in water total: Bq m^{-3}
Concentration in water dissolved: Bq m^{-3}

Concentration in fish: Bq kg^{-1} w.w.

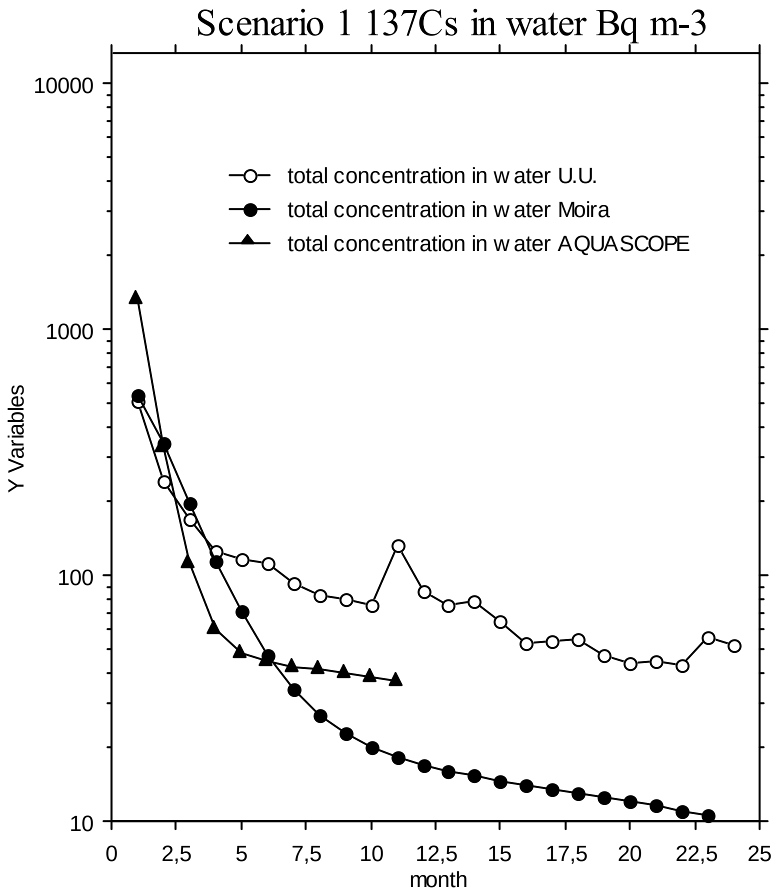
Describe briefly the application of your model to each scenario.

Results of the intercomparison

We list now the most significant results of the model intecomparison exercise.

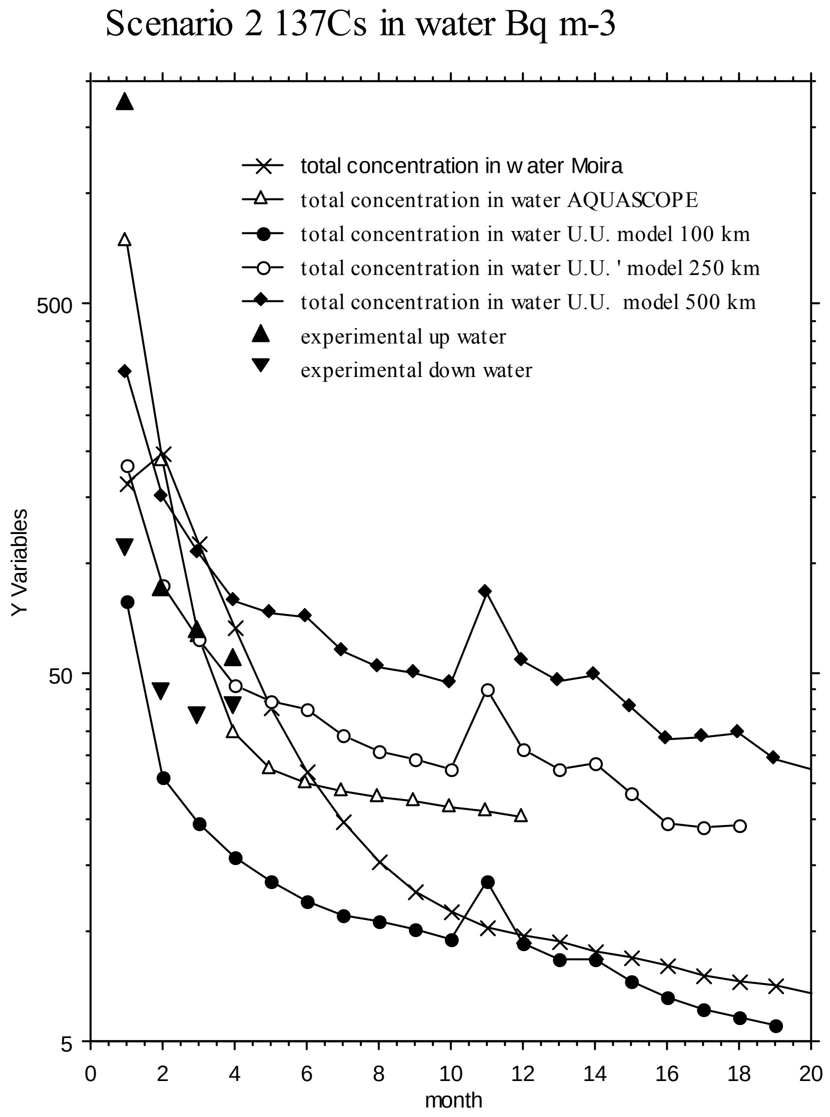
Scenario 1

Models: MOIRA (MARTE), AQUASCOPE, U.U.



The output of the models (concentration of total radiocaesium in water) range within a factor 3 over a period of 2 years. The models clearly show two exponential components (short and medium terms). AQUASCOPE and MOIRA are aimed at assessing the time average concentration of radionuclides in water (although, in principle, they are structured to account for the influence that seasonal variation of water flux may have on the radionuclide concentrations). U.U. model accounts for these effects as shown by the fluctuations of radionuclide concentrations around an average value decaying according to two exponential components.

Scenario 2
Models: AQUASCOPE, MOIRA (MARTE), U.U.



The figure shows the results of models MARTE, AQUASCOPE and U.U. compared with some empirical measurements of radiocaesium concentration in river Po following the Chernobyl accident. It is worthwhile to notice that the data used for this exercise does not correspond to the exact morphologic data of river Po. Nevertheless the comparison of the model with these experimental evaluations gives the opportunity of appreciating:

a) the range of variability of results among the different models;
b) the range of variability of the experimental evaluations.

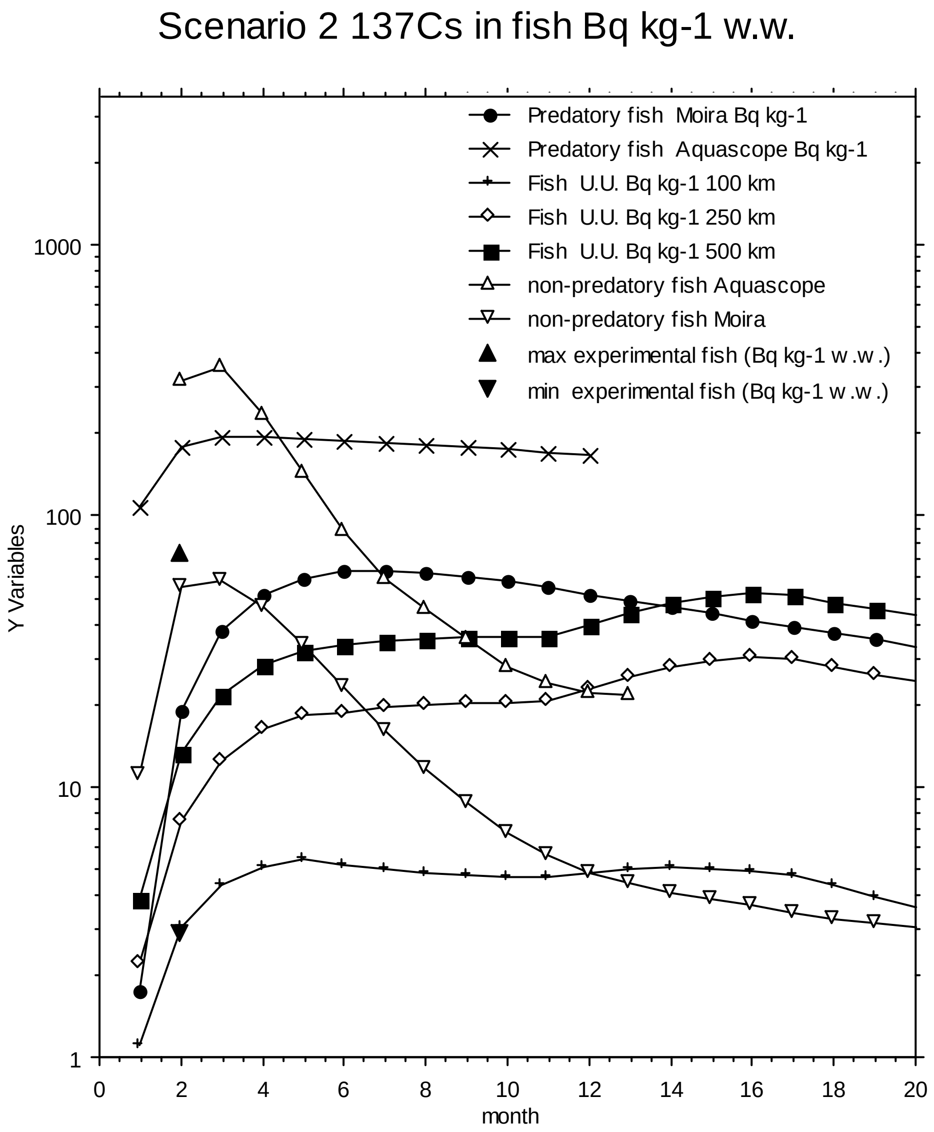
The output of the models covers a range of 1 order of magnitude. The U.U. model output is very sensitive to the distance from the river spring.

An assumed deposition of 5000 Bq m^{-2} can be considered a reliable approximate estimate of the average deposition of ^{137}Cs of Chernobyl origin on the catchment of river Po. Measures carried out by CNTR (Centro Ricerca Termica e Nucleare, ENEL) suggest an average deposition of 10000 Bq m^{-2}. This estimate was obtained averaging the data from 7 fall-out sampling station that were prevailingly located in the northern area of the catchment of river Po. Deposition assessments carried out by measurements of radionuclide contamination of soils samples collected in 5 administrative districts in North Italy suggest deposition average values ranging from 3600 to 8300 Bq m^{-2}. Measurements of ^{137}Cs deposition of Chernobyl origin were also carried out by ENEA laboratories. A deposition of 17000 Bq m^{-2} of ^{137}Cs was measured at Saluggia (a small town in North-west Italy) by using a suitable dry-wet precipitation sampler. Nevertheless, from a large number of deposition assessments carried out by measuring the concentration of radionuclide in soil samples, an average value of 5600 Bq m^{-2} was estimated. The average deposition assessed by ENEA laboratories around Bologna (a town close to the southern part of the catchment of river Po) was, approximately, 2000 Bq m^{-2}.

The above data clearly demonstrate the large spatial variability of ^{137}Cs deposition and the difficulties encountered in assessing the average contamination of large areas.

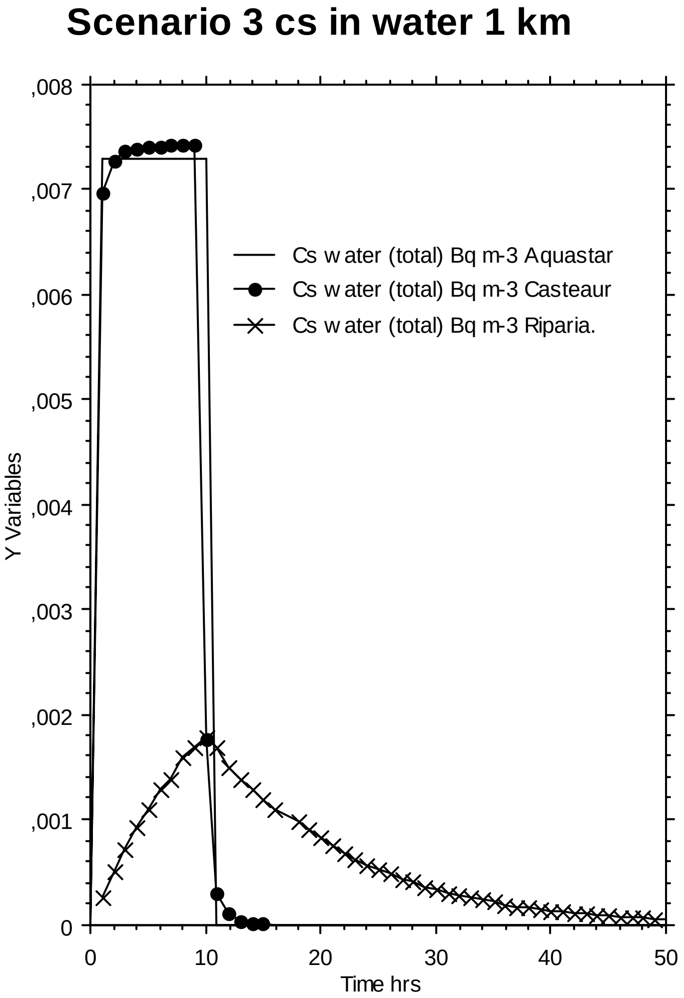
The assessment of the ratio “dissolved/particulate” phases of radiocaesium in water is particularly difficult due to the high intrinsic variability of such quantities.

MOIRA model, for instance, calculates that 30% of caesium is in particulate form. The experimental evaluations suggest values of dissolved caesium ranging from 10% to 60% of total radionuclide.

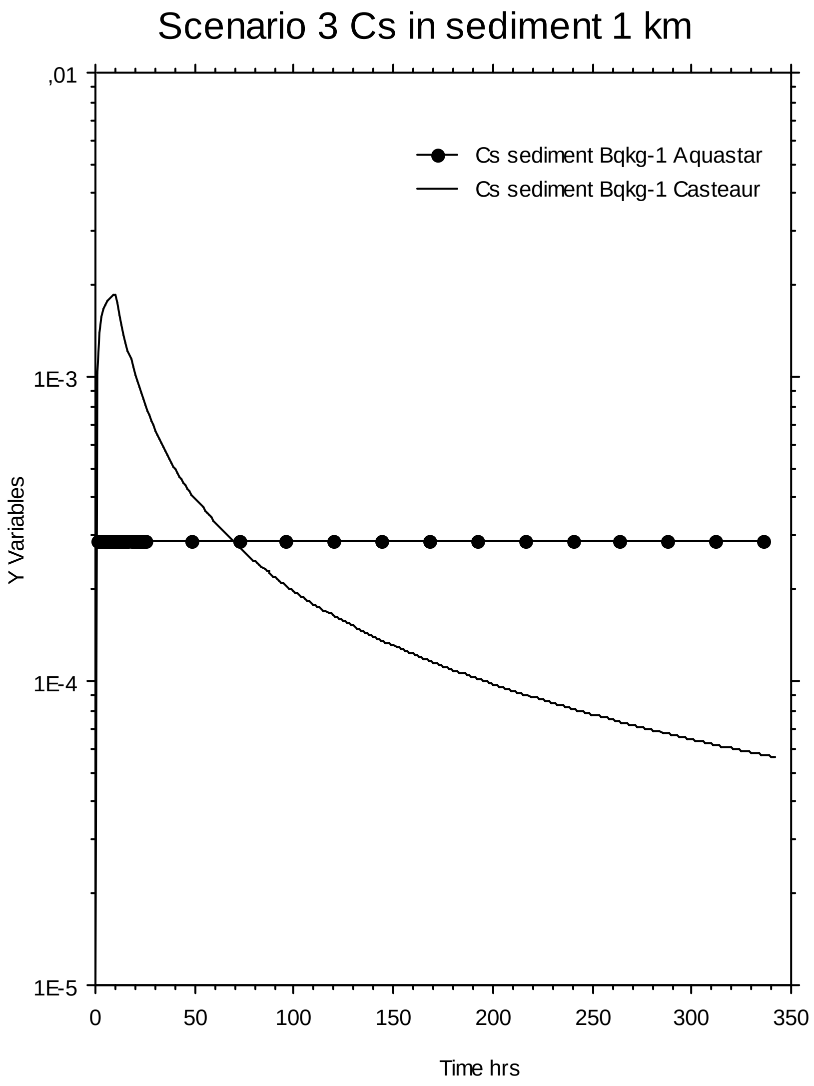


The results of the intercomparison of the predicted concentrations of radiocaesium in biota suggest conclusions that are coherent with the comments done for the assessment of model predictions in water. It is worthwhile to notice that the range of variability of measured radiocontamination in fish is one order of magnitude. The figure shows also the output of a model (MOIRA and AQUASCOPE) for non-predatory fish. The faster dynamic of radionuclides in such species gives reason of the decline of the output.

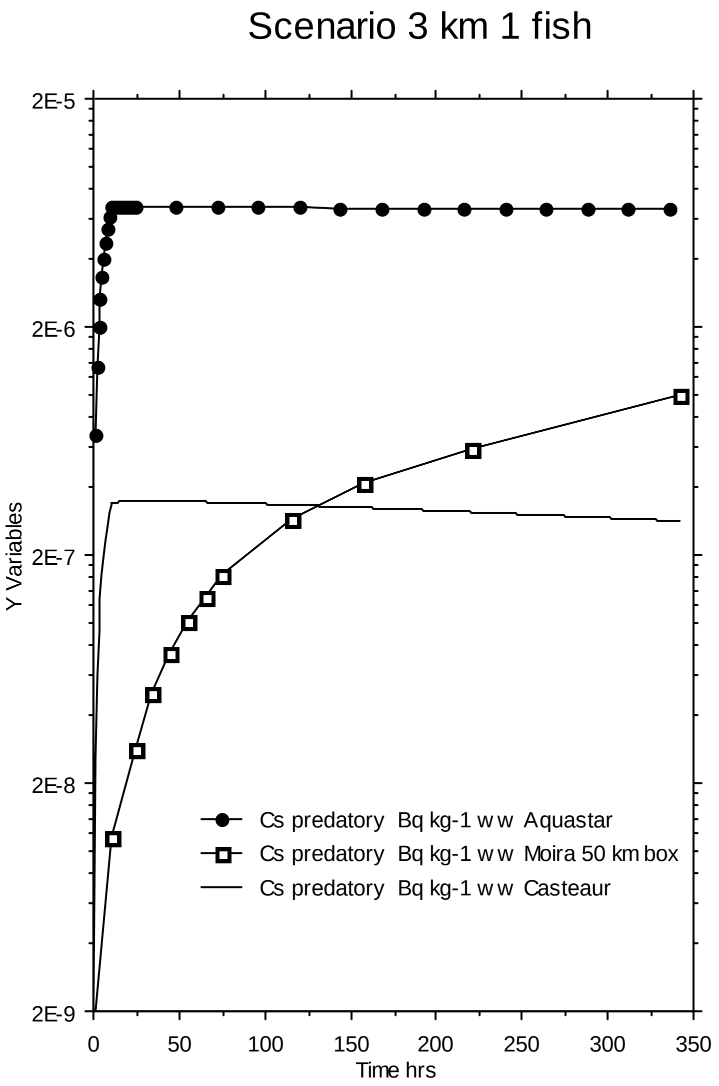
Scenario 3
Models: AQUASTAR, CASTEAUR, RIPARIA, MARTE (MOIRA)



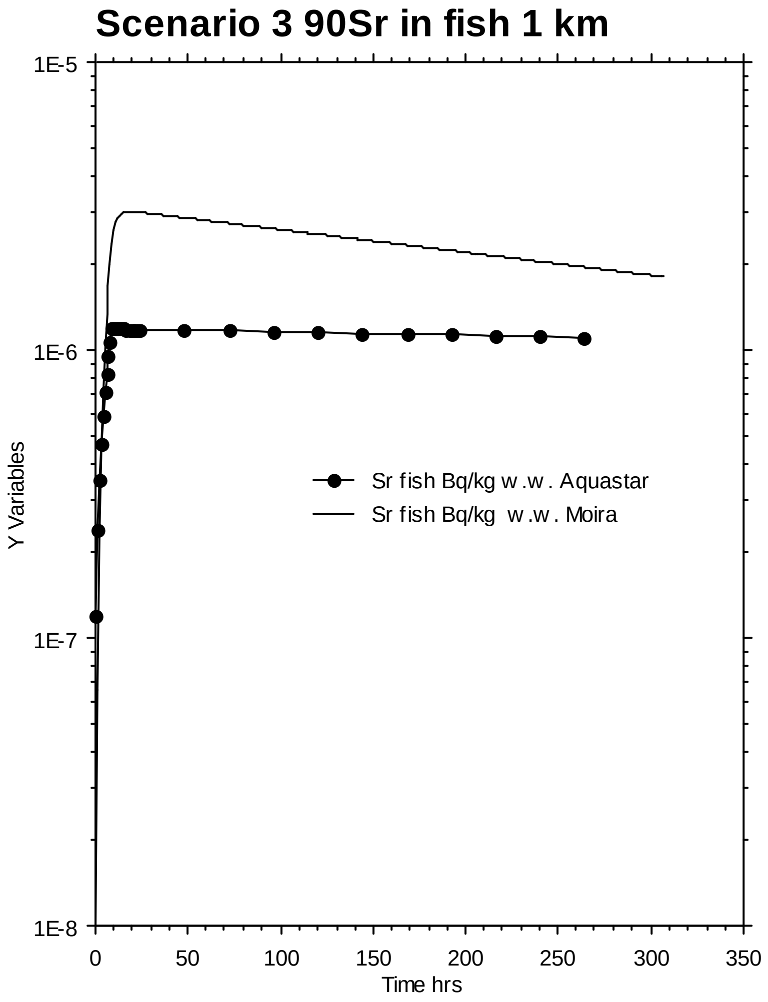
The radionuclide concentrations in water predicted by AQUASTAR and CASTEAUR (diffusion/transport models) following a single pulse release of radionuclide in water are in very good agreement at 1 km from the release point. RIPARIA, that is a compartment model, supplies results characterised by a time behaviour that is significantly different from the previous models. These differences is also controlled, in a complex way, by the size of the compartments in the RIPARIA model (in general, the smaller the compartments the better the agreement with the solution of diffusion-transport models).



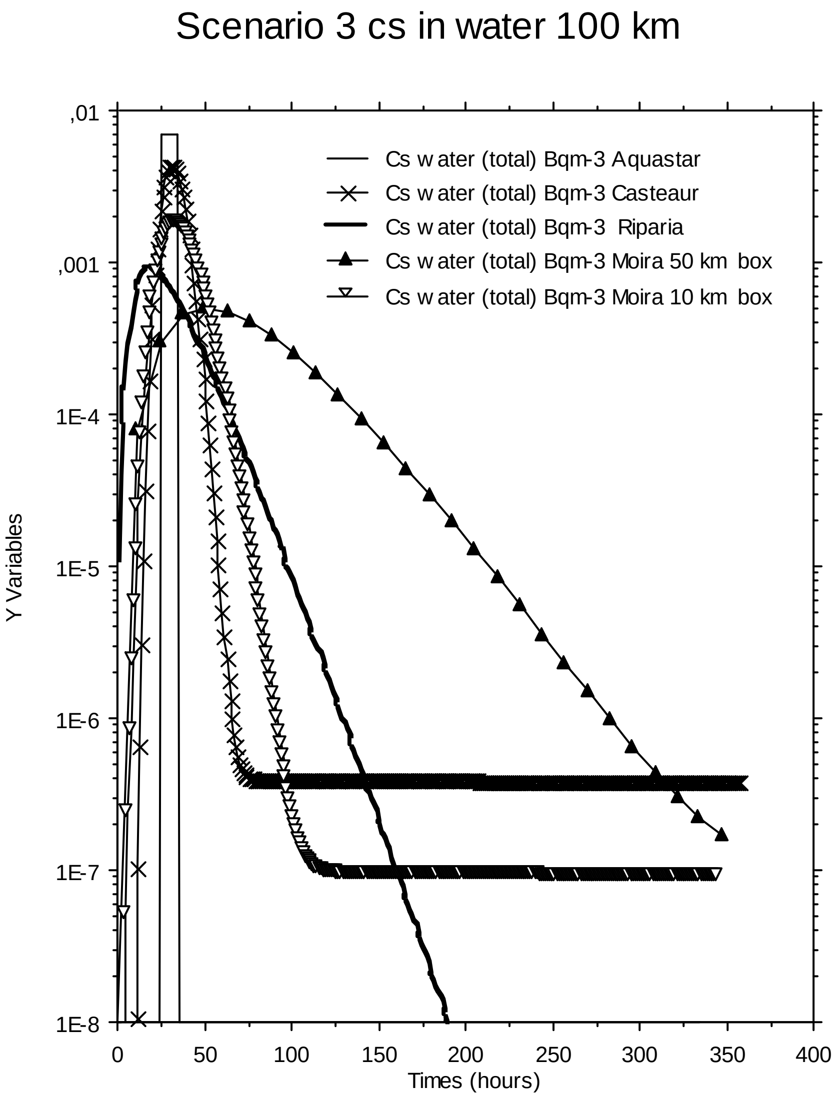
AQUASTAR and CASTEAUR supply predictions of radionuclide concentrations in sediment that are significantly unlike. The reason of such a discrepancy is probably related to the different aims of the models: AQUASTAR is aimed at supplying time averaged values whereas CASTEAUR focuses to determine time dependent values of radionuclide concentration in sediments. For a direct release, the sediment contamination occurs during the flow of radionuclides and mainly by sedimentation of contaminated suspended matter. After this period, sedimentation of non-contaminated matter continues and you have a rapid masses dilution that explains the decrease given by Casteaur



Whereas the predictions of radionuclide concentrations in water are in very good agreement, the results of radionuclide concentration in biota are significantly different (the range is one order of magnitude and more). This is due to the difficulties in modelling the very variable processes occurring at biological and ecological levels. It is not possible to rely on univocal experimental evidences for developing a standard model. On the contrary the prediction of radionuclide in water depend essentially on the processes of transport and dilution and, to a certain extent, on the diffusion. These processes were better understood and can be modelled by using standard techniques. The results of MOIRA are affected by the size of the compartments in the box-structure (two boxes of 50 km) that does not allow a fine spatial and time resolution of the output. It is important to notice that the differences among the results of the models are significantly higher in the short-term period (few hours after the contamination input). This can be explained by the considerable model uncertainty due to the prediction of short-term biological uptake processes.

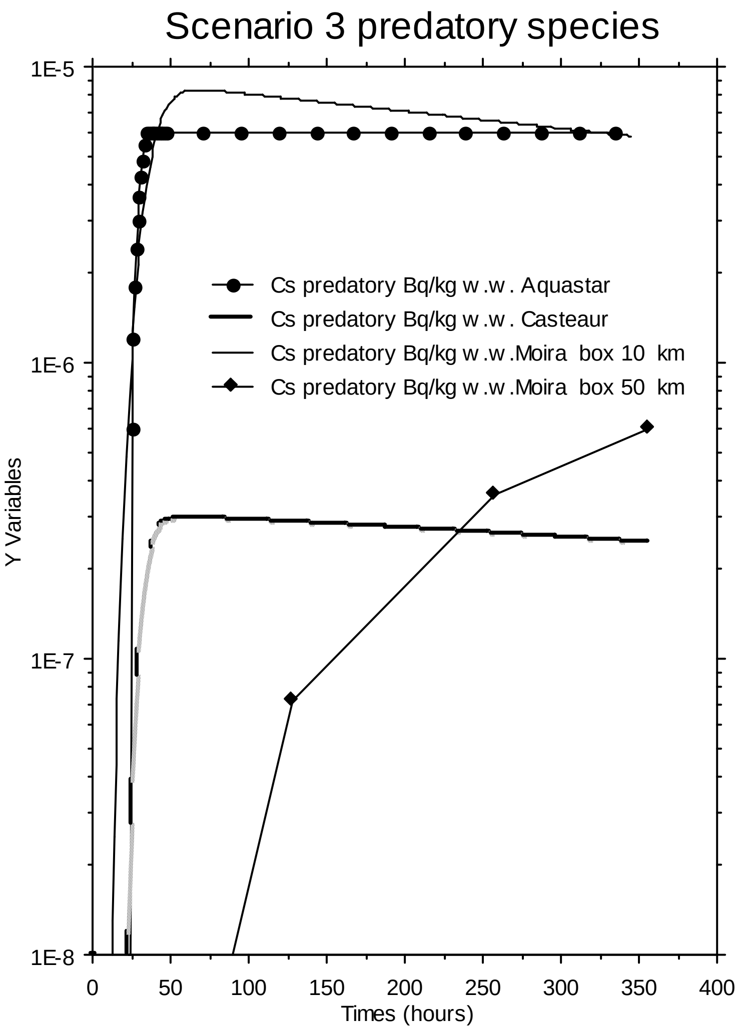


Comparison of MOIRA and AQUASTAR results for ^{90}Sr. As for caesium, the most significant uncertainties, for the specific kind of scenario, occur in biota rather than in water.

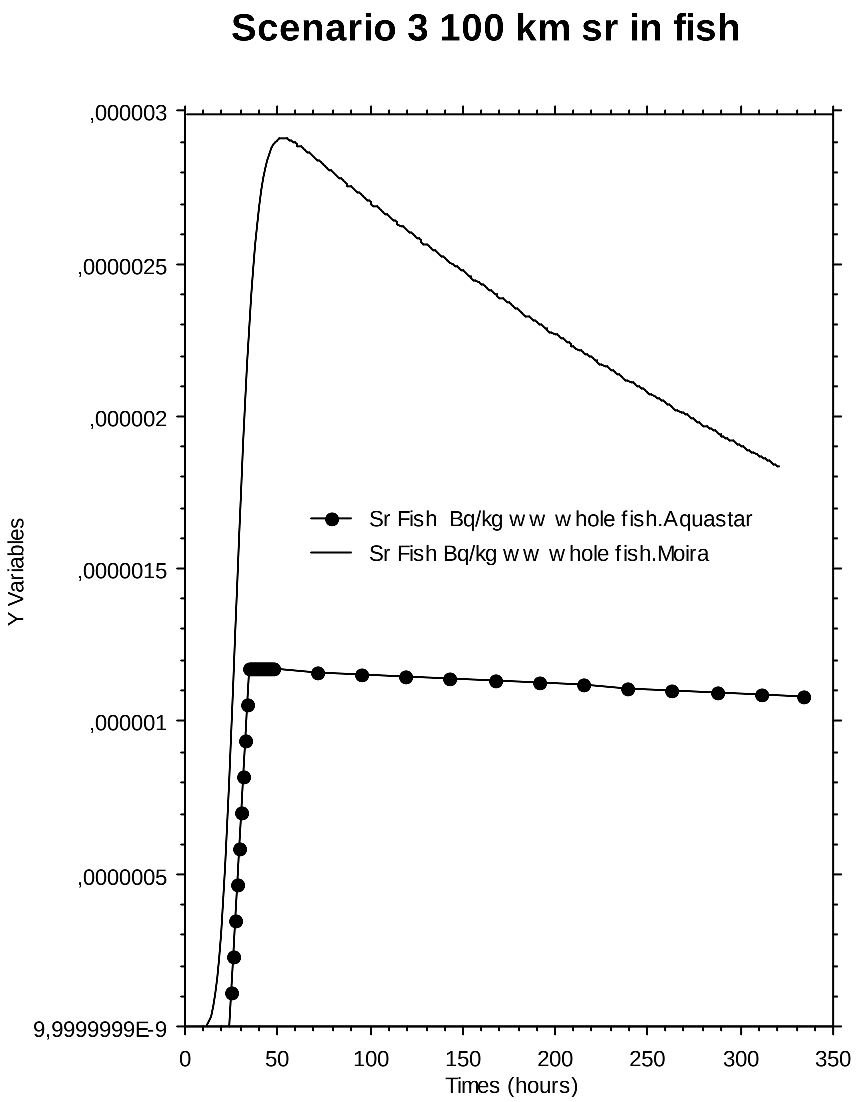


The radionuclide concentrations in water predicted by AQUASTAR and CASTEAUR models following a single pulse release of radionuclide in water at 100 km from the release point are yet in a satisfactory agreement. The areas of both pulses are almost equal in spite of the differences between the peak values (a factor 2). The peaks occur almost at same time (this depends on the speed of the water current that is related to the specific morphologic data of the water body and to the water fluxes). The differences of the peak values are related to the different values of the diffusion coefficient used by diffusion/transport models (AQUASTAR and CASTEAUR) or to the compartment size (MOIRA).

The output of MOIRA was obtained using a box length of 10 km. The data on logarithmic scale clearly show the huge variability of the concentration tails predicted by the models. As previously noticed, this depends on the hypotheses for the quantitative assessment of the diffusion process and by the size of the compartments.



The assessment of the behaviour of the prediction of radionuclide in fishes at distance 1 km from the source point is absolutely in agreement with the conclusions that can be derived from the analysis of the predictions at point 100 km.



Using a compartment length of 10 km for MOIRA, the difference between MOIRA and AQUASTAR results are within a factor 2. It is worthwhile to notice the significant discrepancies of the model predictions in the short-term. This occurrence confirms the belief that the significant biological variabilities of the short-term uptake processes drastically influence the time resolution power of a model.

Conclusions

Among the different pictures shown in the previous paragraphs, the one reporting the intercomparison of the model results for the contamination of fish species can be considered very interesting for drawing general conclusions about the performance of the assessed models.

It is interesting to notice that the range of model results is somewhat comparable to the corresponding range of the empirical measures. This seems to confirm a conclusion that was achieved for models aimed at predicting the behaviour of radionuclides in lacustrine ecosystems. Indeed, it is reasonable to infer that the uncertainty of models reflects the state-of-the-art of the experimental knowledge that, in turn, is affected by some inherent uncertainties that are mainly caused by the intrinsic variability of those environmental and biological processes that cannot be predicted with sufficient accuracy for the lack of information and data.

The results of the present state-of-the-art models are therefore influenced by the incompleteness and the uncertainty of the actual knowledge that has been derived from limited experimental occurrences (the accidents implying significant contamination of the environment at a regional scale). This is a fairly common problem in environmental modelling.

It is difficult or quite impossible to lower, beneath a certain level, the uncertainty of the predictions relevant to some processes (mainly of biological nature) that are significantly influenced by the above mentioned intrinsic environmental and biological variability. Indeed, they produces fluctuations of radionuclide concentrations in environmental and in biological compartments that cannot be predicted with sufficient accuracy in view of the incompleteness of the available information.

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SECTION 5: COASTAL AREAS

REVIEW OF METHODOLOGIES FOR PREDICTING THE BEHAVIOUR OF RADIONUCLIDES IN COASTAL AREAS AND MARINE ENVIRONMENT. A PRELIMINARY EFFORT.

Introduction

Due to the biological value of the coastal zone and the different demands on the utilization of coastal waters, it is easy to understand why so much interest concern this ecosystem. Obviously a similar great interest concerns, more generally, the marine environment. However, in context of aquatic radioecological modelling, it is easy to conclude that, at least in the frame of recent international projects of radioecoloical model assessment, much more efforts have been focused on lakes and rivers than on coastal areas and seas. In fact, it is very difficult to find the data necessary to test coastal models, although new projects (EMRAS initiated by IAEA in September 2003) is intended to compile available data on radionuclide contamination, radionuclide concentrations in water, sediments and biota and the necessary co-variables related to the characteristics of coastal areas, to achieve a proper scenario description needed for model tests and comparative studies.

Preliminary remarks

Many of the developed models are generic, mechanistically-based and meant to be valid for most coastal areas and for most substances, and not only radionuclides. They are dynamic and based on ordinary or partial differential equations and give seasonal variations on radionuclide concentrations in water, sediments and biota (generally fish).

It should be recognised that several of the modelling approaches adopted to predict the migration of radionuclides through coastal areas and through the marine environment are essentially to the ones implemented in models for lakes and rivers that were previously considered in the EVANET-HYDRA assessment.

Hydrodynamical conditions characterising a given coastal or area or sea (such as the Coriolis forces, tidal effects and winds) and the specific processes of water movement are the most important particular mechanisms influencing the migration of toxic substances through these ecosystems.

Several models are based on the assessment of radionuclide diffusion and transport and accounting for the equations of motion and continuity. Diffusion and transport are such tremendously vast subjects that all can be attempted in this paper is to report a short review of the methods used by the assessed models to approach these complicated physical processes.

The pollutant flux, F (Bq m^{-2} s^{-1}), due to molecular and to water turbulent motion can be related to the concentration gradient from equation (5.1) corresponding to the Fick's first law for the molecular diffusion and to an analogous form for the eddy diffusion:

$$\mathbf{F} = -\mathbf{K}^{*}\,\mathbf{grad}C \tag{5.1}$$

where grad is the gradient of C ($\mathbf{grad}C = \mathbf{i}\frac{\partial}{\partial x}C + \mathbf{j}\frac{\partial}{\partial y}C + \mathbf{k}\frac{\partial}{\partial z}C$, C is the pollutant concentration in water, x, y, z are the coordinates and i, j and k are the unit vectors along the coordinate axes). K* is a 3x3 component symmetric tensor (the diffusion tensor). In principle, diffusion process is due to the thermal motion of the molecules. Nevertheless, diffusion of pollutant due to turbulent motion of water is modelled by equation (5.1) as well. Bold characters in equation (5.1) represent vectors and tensors. Equation (5.1) accounts for anisotropic processes of diffusion in the three dimensions. In case of one dimension diffusion, equation (5.1) becomes $F = -K^{*}\frac{\partial C}{\partial x}$, where K* is the so-called diffusion coefficient. The order of magnitude of K* ranges, ordinarily, from 10^{-10} to 10^{-8} m^2 s^{-1}. Turbulent motion of water is responsible for apparently higher values of K*. Indeed the turbulent-diffusion coefficient is many orders of magnitude larger than the molecular-diffusion coefficient.

The pollutant flux due to water transport is related to the concentration C and to the water velocity U (m s^{-1}) by the following equation:

$$F = U \cdot C \tag{5.2}$$

Formula (5.2) can be obtained by dividing the total amount of substance flowing, per unit time, through a surface S by the surface area.

As for the diffusion, equation (5.2) can be generalised to three-dimensional, time dependent transport processes.

Interactions of radionuclide in the water column with suspended matter and bottom sediments are generally modelled according to the same principles applied by lake and river models.

Significant differences are related to the specific environmental conditions of the coastal and marine environment that strongly influence the migration of radionuclides. Among those the effects of water currents are of primary importance. In case of coastal areas the spatial definition of the water system is a crucial point.

One of these processes the tidal effect involves an enhanced mixing of contaminant within the water column and influences its dispersion at the sea-land interface. Several models aimed at predicting the migration of contaminant through large seas account for the effects of Coriolis forces due to the rotation of the earth.

The modelling approach is, obviously, based on a mass-balance assessment. Nevertheless, the evaluation of the quantitative migration of toxic substances in coastal areas and seas requires the introduction of concepts and methodologies that are typical of this particular ecosystem. For instance it is necessary to find suitable techniques for the identification of the coastal area from a topological point of view (topographical "bottlenecks" in relation to the depth of the considered area) (Figure 5.1A). This allows one to define the boundary of a coastal area. Once the coastal area is identified all the particular processes concerning the hydrological properties (water current, salinity, water exchanges and dynamics, etc.) of a coastal system are accounted for in the frame of a mass-balance model. It was emphasised that, at present, there are few validated models. Therefore, exercises of validation of coastal area models are considered of importance for future activities and developments.

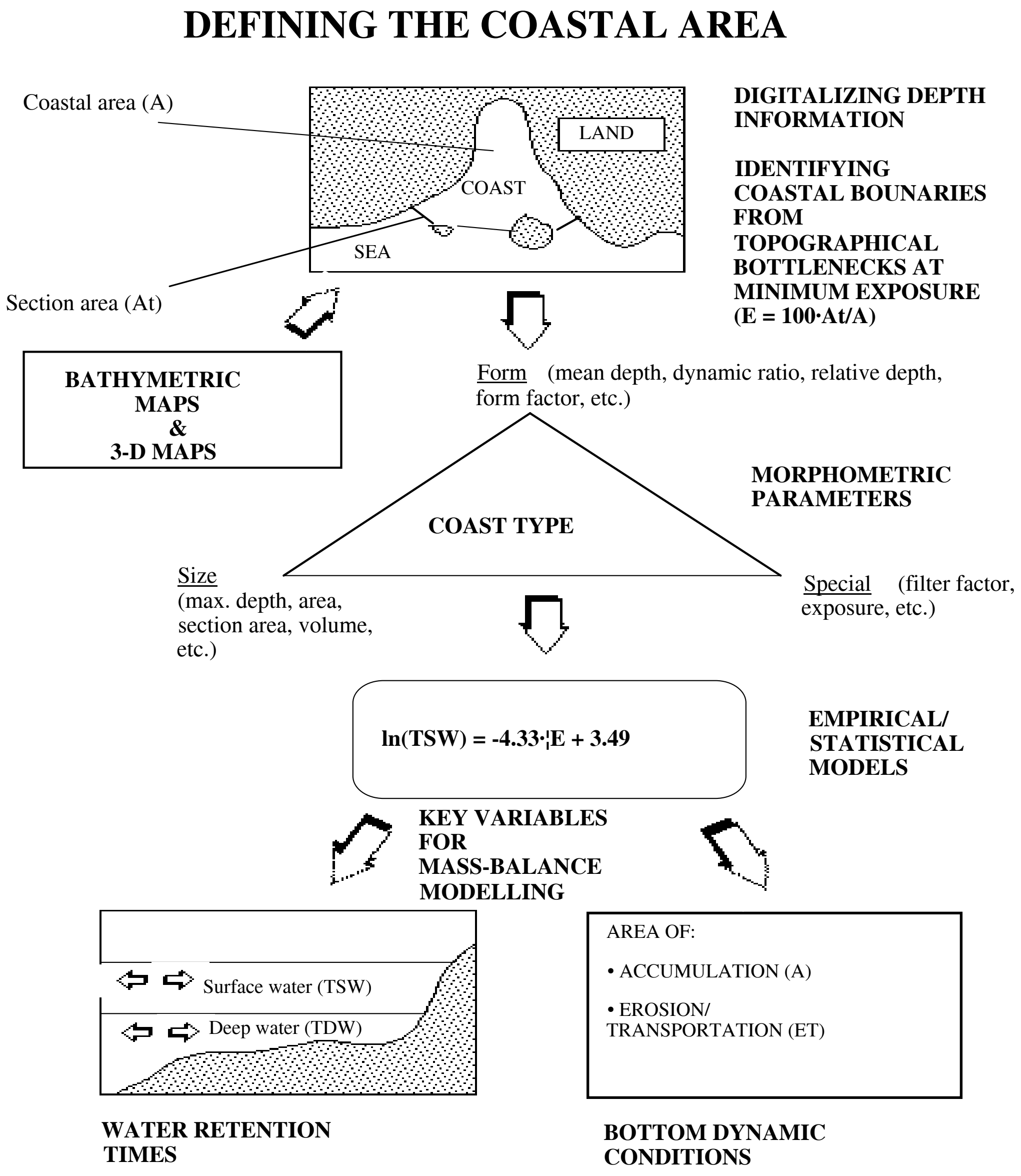

Figure 5.1A The definition of the boundaries of a coastal area is essential for model applications

An example of model for predicting the behaviour of radionuclides in a coastal ecosystem: The CoastMab-model (Uppsala Univ)

This is a box model based on ordinary differential equations. For this model, one needs to define the borderlines which limit the given coastal areas and its boundaries towards the sea and/or adjacent coastal areas? If such borderlines are drawn arbitrarily, one would get arbitrary volumes, areas and mean depths and the mass-balance model would loose predictive power. This model will be outlined in the following text. The fish sub-model connected to this model will also be briefly presented.

Today, there are many modern digitized methods applicable in aquatic studies including Geographical Information Systems (GIS). Those methods enable quick and effective estimations of morphometric variables. The basic criteria to define a coastal area and the boundaries to the open water areas or adjacent coastal areas is to draw the boundary lines at the topographical bottlenecks where the exposure ($Ex = 100 \cdot At/A$) attains minimum values when different alternatives for settling the boundary lines are tested (At = section area; A = enclosed coastal area; method from Pilesjö et al., 1991; see Figure 5.1). Once the coastal area is defined, one can also define important variables for mass-balance calculations, such as the coastal volume (regulating the concentration of any given substance), and important morphometric parameters for internal fluxes, such as the mean depth and the water surface area, and key variables regulating the water exchange between the coast and the sea, such as the section area, the exposure and the filter factor. This method of defining coastal areas also opens a possibility to use empirical models to estimate, e.g., the theoretical water retention times of the surface water (see table 5.1) and the deep water, and the bottom dynamic conditions (regulating sedimentation, resuspension and diffusion) from morphometrical parameters (such as area, mean depth and section area).

From the theoretical surface water retention time (T_{SW} in months), one can calculate the surface water flux (Q_{SW} in m^3/month) as V_{SW}/T_{SW}, where V_{SW} is the surface water volume (m^3) and the flux of the given substance, $Q_{SW} \cdot C_{sea}$ in g/month, where C_{sea} is the concentration of the substance in the sea outside the given coastal area (g/m^3). As a rule of thumb, one can say that the costs of establishing an empirical value of the theoretical water retention time from traditional field measurements (using dye, current meters, etc.) is about 30,000 USD for one coastal area in the size range from 1 to 100 km^2. In many contexts, it may not be very meaningful to build a model if it is a prerequisite that such field work first must be carried out to determine the water retention time as a driving variable (x) predicting target y-variables, such as concentrations of radionuclides in water and fish. This means that it is of major importance that water retention time can, in fact, for many coastal areas be predicted very easily from one coastal morphometric variable, i.e., the exposure (Ex; see table 1).

The coastal model (see Figure 5.2 for illustration; all equations are complied in table 5.2) is modified from two validated models based on the same modelling principles and structures. One is the dynamic mass-balance model for suspended particulate matter (SPM), the other is the phosphorus model. Table 5.3 gives a summary of the validation results for the phosphorus model using data from Baltic coastal areas of different character (similar results have been obtained also for the SPM-model). One can note that for all the tested coastal areas, the model generally predicts within the uncertainty bands given by the variations in the empirical data. Sensitivity and uncertainty tests of the model have also been presented.

The calculation time (dt) of the model is one month to reflect seasonal variations. An important demand, related to the practical utility of the model, is that it should be driven by variables readily accessed from standard monitoring programs or maps. The obligatory driving variables include four morphometric parameters (coastal area, section area, mean and maximum depth), latitude (to predict surface water and deep water temperatures, stratification and mixing) and the concentration of the given radionuclide in the sea outside the given coastal area, which is estimated in this paper using a simple approach based on the ecological halflife.

The model has four compartments. Two water compartments, surface water and deep water. The separation between these two compartments is done not in the traditional manner from measured water temperatures but from sedimentological criteria, as the water depth separating transportation areas from accumulation areas. The model also has two sediment compartments, the ET-areas, i.e., the erosion and transportation areas where fine sediments are discontinuously being deposited, and the A-areas, i.e., the accumulation areas where fine sediments are continuously being deposited. The processes accounted for are inflow and outflow via surface and deep water, direct fallout onto the water surface of the coastal area, sedimentation, burial (the transport from surficial A-sediments to underlying sediments), resuspension, diffusion and mixing between surface and deep water.

The sub-model to predict radionuclide concentrations in fish is shown in Figure 5.3. Basically, the fish model relates radionuclide concentrations in water, on suspended particles and in sediments to concentrations in fish. The bioconcentration factor (BCF) is modified by factors known to influence biouptake and retention of radionuclides in biota:

- The amount in dissolved and particulate phases of the radionucide.
- The feeding habits of the fish.
- The weight of the fish.
- The trophic characteristics of the coastal system.
- Water temperature.
- Salinity.
- Chemical dilution (e.g., the K-concentration in lake water influences the biouptake of ^{137}Cs and the Ca-concentration the biouptake of ^{90}Sr).

The practical use of the CoastMab-model may be illustrated by a ranking of all fluxes to, within and from a “typical” Baltic coastal area, defined here as the default area, is reported in fig. 4. One can note that the fluxes in and out from the sea are the most dominating fluxes and that burial, diffusion, sedimentation to the deep water and resuspension to the deep water are the four smallest fluxes. These results are valid for the default coastal area (but not necessarily for other coastal areas) and they imply that for this area, the conditions in the sea are of utmost importance.

Table 5.1. Empirical models used in this dynamic model to predict theoretical surface water and deep water retention times (T_{SW} and T_{DW} in days) and the fraction of ET-areas (ET) from morphometric parameters in archipelago areas and bays. Note that if reliable empirical data are at hand for a given coastal area on T_{SW}, T_{DW} or

ET, such data should be used rather than the values predicted by these empirical models.

Regression	r^2	n
$\ln(T_{SW}) = (-4.33\cdot(\sqrt{Ex}) + 3.49)$	0.95	14
$T_{DW} = (-251 - 138\cdot\log(At) + 269\cdot\log(Vd))$	0.79	15
$A = 1-ET = (D_{max}-D_{TA})/(D_{max} + D_{TA}\cdot EXP(3-Vd\text{\^{}}1.5)))\text{\^{}}(0.5/Vd)$		
$D_{TA} = WB = Y_{ex1}\cdot(45.7\cdot(Area\cdot 10\text{\^{}}(-6))\text{\^{}}0.5/(21.4+(Area\cdot 10\text{\^{}}(-6))\text{\^{}}0.5)))$		
If $D_{TA} \geq D_{max}$ then D_{max} else D_{TA}		
If $Ex < 0.003$ then $Y_{ex1} = 1$ else $Y_{ex1}= (Ex/0.003)\text{\^{}}0.25$		

Model domain: $0.002 < Ex < 1.3$; $0.0006 < At < 0.08$; $0.5 < Vd < 1.5$; data from coastal areas with very little tidal range; note that T_{SW} and T_{DW} are never permitted to be < 1 day and T_{DW} never > 120 days.

Ex (exposure) = $100\cdot At/A$; Vd (the form factor) = $3\cdot D_m/D_{max}$; At = section area (km^2); A = coastal area (km^2); D_m = mean coastal depth (m); D_{max} = max. coastal depth (m); A = the fraction of A-areas; ET = the fraction of ET-areas; D_{TA} = WB = the wave base (m).

Table 5.2. Compilation of equations for the coastal model (for further information, see Håkanson, 2000; Håkanson et al., 2004). M = mass (Bq); F = flux (Bq/month); R = rate (1/month); C = concentration (Bq/m^3); DC = distribution coefficient (dim. less); T = age (months); V = volume (m^3); de = decay; bur = burial; SW = surface water; DW =

deep water; ET = ET-areas; A = A-areas; flux from SW to DW = F_{SWDW}, etc.; concentration in SW = C_{SW}, etc.; age of ET-sediments = T_{ET}, etc.; table 5.3 gives calculated values for many models constants for the default coastal area.

Compartment surface water

$M_{SW}(t) = M_{SW}(t - dt) + (F_{seaSW} + F_{DWSWx} + F_{ETSW} + F_{trib} + F_{atm} - F_{SWsea} - F_{SWDW} - F_{SWET} - F_{SWDWx} - {}_{FSWde})\cdot dt$

$F_{seaSW} = Q_{SW}\cdot C_{sea}$ [flow from sea to SW]

$F_{DWSWx} = M_{DW}\cdot R_{mix}$ [mixing from DW to SW]

$F_{ETSW} = M_{ET}\cdot(1/T_{ET})\cdot(1\text{-}Vd/3)$ [resuspension from ET to SW]

F_{trib} = River inflow [from river model]

$F_{atm} = \text{Fallout}\cdot\text{Area}$

$F_{SWsea} = M_{SW}\cdot(1/T_{SW})$ [flow from SW to sea]

$F_{SWDW} = M_{SW}\cdot PF\cdot(v/D_{SW})\cdot(1\text{-}ET)\cdot(1\cdot(1\text{-}DC_{SWres})+10\cdot DC_{SWres})$ [flow from SW to DW]

$F_{SWET} = M_{SW}\cdot PF\cdot(v/D_{SW})\cdot ET\cdot(1\cdot(1\text{-}DC_{SWre}S)+10\cdot DC_{SWres})$ [flow from SW to ET]

$F_{SWDWx} = M_{SW}\cdot R_{mix}$ [mixing from SW to DW]

$F_{SWde} = M_{SW}\cdot R_{de}$ [physical decay]

Compartment deep water

$M_{DW}(t) = M_{DW}(t - dt) + (F_{SWDW} + F_{ETDW} + F_{SWDWx} + F_{seaDW} + F_{ADW} - F_{DWSWx} - F_{DWA} - F_{DWsea} - F_{DWde})\cdot dt$

$F_{SWDW} = M_{SW}\cdot PF\cdot(v/D_{SW})\cdot(1\text{-}ET)\cdot(1\cdot(1\text{-}DC_{SWres})+10\cdot DC_{SWres})$

$F_{ETDW} = M_{ET}\cdot(1/T_{ET})\cdot(Vd/3)$

$F_{SWDWx} = M_{SW}\cdot R_{mix}$

$F_{seaDW} = Q_{DW}\cdot C_{sea}$

$F_{ADW} = M_{A}\cdot R_{diff}$

$F_{DWSWx} = M_{DW}\cdot R_{mix}$

$F_{DWA} = M_{A}\cdot PF\cdot(v/D_{DW})\cdot(1\cdot(1\text{-}DC_{DWres})+ 10\cdot DC_{DWres})$

$F_{DWsea} = M_{DW}\cdot Q_{DW}/V_{DW}$

$F_{DWde} = M_{DW}\cdot R_{de}$

Compartment ET-sediments

$M_{ET}(t) = M_{ET}(t - dt) + (F_{SWET} - F_{ETDW} - F_{ETSW} - F_{deET})\cdot dt$

$F_{SWET} = M_{SW}\cdot PF\cdot(v/D_{SW})\cdot ET\cdot(1\cdot(1\text{-}DC_{SWres})+10\cdot DC_{SWres})$

$F_{ETDW} = M_{ET}\cdot(1/T_{ET})\cdot(Vd/3)$

$F_{ETSW} = M_{ET}\cdot(1/T_{ET})\cdot(1\text{-}Vd/3)$

$F_{deET} = M_{ET}\cdot R_{de}$

Compartment A-sediments

$M_A(t) = M_A(t - dt) + (F_{DWA} - F_{bur} - F_{ADW} – F_{deA})\cdot dt$

$F_{DWA} = M_{DW}\cdot PF\cdot(v/D_A)\cdot(1\cdot(1\text{-}DC_{DWres})+10\cdot DC_{Dwres})$ [see also eq. 1]

$F_{bur} = M_A/T_A$

$F_{ADW} = M_A\cdot R_{diff}$

$F_{deA} = MA\cdot R_{de}$

Concentration in sea

$C_{sea}(t) = C_{sea}(t - dt) + (M_{Csea} - Out_{Csea})\cdot dt$

M_{Csea} = Fallout

$Out_{Csea} = C_{sea}/T_{sea}$

Other equations

$T_A = 12\cdot BF\cdot D_{AS}/Sed$ [BF = bioturbation factor (dim. less); D_{AS} = depth of active sediments in cm; sed = sedimentation in cm/month; see Håkanson et al., 2004]

$T_{ET} = 1$ [month]

$C = (M_{SW}+M_{DW})/V$ [Bq/m^3]

$C_{diss} = C\cdot(1\text{-}PF)$ [concentration in dissolved phase; Bq/m^3]

C_{sea} (initial) = Fallout/100 [the assumed default initial concentration in the sea outside the coast; Bq/m^3]

$C_{DW} = M_{DW}/V_{DW}$ [Bq/m^3]

$C_{SW} = M_{SW}/V_{SW}$ [Bq/m^3]

u = 2.5 [mean coastal current velocity; cm/s; see Håkanson, 2000]

$D_{DW} = (D_{max}\text{-}WB)/2$ [WB = wave base; the depth separating the SW and DW compartments; m]

$DC_{SWres} = (F_{ETSW})/(F_{ETSW}+F_{seaSW}+F_{DWSWx}+F_{trib}+F_{atm})$ [the resuspended fraction in SW; dim. less]

$Q_{DW} = V_{DW}/(T_{DWd}/30)$ [water flow into DW in m^3/month]

$DF = 1/(1+(Kd\cdot SPM)/1000000)$ [the dissolved fraction for ^{137}Cs; see Håkanson, 2000]

$D_{SW} = WB/2$ [the mean depth of the SW compartment; m]

$V_{DW} = V\text{-}V_{SW}$ [the SW water volume; m^3]

$Temp_{SW}$ = If ABS($Temp_{SW}$-$Temp_{DW}$)<4 then ($Temp_{SW}$+$Temp_{DW}$)/2 else $Temp_{SW}$ [temperatures; °C]

$Temp_{DW}$ = If < 4 then 4 else $Temp_{DW}$ [temperatures; °C]

ET = (1-A) [the fraction of ET-areas; dim. less]

Ex = 100·At/Area [Exposure; At = section area in m^2; Area = coastal area; m^2]

Vd = 3·D_m/D_{max} (the form factor, also often called the volume development; dim. less]

T_{sea} = 3·12 [the assumed default ecological halflife of the radionuclide in the sea; months]

$C_K = C_{KURS}$ = (SPM_{URS}+1)·0.03)/0.0391 [the estimated concentration of potassium in the coastal area and in the upstream river stretch; mg/l]

Kd = 800000/C_K [Kd for ^{137}Cs; from Håkanson, 2000]

R_{mix} = if ABS($Temp_{SW}$-$Temp_{DW}$)<4 then R_{mix} = 1 else R_{mix} = 1/ABS($Temp_{SW}$-$Temp_{DW}$) [the mixing rate; 1/month]

PF = (1-DF) (the particulate fraction of the radionuclide; dim. less]

R_{de} = 0.693/(30.2·12) [the physical decay rate for ^{137}Cs; 1/months]

1/T_{SW} = if (1/T_{SWbay})+(1/T_{SWtide})+(1/T_{SWu}) > 30 days then 1/T_{SW} = 30 else 1/T_{SW} = (1/T_{SWbay})+(1/T_{SWtide})+(1/T_{SWu})

$v = v_0 \cdot Y_{SPM} \cdot Y_{sal}$ [the settling velocity for the particulate fraction; m/month]

v_0 = 12/12 [the default settling velocity for SPM; m/y]

SPM = if SPM_{URS}/4 < 4 mg/l then SPM = 4 else SPM = SPM_{URS}/4 [the suspended particulate matter concentration; mg/l]

$Q_{SW} = V_{SW}/T_{SW}$ [the water flux to the SW compartment; m^3/month]

V_{SW} = if WB = 0 or Temp = 100 then V_{SW} = V else V_{SW} = ((Area-$Area_{WB}$)·WB/(3/Vd)+$Area_{WB}$·WB) [volume of SW compartment; m^3]

T_{DWd} = if > 120 then T_{DWd} = 120 days else T_{DWd} [theoretical deep water retention time; days]

Tidal amplitude (amp) = (0+0.01) [cm]

T_{SWbay} = if Ex $\geq$ 1.3 then T_{SWbay} = T_{SWu} else T_{SWbay} = T_{SW1} [theoretical SW retention time; months]

T_{SWu} = if Ex < 1.3 then T_{SWu} = 100 else T_{SWu} = V_{SW}/(Y_{cur}·u·0.01·60·60·24·30·0.5·At)

T_{SWtide} = V_{SW}/(Area·amp·Y_{tide}·0.01·30)

T_{SW1} = If EXP(3.49-4.33·($Ex^{0.5}$))/30 < 1/30 then T_{SW1} = 1/30 else T_{SW1} = EXP(3.49-4.33·($Ex^{0.5}$))/30

Volume (V) = Area·D_m [m^3]

WB = $Y_{Ex1}\cdot 45.7\cdot(\text{Area}\cdot 10^{-6})^{0.5}/(21.4+(\text{Area}\cdot 10^{-6})^{0.5})$; if Ex < 0.003 then $Y_{Ex2} = 1$ else $Y_{Ex2} = (\text{Ex}/0.003)^{0.25}$; if $Y_{Ex2} > 10$ then $Y_{Ex1} = 10$ else $Y_{Ex1} = Y_{Ex2}$ [wave base and boundary conditions; m]

Y_{cur} = if $Y_{Ex} > 1$ then $Y_{cur} = 1$ else $Y_{cur} = Y_{ex}$ [Y_{cur} dimensionless moderator for current influences on water exchange]

$Y_{ex} = (1+0.5\cdot((\text{Ex}/10)-1))$ [Y_{ex} dimensionless moderator for influences of exposure on water exchange]

$Y_{sal} = (1+1\cdot(\text{Sal}/1-1))$ [dimensionless moderator for salinity influences on sedimentation]

$Y_{SPM} = 1+0.75\cdot(\text{SPM}/50-1)$ [dimensionless moderator for SPM influences on sedimentation]

Y_{tide} = if $Y_{ex} > 1$ then 1 else Y_{ex} [dimensionless moderator for tidal effects on water exchange]

Table 5.3. Data need to run the CoastMab-moodel for the Black Sea estuary.

Obligatory coastal-area specific driving variables

Coastal area (= Area) = $x\cdot 10^6$ m^2

Latitude (= Lat) = x °N

Max depth (= D_{max}) = x m

Mean depth (= D_m) = x m

Mean annual precipitation (= Prec) = x mm/yr

Salinity (= Sal) = x ‰

Section area (= At) = x m^2

Mean fallout to the catchment of Bog = x Bq/m^2

Mean fallout to the catchment of Djnepr = x Bq/m^2

Mean fallout to the catchment of the Black Sea = x Bq/m^2

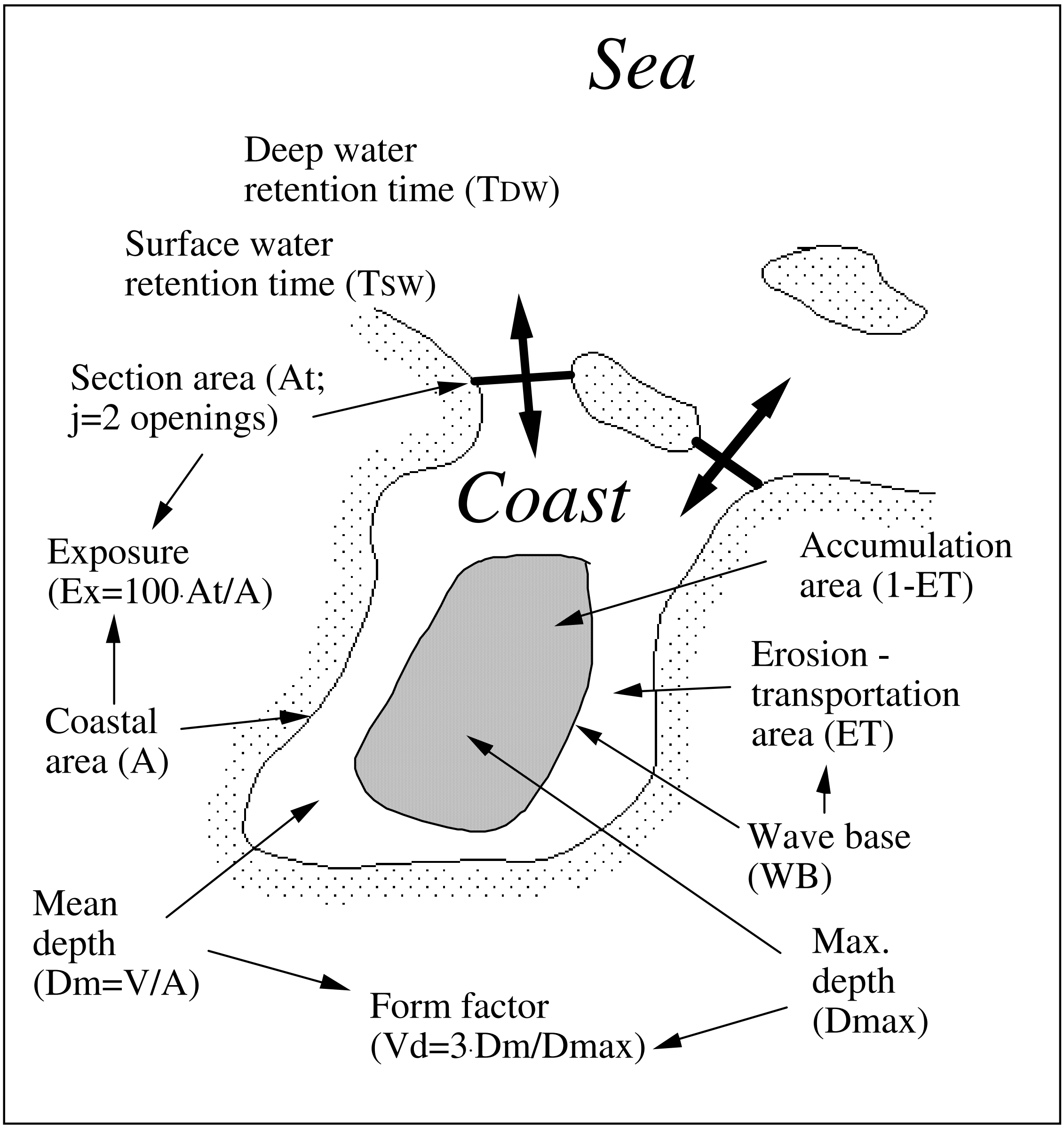

Figure 5.1. Illustration of key coastal parameters in mass-balance modelling. The most important criteria in this context is to define the boundary lines, i.e., where the coastal area ends and the sea or adjacent coastal area begins. The approach used in this work is to define the boundary lines so that the topographical openness (the exposure, Ex, defined by the ratio between the section area, At, and the enclosed coastal area, A) attains a minimum value.

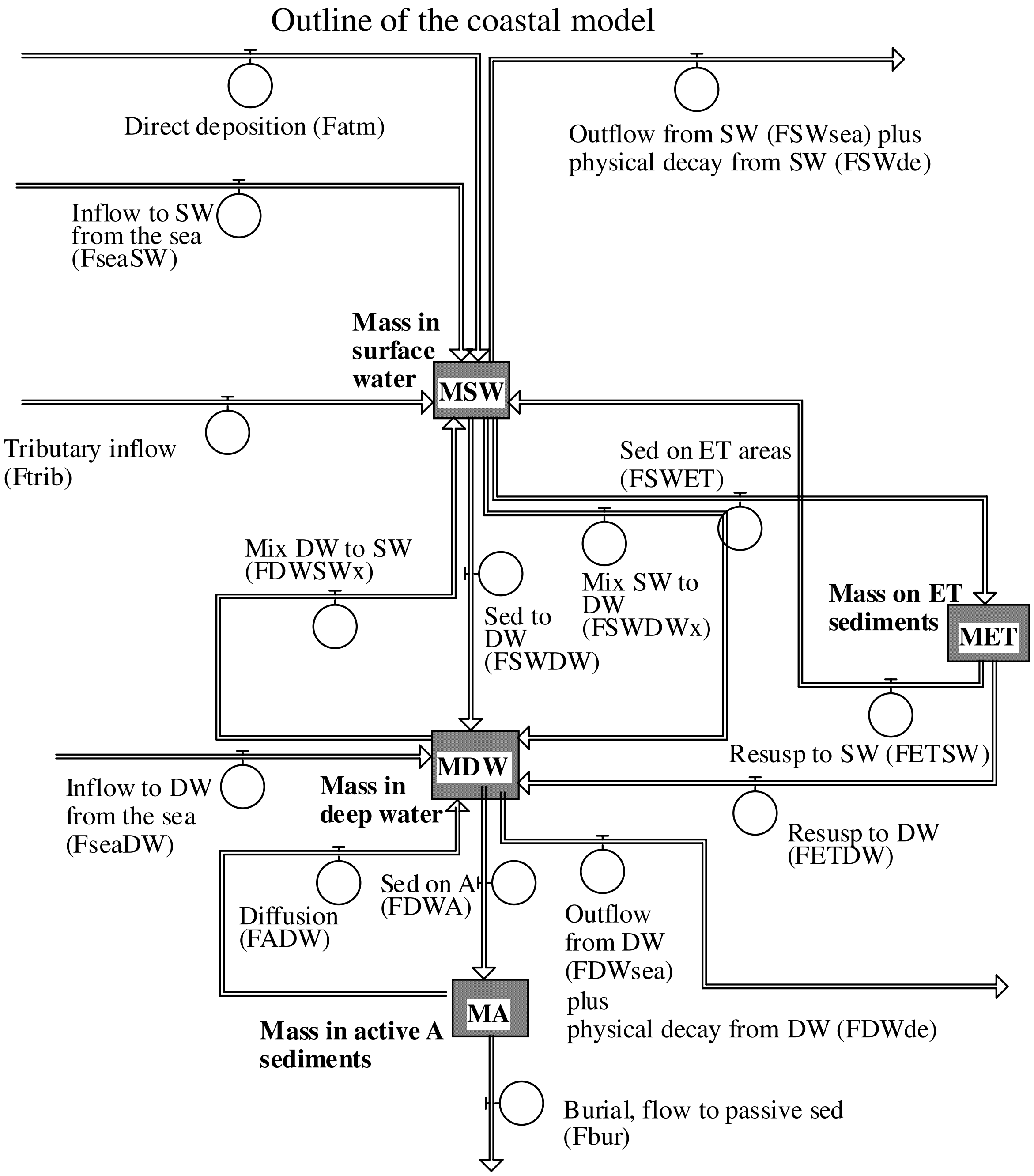

Figure 5.2. An outline of the mass-balance model for fluxes into (from rivers, from the sea or adjacent coastal areas or direct fallout onto the coastal area), out of the coastal area (via surface water or deep water exchange processes) and within coastal areas (sedimentation, resuspension from ET-areas either to surface water or deep water, diffusion from A-areas, mixing to and from the surface and the deep water compartments and burial).

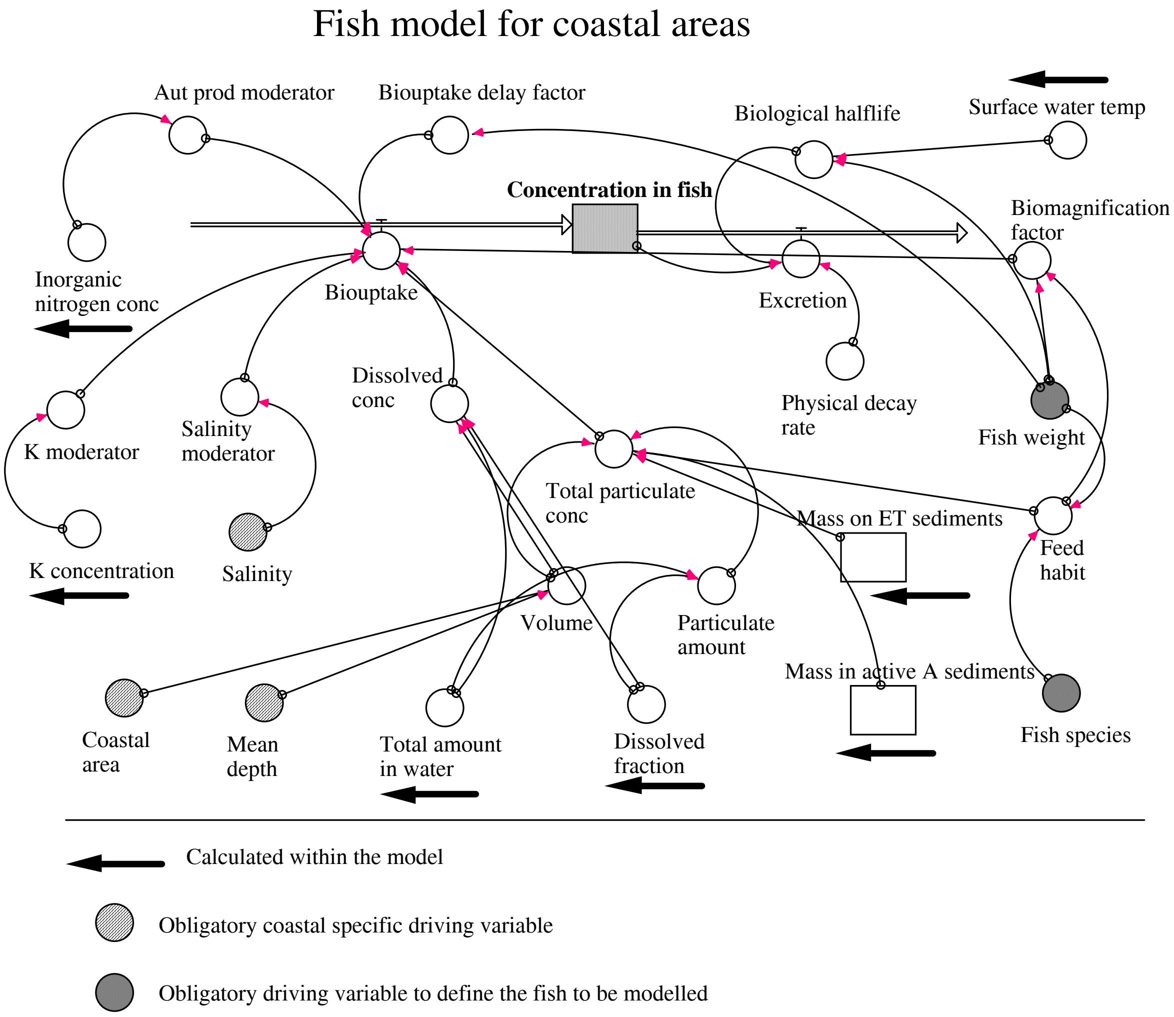

Figure 5.3. An outline of the fish model for coastal areas (modified from Håkanson, 2000).

Conclusions

We have presented here a preliminary assessment of models for predicting the behaviour of radionuclides in coastal areas and in the marine environment. The subject is, obviously, overwhelmingly complex and vast although several approaches and concepts are common to fresh water radioecological modelling sector. Moreover, during recent years, more emphasis was focused on lakes and rivers rather than on coastal areas and seas. Therefore, the present work should be considered as an initial effort for initiating a systematic assessment of the specific sector comparable with the analysis carried out for the rationale of models predicting the behaviour of radionuclides in rivers and lakes. We have here presented an example of a model that evaluate the behaviour of radiocaesium in coastal areas in an ecological perspective. Obviously, those parts of the models that assess the water circulation pertain to hydrology more than to radioecology. A scenario for validation of models predicting the migration of radiocaesium and radiostrontium of Chernobyl origin in water of Dnieper-Bug estuary was developed by IMMSP (Ukraine). This will be of help to evaluate performances of this kind of radioecological models.

SECTION 6: COUNTERMEASURES

Modelling the consequences of countermeasure has been carried out in the frame of VAMP (Håkanson et al., 1996) and MOIRA (Monte et al. 2000). Other CDSSs do not include a similar wide range of countermeasure models for the aquatic environment.

In the event of radioactive contamination of aquatic ecosystems there are a number of feasible countermeasures available. A list of countermeasures considered in CDSS is reported in table 6.1 (Brittain et al. 2000).

Some of the above countermeasures are aimed at removing contaminated matter or at reducing doses to man by different kind of restrictions.

In a large-scale study in Sweden different chemical remedial measures against radiocaesium were experimentally assessed. They generally gave the intended response in water chemistry (modification of water pH, K content etc.). However the reduction in radiocaesium in fish was not rapid and decisive.

Countermeasure feasibility and applications are described in more details in Monte et al. 2001.

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Brittain, J., Håkanson, L. & Gallego Díaz E. 2000 Target ecosystems, key fish species, dose to biota and the impact and feasibility of countermeasures in aquatic systems. In: The project MOIRA: a model-based computerised system for management support to identify optimal remedial strategies for restoring radionuclide contaminated aquatic ecosystems and drainage areas. Monte, L. Van Der Steen, J., Bergström, U., Gallego Díaz, E., Håkanson, L. & Brittain, J. (Eds). ENEA RT/AMB/2000/13, Roma; pp. 23-48.

Monte, L, Brittain, J. E., Håkanson, L., Gallego Díaz, E., Zheleznyak, M., Voitsekhovitch, O., Kryshev, I. & Marinov Petrov, K. (Ed.s). 2001 Implementing Computerised methodologies to evaluate the effectiveness of countermeasures for restoring radionuclide contaminated fresh water ecosystems. RT/AMB/2001/28 ENEA, Italy

Table 6. 1 Countermeasures in aquatic ecosystems and their mode of action.

APPROACH	ACTION	LOCATION OF ACTION	MODE OF ACTION	EXPERIENCE, MODELS & DATA
Chemical	Potash treatment	Lakes, reservoirs, rivers, coastal	Chemical "dilution"	Some experience and data for lakes. Models available.
Chemical	Direct liming	Lakes, reservoirs, rivers, coastal	Changes pH, which influences for example biouptake	Considerable experience in relation to acidification. Models available.
Chemical	Fertilisation	Lakes, reservoirs, rivers, coastal	Increases biomass, "biological dilution"	Considerable experience in relation to eutrophication. Models available.
Biological	Fishing (removal of shellfish)	Lakes, reservoirs (coastal)	Removal of fish (shellfish) biomass/changes in ecosystem structure	Considerable experience for economic species. Models available.
Biological	Fish removal	Lakes, reservoirs (coastal)	Removal of fish biomass using fish poisons such as rotenone	Some experience. Models available.
Physical	Control water flow through rate	Lakes, reservoirs, rivers, polders	Change water retention time; open dams, fill reservoir, etc.	Site-specific. Limited experience, limited success. Models available.
Physico-chemical	Removal of contaminated sediments	Lakes, reservoirs, rivers, coastal	Reduction in active sediment layer and/or direct exposure to man	Little experience. Can be modelled.
Physico-chemical	Sediment traps	Lakes, reservoirs, rivers	Collection of radionuclides associated with particles	Tried after Chernobyl but unsuccessful. Can be modelled.
Physico-chemical	Removal of contaminated snow and ice	Lakes, reservoirs, catchments, rivers, coastal	Reduction in source term and/or direct exposure to man	Site-specific. No experience, but can be modelled.
Physico-chemical	Treatment of drinking water	Lakes, reservoirs, rivers	Reduction in dose from drinking water	Some experience after Chernobyl. Can be modelled.
Chemical/ social	Food preparation	All ecosystems	Reduction in dose through food	Some experience. Can be very effective.
Social	Bans on fish consumption	Lakes, reservoirs, rivers, coastal	Reduction in dose through food	Some experience. Can be effective. Models available.
Social	Alternative drinking water sources, e.g. groundwater	Lakes, reservoirs, rivers	Reduction in dose from drinking water	Site-specific. Some experience. Effective. Can be modelled.
Social	Dietary changes (e.g. use of aquaculture where non-contaminated food is given)	All ecosystems	Reduction in dose through food	Some experience; can be effective. Can be modelled.
Social	Irrigation bans/ restrictions	Lakes, reservoirs, rivers	Reduction of uptake in crops	Some experience; can be effective. Can be modelled.
Social	Restricted areas	All ecosystems	Reduction in dose to population	Site-specific. Some experience; can be effective. Can be modelled.

APPENDIX – CENSUS OF MODELS AND PROJECTS

TITLE: Modelling fluxes and bioavailability of radiocesium and radiostrontium in a freshwater in support of a theoretical basis for chemical/hydrological countermeasures.
ACRONYM: **ECOPRAQ**
Contract: No F14P-CT95-0018

AIMS: To develop and critically test models for: sediment Kd, macroscopic algae as collectors of radionuclides, trophic chain transfer in laboratory conditions, sediment-water exchange and bioavailability in large-scale laboratory setup, chemical and/or hydrological countermeasures, aquatic fauna, accumulation and elimination by aquatic plants, and mechanistically based whole-ecosystem models.

RESULTS AND ACHIEVEMENTS:
New sub-models and algorithms for radiocesium and radiostrontium have been developed and presented in international journals concerning:
(1) Transport from land to water; accounting for inflow- outflow areas, topography, trajectory distance and soil types.
(2) Lake and sediment Kd; accounting for frayed edge sites, K+, NH+ activities.
(3) Biouptake rates; based on Michaelis-Menten kinetics
(4) Retention rates; based on stratification and mixing.
(5) Sensitivity and uncertainty analyses to rank factors, processes of importance relative to given predictions.
The results also include papers on the testing of remedial measures, like lake and wetland liming, potash treatment and fertilization.

PARTICIPANTS:
Netherlands Energy Research Foundation, ECN; Italian Environmental Protection Agency, ANPA; The Departamento de Protecção e Segurança Radiológica, DGA/DPSR, Portugal; Institutt for Energiteknikk, IFE, Norway; Norwegian Institute for Water Research, NIVA, Norway; Institute of Freshwater Ecology, IFE, U.K.; Univ. of Antwerp, Belgium; Univ. of Malaga, Spain; Uppsala University, Uppsala, Sweden; KEMA Nuclear, Arnhem, The Netherlands

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TITLE: Aquatic systems in the Chernobyl area: observations and predictive evaluation.
ACRONYM: **AQUASCOPE**
Contract N° IC15 CT98 0205

AIMS: The aim of AQUASCOPE was to develop and test simplified models for predicting concentrations of key radionuclides in surface waters and freshwater fish following a spatially distributed accidental deposition to surface waters and catchments.

RESULTS AND ACHIEVEMENTS:

1. "Closed" lake systems have been identified as being uniquely sensitive to high radiocaesium contamination after a deposition event. Our detailed analysis of these systems has led to the development of a simplified predictive model for radiocaesium concentrations in water and fish in closed lakes.
2. Current models for radionuclides in lake systems assume that physical resuspension is an important factor in predicting the long-term contamination of lakes. Our results contradict this hypothesis and tend to indicate instead that chemical remobilisation is the determining factor.
3. Simplified models have been developed for the prediction of radiocaesium and radiostrontium concentrations in water and fish of rivers and open lake systems. These models have been "blind" tested against independent measurements.
4. In collaboration with the Inco-Copernicus "STREAM" project a GIS based model has been developed for the prediction of runoff of radiocaesium and radiostrontium in large river catchments in Europe and Asia.

SOFTWARE DELIVERABLE: AQUASCOPE models working in EXCEL.

PARTICIPANTS: CEH (UK); TYPHOON (Russia); ECN (Netherlands); IGSB (Belarus); UHMI (Ukraine); DPSR (Portugal); Fachhochschule Weingarten (Germany).

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REFERENCE:

Smith, J.T., Konoplev, A. V., Bulgakov, A. A., Comans, R. N. J., Cross, M. A., Kaminski, S., Khristuk, B., Klemt, E., de Koning, A., Kudelsky, A. V., Laptev, G., Madruga, M.J., Voitsekhovitch, O., V. & Zibold, G. - AQUASCOPE Technical Deliverable. Simplified models for predicting ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{131}I in water and fish of rivers, lakes and reservoirs.CEH Centre for Ecology and Hydrology, Natural Environment Research Council. 2002

TITLE: Evaluation of short term releases of radionuclides to rivers.
ACRONYM: **AQUASTAR**
Contract N° UK Environment Agency contract.

AIMS- The aim of the project was to develop a simplified model for predicting the consequences of short term (authorised or accidental) releases of radionuclides to rivers.

RESULTS AND ACHIEVEMENTS:

An advection-dispersion model has been developed to predict activity concentrations in water and fish of H-3, C-14, P-32, Co-60, Zn-65, Sr-89,90, I-125,131, Cs-134,137, Pu-238,239,240, Am-241, U-234,235,238.

SOFTWARE DELIVERABLE: AQUASTAR model code in FORTRAN, and model predictions in graphical form.

PARTICIPANTS: CEH (UK).

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TITLE: A model-based computerised system for management support to identify optimal remedial strategies for restoring radionuclide contaminated aquatic ecosystems and drainage areas

ACRONYM: **MOIRA** Contract N° FI4P-CT96-0036

AIMS: The aim of the MOIRA project was to develop a user-friendly, computerised Decision Support System that allows decision makers to choose optimal countermeasure strategies for different kinds of aquatic ecosystems contaminated by radionuclides taking into account ecological, social and economic consequences.

RESULTS AND ACHIEVEMENTS: A computerised DSS was developed. MOIRA DSS evaluates several types of countermeasures to reduce the dose via aquatic pathways and to advise the user of the most effective method by accounting for the impacts on the economy, the society and the environment.

MOIRA DSS makes use of:

- environmental models yielding high predictive power for assessing the behaviour of radionuclides in fresh water systems and the effects of countermeasures on the contamination levels;
- a Multi-Attribute Analysis module to rank remedial strategies according to their effectiveness and their impacts on the economy the society and the environment;
- suitable Ecosystem Indices for an objective evaluation of the countermeasure ecological impact;
- MOIRA Software Framework including: a) MOIRA User Interface intending to help the decision maker to make steps of decision making in most convenient and natural way; b) MOIRA OS based on LIANA Models Integration System giving the possibility to easy configure MOIRA Software, integrate and run a wide range of models and tools, manage data sets c)Internet Report, GIS connection and Powersim® connection modules.
- Geographical Information System (GIS) - giving the possibility: a) keep and manage the cartographic information, population data and the geographically-related environmental data used by DSS models b) estimate some parameters values using the geographical information c) use interactive maps as part of MOIRA User Interface.
- Database of socio- and economical- related parameters used by DSS models

SOFTWARE DELIVERABLE: MOIRA DSS working on PC. Distributed on CD

PARTICIPANTS: ENEA, (Italy), NRG (The Netherlands), Studsvik Eco & Safety AB (Sweden), Universidad Politécnica Madrid (Spain), Uppsala University (Sweden), University of Oslo (Norway)

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TITLE: **CASTEAUR** (French acronym for Simplified CAlculation of radioactive nuclides Transfer in Receiving WATERways)

AIMS: Operational tool to assess the short and middle term impact on fluvial ecosystems of both accidental and routine radioactive releases.

RESULTS AND ACHIEVEMENTS: This code is organised over a simplified representation of the hydrographic network, on which simplification was applied to the five domains: hydraulics, sedimentary dynamics, ecology and radioecology. The ecosystem could be described by six components: water, suspended and settled matters, primary producers, first order consumers and fish. According to time and space and with the possibility to take into account four kinds of radioactive releases, from pulse to continuous pollution, CASTEAUR assesses the radioactive nuclides concentrations in these components. These concepts are formalised in a prototype, which offers the possibility to combine the different kind of releases, pollutants and ecosystem components for ^{110m}Ag, ^{241}Am, ^{58}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{54}Mn and ^{106}Ru..

SOFTWARE DELIVERABLE: CASTEAUR

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REFERENCE

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TITLE: Real-time On-line DecisiOn Support system, **RODOS**

AIMS: Designed as a generic tool, the RODOS system will be applicable from the very early stages of an accident up to many years after the release and from the vicinity of a site to far distant areas. Decision support is provided at various levels ranging from the largely descriptive, with information on the present and future radiological situation, to an evaluation of the benefils and disadvantages of different countermeasures' options.

RESULTS AND ACHIEVEMENTS: The integrated and comprehensive Real-time On-line DecisiOn Support system, RODOS, for off-site emergency management of nuclear accidents was developed with support of the European Commission and the German Ministry of Environment. The software framework of RODOS provides tools for processing and managing a large variety of different types of information, including meteorology, radiology, economy, emergency actions and countermeasures, rules, preferences, facts, maps and statistics.
Hydrological module for the decision support system RODOS. - A model chain was outlined covering the processes such as run-off of radionuclides from watersheds following deposition from the atmosphere, transport of radionuclides in river systems and the radionuclide behaviour in lakes and reservoirs. The output from the hydrological transport chain is used to calculate the main exposure pathways such as the doses derived from the consumption of drinking water, fish, irrigated foodstuffs and from extemal irradiation. Test and validation studies of the whole chain as well as for individual models were performed on the basis of experimental data from the basins of the Dnieper and Rhine. A user-friendly graphical interface was developed to operate the individual models inside the hydrological module.

SOFTWARE DELIVERABLE: RODOS DSS transportable package to run on workstation with the UNIX operating system.

PARTICIPANTS: A large number of West and East European institutes were involved in its development.

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TITLE: Implementing computerised methodologies to evaluate the effectiveness of countermeasures for restoring radionuclide contaminated fresh water ecosystems, **COMETES**
Contract N° ERB IC15-CT98-0203

AIMS: Preparation of Site-Specific Databases of radionuclide (^{137}Cs and ^{90}Sr) concentrations in water of European Rivers and Lakes contaminated after the Ural and Chernobyl Radiation Accidents; testing and improvement of models for predicting the radionuclide migration in freshwater systems and the influence of the countermeasures on radioactivity levels by applications to contaminated sites; Retrospective analysis of countermeasures applied to contaminated aquatic ecosystems; Application of Multi-Attribute Analysis and implementation of methodologies for evaluating the social, economic and ecological impact of countermeasures.

RESULTS AND ACHIEVEMENTS: The project activities demonstrated the applicability of MOIRA DSS to real contamination scenarios. A revised version of MOIRA (MOIRA 2) was developed as result of the DSS validation and testing.

SOFTWARE DELIVERABLE: MOIRA 2 DSS working on PC. Distributed on CD

PARTICIPANTS: ENEA, (Italy), Bulgarian Academy of Sciences (Bulgaria), IPMMS-Academy of Sciences (Ukraine), Typhoon (Russia), UHMI-Ministry of Environmental Resources (Ukraine),Universidad Politécnica Madrid (Spain), University of Oslo (Norway), Uppsala University (Sweden),

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TITLE: Spatial Redistribution of Radionuclides within Catchments: Development of GIS-based Models for Decision Support Systems

ACRONYM: **SPARTACUS**

Contract No. IC15 CT98 0215

AIMS – The aim of SPARTACUS was to develop GIS-based models of event-based and long-term Cs-137 redistribution models within catchments.

RESULTS AND ACHIEVEMENTS

1. Observed patterns of radiocaesium contamination could be well related to soil erosion processes and tillage operations. The magnitude at which radiocaesium redistribution occurs strongly depends on land use and soil characteristics. The model experiments showed that radionuclide redistribution can be strongly influenced by soil erosion that occurs before the first ploughing in the period after the initial fallout.

2. In addition, investigation of radiocaesium deposition patterns on a Russian floodplain demonstrated that the spatial variation in radiocaesium contamination can be largely attributed to the water level during the initial Chernobyl fallout. Despite this dominant pattern, detailed field survey showed that enhanced radiocaesium contamination of floodplain soils and bottom sediments are found on locations were sedimentation takes place.

3. The GIS-based models developed within the framework of the SPARTACUS project comprise models to simulate event-based radiocaesium transport due to surface runoff and soil erosion and long-term radiocaesium transport due to soil erosion and tillage translocation. In total, a set of nine models have been developed and issued. The models have been implemented in the PCRaster GIS, since this enables an easy integration into the environmental decision support system developed in the RESTORE project (FI4P-CT95-0021c).

SOFTWARE DELIVERABLE: Cs-137 redistribution models and improved version of RUNTOX; available on CD-ROM (Annex to the final report)

PARTICIPANTS: UU (Netherlands); OSMU (Ukraine); Univ. Of Exeter (UK); VÚJE (Slovakia); UHMI (Ukraine); IPMMS (Ukraine); IGAC (Russia)

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SPARTACUS. Spatial redistribution of radionuclide within catchments: Development of GIS-based models for decision support systems. Final Report. Edited by M. Van der Perk, A.A. Svetlitchnyi, J. W. Den Besten & A. Wielinga. Universiteit Utrecht, 2000

TITLE: Large-scale and Long-term Environmental Behaviour of Transuranic Elements as Modelled through European Surface Water Systems
ACRONYM: **TRANSURANIC**
Contract N° FI4P-CT96-0046

AIMS: To assess the major forcing processes that influence the behaviour of the transuranic elements in surface water.

RESULTS AND ACHIEVEMENTS: Evaluations of the balance and the behaviour of reactive radionuclides in three lake systems characterising different European types of freshwater in regions with a wide-range of environmental conditions.

PARTICIPANTS: Uppsala University (Sweden), University of Liverpool (UK), Universidad de Sevilla (Spain), Forschungsverbund Berlin e. V. - Gemeinsame Verwaltung (Germany), Université de Nice (France)

CONTACT: Dr. F. El-Daoushy
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Sweden
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REFERENCE
El-Daoushy, Appleby, P.G., Garcia-León M., Casper P. & Ardisson, G. (2001). Large-scale and Long-term Environmental Behaviour of Transuranic Elements as Modelled through European Surface Water Systems. IN: Radiation protection Fourth framework programme (1994-1998) Project summaries. EUR 19792 EN European Commission, Brussels pp. 175-179.

NON-EC PROJECTS ON MODELLING RADIONUCLIDE BEHAVIOUR IN FRESH WATER ECOSYSTEMS

TITLE: BIOspheric MOdel Validation Study,
ACRONYM: **BIOMOVS**
Organisation: NIRP (Sweden)

AIMS: Intercomparison and validation of models for predicting the behaviour of radionuclides in the environment.

RESULTS AND ACHIEVEMENTS (for the fresh water environment): A number of exercises of model intercomparison and validation were performed:
Model intercomparisons:

- trasport of radionuclides with groundwater from the aquifer through sediments into a river or onto agricultural soil (Np-237, Pu-239, Sr-90 Cs-137);
- release of radium-226 and Thorium-230 to a lake, simulation of use of silted up contaminated lakes;

Model validations:

- Mercury in creeks and rivers;
- Release of ^{137}Cs of Chernobyl origin in Swedish lakes.

PARTICIPANTS: many international institutions from Europe, USA and Japan.

REFERENCE
On the Validity of Environmental Transfer Models. Proceedings of a Symposium, Stockholm-Sweden. Swedish Radiation Protection Institute. 1991

TITLE: BIOspheric MOdel Validation Study - Phase II
ACRONYM: **BIOMOVS II**

Organisation: Atomic Energy Control Board, Canada; Atomic Energy of Canada Limited; Centro de Investigaciones Energeticas Medioambientales y Tecnologicas, Spain; Empresa National de Residuos Radioactivos SA, Spain; SSI, Sweden

AIMS: Intercomparison and validation of models for predicting the behaviour of radionuclides in the environment; recommandation for future researches to improve model performances.

RESULTS AND ACHIEVEMENTS (for the fresh water environment): A number of exercises of model assessment, intercomparison and validation:

- radionuclide wash-off from watershed using Chernobyl data;
- radioactive contamination of Chernobyl NPP cooling pond;
- fate of ^{14}C in lakes.

PARTICIPANTS: more than 160 international institutions in 31 countries from both West and East Europe, Canada, USA and Japan.

REFERENCE
BIOMOVS II, Special Issue of Journal of Environmental Radioactivity. 42, 2-3, 1999

TITLE: VAlidation of environmental Model Predictions, **VAMP**
Organisation: International Atomic Energy Agency

AIMS: Validation of models for predicting the behaviour of radionuclides in the environment.

RESULTS AND ACHIEVEMENTS (for the fresh water environment): Validation of models for predicting the behaviour of 137Cs of Chernobyl origin in seven European lakes.

Validation of models for predicting the behaviour of 137Cs and 90Sr in the Dnieper reservoir cascade and in the Tennessee river.

The project brought together a considerable amount of empirical data for freshwaters contaminated by Chernobyl fallout, which was subsequently utilised in models development and validation.

PARTICIPANTS: many International Institutions from Europe and USA

REFERENCE

Modelling the transfer of radiocaesium from deposition to lake ecosystems. IAEA/CEC CO-ordinated Research Programme on the Validation of Environmental Model Predictions (VAMP). IAEA-TECDOC-1143. 2000

PART 2

EC COMPUTER SYSTEMS IN THE FIELD OF HYDROLOGICAL DISPERSION MODELLING AND AQUATIC RADIOECOLOGICAL RESEARCH: STATE OF THE ART, END-USER EXPERIENCES AND RECOMMENDATIONS FOR IMPROVEMENTS.

D.Hofman[1], L.Monte[2], J.Brittain[3], P. Boyer[4], G. Donchyts[5], E.Gallego[6], D. Gheorghiu[7], R.Heling[8], L. Håkanson[9], A. Kerekes[10], G. Kocsy[10], S. Lepicard[11], O. Mirzeabassov[12], J. Smith[13], M. van der Perk[14], P.Pecha[15], B. Mieczyslaw[16], O. Slavik[17], D. Slavnicu[7], B.Yatsalo[12], M.Zheleznyak[5]

1.Studsvik Nuclear AB (Sweden)
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3. University of Oslo (Norway)
4. Institute de Radioprotection et de Sureté Nucléaire (France)
5.Institute of Mathematical Machines and System Problems of National Academy of Sciences (Ukraine)
6.Universidad Politécnica de Madrid (Spain)
7.IFIN-HH - National institute of R&D for Physics and Nuclear Engineering, Atomistilor (Romania)
8.NRG - Nuclear Research & Consultancy Group, The Netherlands (Principal Contractor)
9.Uppsala University (Sweden)
10.National Research Institute for Radiobiology and Radiohygiene (Hungary)
11.CEPN (France)
12.Obninsk Institute of Nuclear Power Engineering (Russia)
13.Centre for Ecology and Hydrology (UK)
14.University of Utrecht (The Netherlands)
15.IITA, Institute of Information Theory and Automation (Czech Republic)
16. IAE-Institute of Atomic Energy (Poland)
17.VUJE Trnava Inc. (Slovak Republic)

Executive summary

The objective of the EVANET-HYDRA network was to assess the state of the art of the Decision Support Systems (DSS) and models in the field of the management of radionuclide contaminated fresh water environments developed in the 4th EC framework programme and to plan necessary improvements on the basis of critical evaluations gained by users during the processes of DSS testing, application and customisation. The following DSS were the subject of evaluation: MOIRA DSS, Hydrological Module of the RODOS DSS (RODOS-HDM), AQUASTAR, AQUASCOPE, CASTEAUR, RIPARIA, SPARTACUS. In order to reflect current state of the art in the development of the GIS-based DSS and explore the potential links, the demonstration of the PRANA DSS (a DSS for management of rehabilitation of radionuclide contaminated areas in the Bryansk region) was also performed during EVANET-HYDRA meetings.

The goals of the assessment of the DSS software in the frame of Work Package 4 of EVANET-HYDRA were:

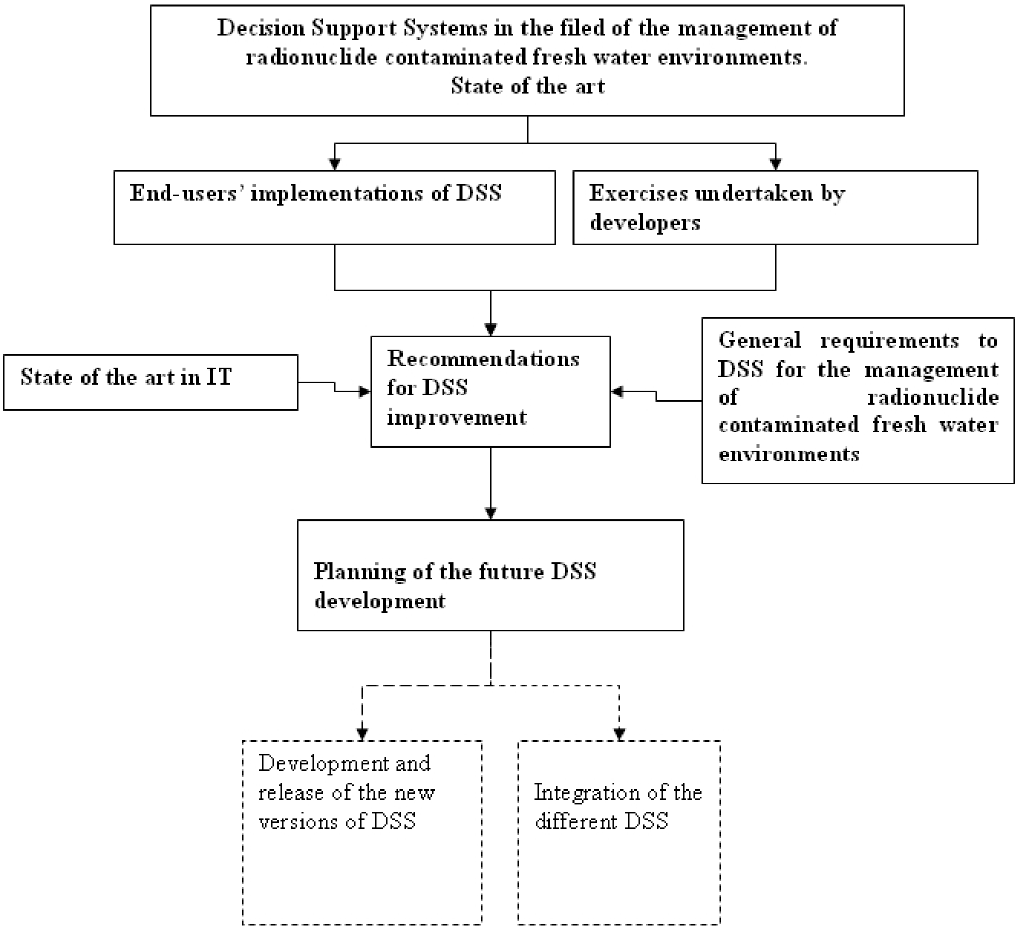
- to identify availability, applicability and usability of the DSS:
  - What is the "application domain" and what are the potential users of each software product?
  - Does software provide all the information required for the decision making support in this "application domain"?
  - Does presentation of the information and input of new information through the user interface satisfy the requirements of decision makers and operators?
  - Do data, costs and manpower resources required for the software installation and site-specific customisation correspond to the end-user achievements?
  - Are documentation and support currently provided sufficient for the end-users?
- to identify if architecture and programming codes of the DSS correspond to the level of quality and flexibility achievable from a modern software product ;
  - Does software include the features corresponding to the current state-of-art in IT and expected by end-users as standard?
  - Does software have sufficiently flexible structure for future developments and extensions, and how is this supported from the software engineering point of view?
- to identify the improvements necessary in each DSS and the improvements necessary to establish transparent data exchange between DSS.

These goals of WP4 were achieved by the following activities:

- Demonstrations, discussion meetings and exercise seminars with the participation of both software developers and potential users.
- Distribution of the most recent versions of the software and documentation to the current and potential users of DSSs (both participants and non-participants in the EVANET-HYDRA network).
- Development of the criteria for the assessment of the CDS systems (Annex 1 of this report)
- Collecting and documenting (through questionnaires and analysis of the presentations and publications) of the characteristics of each DSS. (Part1 and Annex 3 of this report)
- Test implementation of the software, undertaken by end-users and participants of EVANET-HYDRA (in cooperation with WP5) (described in Part 2 of this report)
- Test implementation of the software undertaken by its developers (described Part 2 of this report)

- Collecting (through the questionnaire) the general users' requirements for the DS systems. (Annex 2 of this report)
- Collecting the experience gained in testing software implementations by organisations not involved in the network activities. (described Part 2 of this report)
- Planning improvements in each DSS and improvements necessary to establish data exchange between different DSS.

The diagram illustrates the methods and future implementation of the results of the WP4 of EVANET-HYDRA.



The basic characteristics of the DSS evaluated in the frame of EVANET-HYDRA are given in the Part 1 of the report and summarised in Tables I and II .Results of the end-users experience with DSS are presented in Part 2 and summarised in Table III. Part 3 summarises the improvements necessary to implement all the DSS. Part 3 also gives the overview of the architecture of the network of the integrated DSS for the management of radionuclide contaminated aquatic areas.

The following conclusion had been reached as result of the EVANET-HYDRA WP4 activities:

Evaluation of the decision support systems performed in the framework of the EVANET-HYDRA have shown that current releases of the MOIRA, RODOS-HDM, AQUASCOPE, AQUASTAR, RIPARIA and SPARTACUS are ready-to-use and available tools for the solving of the end-users' practical tasks related to the prediction of the migration of radionuclides in the aquatic environment. CATEAUR is available for the end-user as the prototype tool.

EVANET-HYDRA evaluations and exercises allowed specification (implementation already started in some cases) of the short-term improvements necessary in each DSS as well as correctly identifying directions for long-term improvements.

As result of the evaluations made in the frame of EVANET-HYDRA, a new issue, integration, has appeared. It was recognised that support for automated run-time data exchange between MOIRA and RODOS-HDM would be simplified using of these two systems as the complimentary tools. Taking into account the high flexibility of model integration already present in MOIRA and RODOS-HDM , such a connection would allow easy "binding" of all the DSSs evaluated in the frame of EVANET-HYDRA, and would help to establish a network of integrated DSS for the management of radionuclide contaminated aquatic areas.

SECTION 1. STATE OF THE ART

Table I documents the characteristics of the DSS evaluated, with emphasis on their “software” features such as components, user interface, support of site-specific customisation and flexibility. Table II (taken from Final Technical Report of EVANET-HYDRA network) describes their application domain, modelled radionuclides, special and temporal domains for the models in each DSS, necessary to understand the DSS applicability.

Software acronym	Application domain, modelled radionuclides, special and temporal domain	Main components	Level of availability	User interface	Site-specific customisation	Data exchange with other applications	Internet	Features
MOIRA	See MOIRA in the table 2. Level 3 DSS	MOIRA is an integrated system encompassing: a. lake and river Cs-137 and Sr-90 models , dose model, lake ecosystem index model, economic model b. MAA module c. MOIRA Software Framework - MOUIRASF (GUI,.model integration system, RefDBMS, management of scenarios and alternatives) d. RefDB - data base of default values and ranges for parameters e. MOIRA geodatabases and set of GIS-based models	MOIRA software is downloadable from Internet Requirements: PC/Windows PowerSim RunTime 2.51 –required at run-time for the simulation (limited number of licenses are available from developers on request). Data editing and visualisation as well as MAA functions of MOIRA can be performed even if PowerSim is not available. Availability of MapInfo Pro on the user's PC will increase MOIRA data visualisation possibilities at run-time, while MOIRA can function without it.	Advanced GUI combining object-based style of data browsing with GIS-like features.	Site-specific customisation of spatially-distributed data is required for river characteristics only. These data are given as text files. MOIRA provides tool for the editing of these files. Default and range values for all input parameters can be specified using MOIRA GUI. MOIRA is supplied with the set of default data for the socio-economic parameters. MOIRA is supplied with the set of geodabases containing general environmental and population data for the Western Europe. Site-specific customisation of these geodatabases is recommended to increase data input and visualisation friendliness for the inexperienced end-user. MapInfo Pro is required for customisation.	Data in tables and graphs can be copied to clipboard.	Data and results summary as report in HTML format.	MOIRA models are .exe files or PowerSim (.sim) files. MOIRA provides high flexibility in integration of new or updated models with the MOIRASF. Even after integration same model can be used both in the frame of MOIRA and stand-alone. Integration of updated model often can be done just by substituting of the corresponding file. This provides reach possibility for model testing and validation.
RODOS-HDM	See RIVTOX and LAKECO in the	RODOS-HDM is a part of the RODOS DSS. RODOS-	Part of the RODOS v.5 distributive	RETRACE, LAKECO,	Site-specific customisation			By integration with RODOS

	table 2	HDM consists of : RETRACE (run-off model) RIVTOX (river model) + GUI LAKECO (lake model) POSEIDON (coastal areas model) COASTOX (coastal areas model) + GUI TREETOX (3-d model) + GUI Top-level GUI	Requirements: HP workstation/ Unix RODOS system and AllBase SQL are required at run-time	POSEIDON – command line interface RIVTOX, COASTOX/THREE TOX - advanced GUI combining object-based style of data browsing with GIS-like features.	of spatially distributed data is required before use. ArcView is required for customisation. HDM provides set of the tools to convert data from ArcView formats to internal format.			system HDM can receive results of RODOS ADM (Atmospheric Dispersion Module) and supply results to RODOS FDMA (Aquatic Food Chain Module)
CASTEAUR	See CASTEAUR in the table 2.	CASTEAUR is an integrated system encompassing: Hydrographic model, hydraulics model, sedimentary model, food chain model, radioecological models, user interface	Prototype version Available on request Requirements: PC/Windows MS Excel	Form –based GUI (based on the VBA integrated with MS Excel)		Same as MS Excel	Same as MS Excel	

AQUASCOPE	See AQUASCOPE in the table 2.		Available on request Requirements: PC/Windows MS Excel	MS Excel-spreadsheet UI	Worksheet is divided into “Parameters to be input by the user”, “Constants of the model” and “Calculated parameters”. The constants of the model may be changed, but this is not recommended.	Same as MS Excel	Same as MS Excel	Has a “Water residence time calculator” and a “Kappa calculator”. These tools aid the user in calculating the lake water residence time and radionuclide removal rate
AQUASTAR	See AQUASTAR in the table 2.		Available on request Requirements: PC/Windows MS Excel	MS Excel- spreadsheet UI plus model output in graphical form.		Same as MS Excel	Same as MS Excel	
RIPARIA	See RIPARIA in the table 2.		Available on request Requirements: PC/Windows	Command line interface	Inputs and outputs are provided via text files.			
SPARTACUS	Post release, long-term management/restoration	GIS-based model of long-term redistribution of ^{137}Cs within catchments.	Requirements: PC/Windows PCRaster	Visualisation of the information is available via PCRaster possibilities		Same as PCRaster	Same as PCRaster	

Table I Basic characteristics of DSSs object of the EVANET-HYDRA assessment

Model	Target variables (concentrations)	Aims	Radionuclides	Space horison	Time horizon	Time Resolution Power	Spatial Resolution Power (SRP)	Dimension	Main Processes	Main characteristics of the method of solution
AQUASCOPE	Water, sediment and fish	Long term assessment following deposition on the whole catchment	Sr, Cs and I	Lakes, Large catchment	Medium and long term	Monthly averages	Entire water body	-	Migration from the whole catchment	Transfer function
AQUASTAR	Water, sediment and fish	Accidental and routine release in water	Cs, Sr P, I Co, ^{14}C, Pu, U, Zn, Am	River at any space scale	Any timescale	Minutes or hours	In principle punctual predictions	2-dimensional	Transport, transverse dispersion, migration to sediment (particle settling), 1st-order uptake by fish species (prey and predator)	Contaminant input-output balance (Transport downstream, uptake by fish species). Analytical (Transverse dispersion)
CASTEAUR v0.0	Water and fish	Accidental and routine releases in water	Fission products	River at any space scale	Short and medium term	Minutes or hours	In principle, punctual predictions	1-dimensional	Transport, diffusion, migration to sediment (particle settling), 1st-order uptake by fish species (prey and predator)	Analytical within a reach. Input-output balance among reaches and for biota
MOIRA	Water, sediment and fish	Medium and long term assessment of contamination and countermeasures	Sr and Cs (high flexible structure, easy to convert for assessment of other	Lakes, Catchment and river (medium and large	Medium and long term	Monthly averages	Whole lake, 1/20 of the entire river length	1-dimensional	Migration from catchments, transport, migration to sediment, resuspension and non-reversible migration to deep sediment (1st-order),1st-order uptake by fish species	Contaminant input-output balance and compartment models derived by Radionuclide

		effects. Contamination of catchment and direct release in water.	radionuclides)	size)					(prey and predator), effects of fish movement on their contamination levels , effects of countermeasures on contamination levels.	Transfer Functions
RIPARIA	Water, sediment, fish	Accidental and routine release in water	Fission products, 3H, NORM,	River at any space scale	Any time scale	Depends on the compartment size	Depends on the compartment size	1-dimensional	Compartment model assuming: a homogeneous distribution of radionuclide within a compartment; radionuclide fluxes calculated in terms of annual average transfer of water volumes. Radionuclide migration to sediment and resuspension Radionuclide concentration in fish and water assumed to be in equilibrium.	Input-output balance among compartments
RIVTOX (THREETOX is a three-dimensional dispersion model based on similar approaches)	Water, sediment, fish	Accidental and routine release in water. Contamination of catchment (Connected to RETRACE model, Popov et al., 1996)	Fission products, NORM, 3H	River at any space scale	Any time scale	Days	In principle, punctual predictions	1-dimensional	Diffusion-transport equation, radionuclide migration to sediment and resuspension.	Numerical/analytical. In principle, the model equations are derived by averaging 1-dimensional equations over depthand width
LAKECO	Water, sediment, fish	Accidental and routine release in water.	Fission products	Lakes	Medium and long term	Monthly averages	Entire river	-	Migration from river sub-catchments, transport, migration to sediment, resuspension and non-reversible migration to deep sediment. Migration to biota.	Contaminant input-output balance and compartment models

Table II. .Main characteristics of the models object of the present assessment (is taken from Final Technical Report .of EVANET-HYDRA)

MOIRA DSS

MOIRA DSS [Monte et al. 2000] ("A Model-Based Computerised System For Management Support To Identify Optimal Remedial Strategies For Restoring Radionuclide Contaminated Aquatic Ecosystems And Drainage Areas") helps decision-makers to evaluate and rank alternative strategies, which could be implemented to reduce consequences of accidental radioactive contamination of lakes and rivers. The evaluation of each strategy (including "no actions") is done in MOIRA in terms of exposure doses received by population as well as environmental and economic consequences. Ranking of the different strategies is made using Multi-Attribute Analysis (MAA) techniques.

The architecture of the MOIRA DSS is shown in Figure 1 [Hofman et. al 2000]

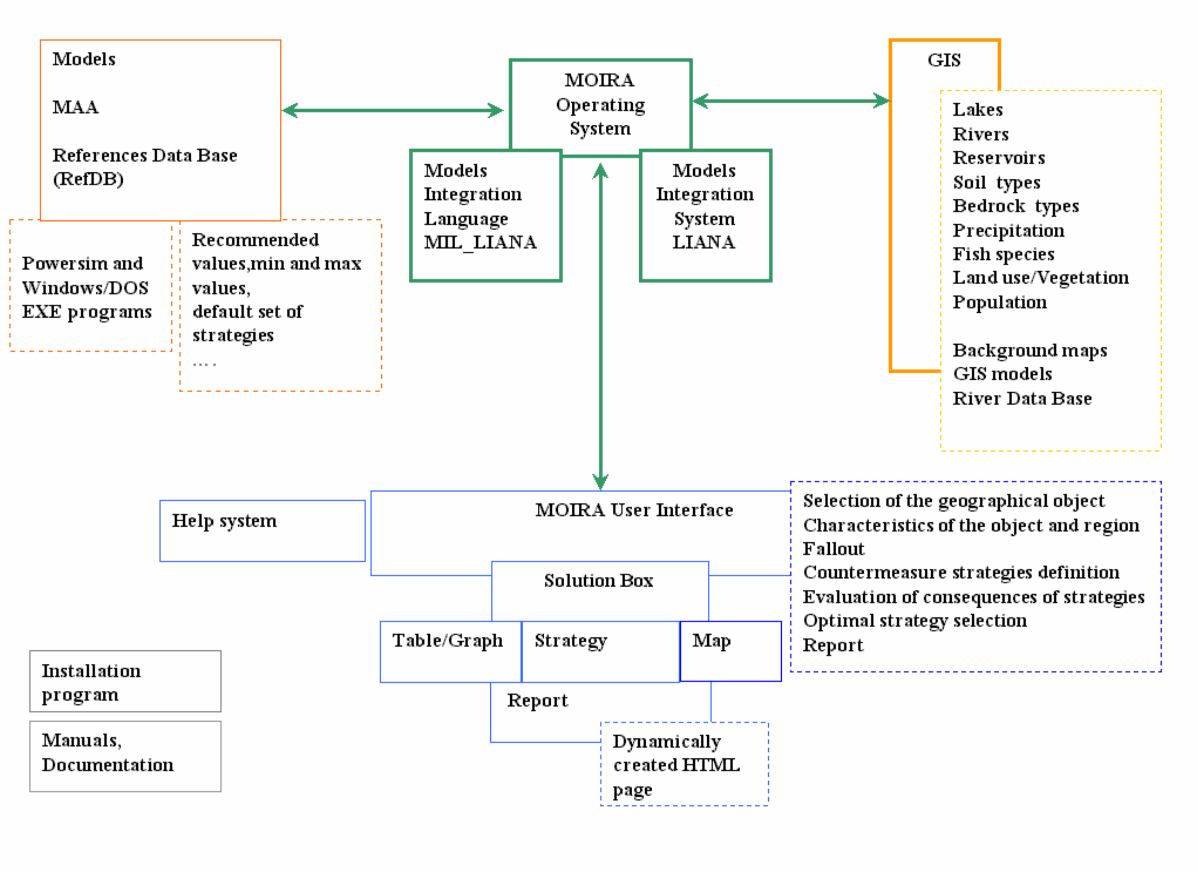


Figure 1

MOIRA includes a set of models to predict distribution of Cs-137 and Sr-90 in lakes and rivers, models evaluating chemical characteristics of the lake water, lake ecosystem index model, dose assessment model, economic model and MAA Module [Monte, Brittain 1998; Monte et al. 2000; Håkanson et al. 2000; Gallego et al. 2002]. The models and MAA software were implemented in the environment of Powersim® 2.5 package [www.powersim.com] or as stand-alone Windows or DOS applications. MOIRA Software Framework [Hofman 1998, Hofman, Nordlinder 2003] includes MOIRA OS and MOIRA GUI as well as provides support for MOIRA GIS.

MOIRA Software Framework

(by D.Hofman)

MOIRA Software Framework (MOIRASF) supports the following functionality of MOIRA DSS:

- It helps to integrate different MOIRA components (models, MAA module , user interface, GIS and data base) into the unit system and make the process of integration easy both for the developers of the models and for the software developers.
- It provides MOIRA with the friendly GUI.
- It helps user in the selection of the “target” object and definition of its site-specific characteristics via connection with MOIRA GIS.
- It provides the possibility to keep and retrieve in the user-friendly way default values and check the ranges for the input parameters.
- It provides system for the user-friendly definition of the alternative strategies of the countermeasures.
- It provides system for the fast selection and running of the sequence of the models appropriate to the case (lake/river , Cs/Sr/Cs+Sr) and data exchange between model chain and GUI
- It establishes interaction with MAA module in order to make ranking of the strategies based on the alternative strategies definition and sequences
- It makes summary of all data, results and strategies ranking in the form ready to be represented with Internet
- It save any work done with the possibility to retrieve it later.

MOIRA keeps all the input data and results related to the current scenario in the same directory as the files. This directory and corresponding workspace when directory is loaded with MOIRA GUI have name "solution box". User can change all the input data in solution box, make simulation and preview all the results with MOIRA GUI. Data sets inside solution box are path-independent and directory can be moved to another place or another PC. Data for each solution box are kept consistent.

Working with MOIRA GUI user is able to input all the necessary data, but to simplify this process MOIRA system gives the possibility to store site-specific and region-specific data in MOIRA GIS (in MapInfo® format) and than just reuse these data when necessary. Such a customisation of MOIRA GIS data with region-specific detailed data is recommended for the long-term usage of MOIRA in emergency centres in order to increase its friendliness for the inexperienced users.

MOIRA Reference Data Base (RefDB) can contain minimum, maximum and default values for each input parameter. These values are used to validate user input and help user in identification of values for unknown parameters. RefDB can contain examples for the whole user interface tables.

The MOIRASF supports MOIRA DSS stability via:

a) avoid user’s errors in input data by check the data type and ranges of inputted values
b) make warning with the request to decrease calculation time-step in the case of negative values or overflow in calculated results
c) react in the form of warning on resource-related problems (such as for example if file can not be created due to the small disk space available)
d) react in the form of warning case if some components (such as for example GIS or graphics supporting software) are not installed, check software in installation program

MOIRA GUI

MOIRA GUI (Fig. 2) has the data-centred design [Microsoft, 2003a]. Data-centered design was implemented as response to the requirement [Appelgren et. al 1996] that MOIRA DSS should be a friendly system for the all users independently of their level of experience in environmental modelling. Content of all MOIRA data collections is available in a browser-like style. The input and result data used in system are combined in the groups (data sets). Each data set is presented as an icon in MOIRA user interface. Icons are combined in the logical groups reflecting all the steps of decision making. Clicking on the icon results in opening (with MFC Document/View mechanism) a corresponding UI tool or starting the chain of models to obtain data set information. With MOIRA GUI the user can perform necessary actions "step-by-step" or start from the direct request of the data of interest (it could be for example "ranking of the alternative strategies" for the decision maker or "concentration of Sr-90 in the water" – for expert in radioecology). MOIRA GUI combined object-oriented style of the data presentation with the GIS-like possibilities for working with spatially distributed objects (such as rivers).

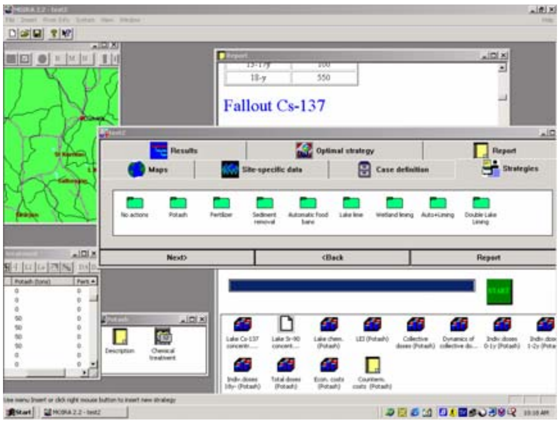


Figure 2

Description of the MOIRA GUI components is presented in Table 1

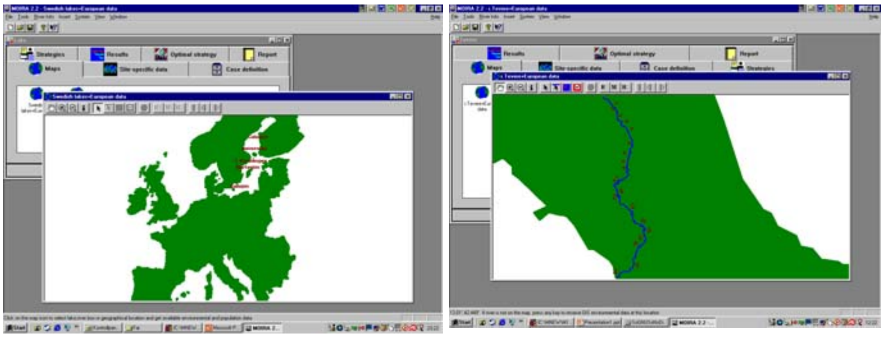
Function	**Component**	**Description**
Data input	Table/Graph interface tool	Presentation data in table form
Graphical data presentation	Table/Graph interface tool	Presentation of one or several data time-series in linear and log. scales
Presentation of the geographical information	Map tool	Using MapInfo Integrating Mapping technology , Map tool reflects the geographical maps in it's own windows in the same way and with the similar possibilities(zoom, recenter, selection etc.) as if they are reflected in MapInfo.
On-line presentation of the modeling process	Progress bar in Results folders, Own GUI of each model	Progress bar and the possibility (for advanced users) to view directly Powersim model's interface
Presentation of the data alternatives	File menu, Solution Box	Each scenario is represented as separate "solution box" for which menu commands like "New", "Open", "Open last", "Save as..." and list recently opened solution boxes are available. Each alternative strategy is represented in solution box as a pair of folders (in sections Strategies and Results) containing respectively strategy-specific countermeasures and results of implementation of the given strategy.
Summarization of the results	MOIRA HTML Report tool	All the data, alternative strategies, selected results of implementation of each strategy and ranking of strategies are summarized in the form of HTML file. This file can be previewed by the build-in tool or by any internet browser.

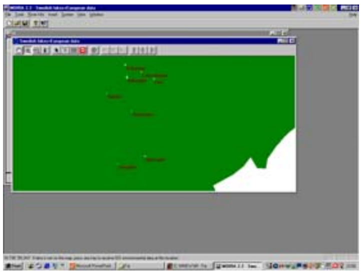
MOIRA GIS. Site-specific customisation of the MOIRA DSS

Working with MOIRA GUI user is able to input all the necessary data, but to simplify this process MOIRA system gives the possibility to store site-specific and region-specific data in MOIRA GIS (in MapInfo® format) and than just reuse these data when necessary. Such a ccustomisation of MOIRA GIS data is recommended for the long-term usage of MOIRA in emergency centres in order to increase its friendliness for the inexperienced users.

MORA GIS geodabases contain the following data

- Bedrock type
- Soil type
- Land use
- Precipitation
- Population
- River topology
- Lake shape and characteristics



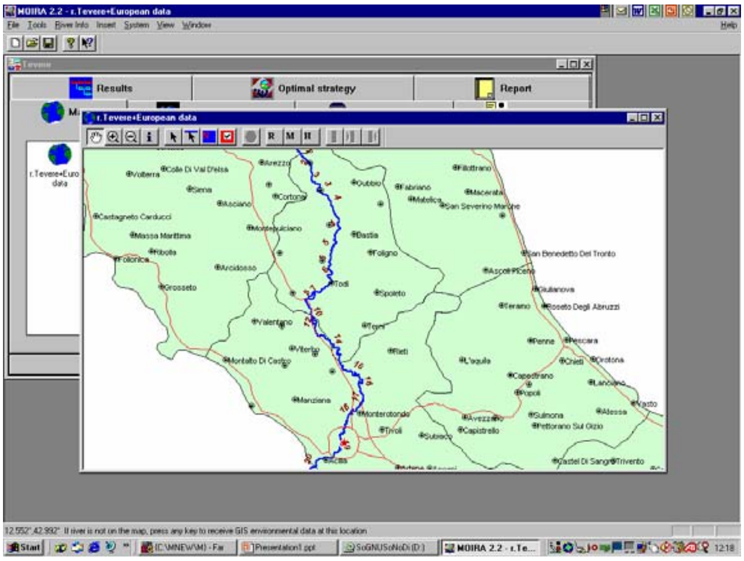


GIS-based data distributed with MOIRA 2.2
Precipitation (Europe)
Bedrock types (Europe)
Fish species (Europe)
Soil types (Europe)
Land use (Europe)
Population (Europe)
Maps and detailed parameters for 30 lakes (Sweden)
Map of the r.Tevere
Background map of Europe
Data for r.Tevere
Default socio-economic data

Figure 3

Important part MOIRA GIS are MapBasic® routines helping to extract the data above or estimate them if necessary . MOIRA GIS contains also set of the text-based data (so called RiverDataBase) describing river specific parameters.

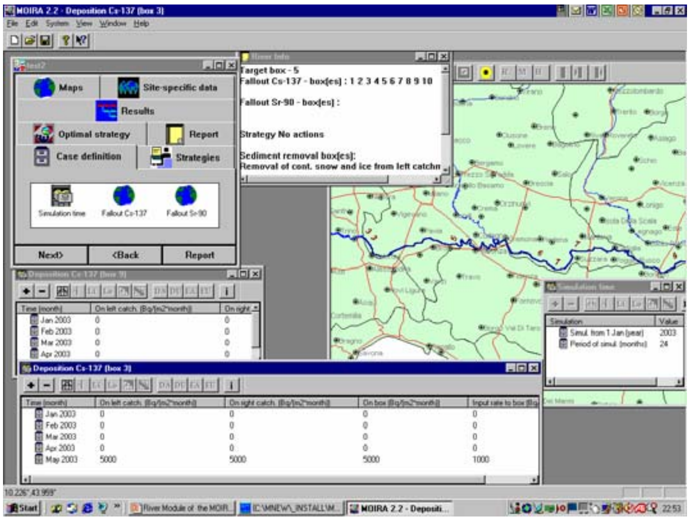
“Basic” MOIRA GIS data can be easy extended with “background” data, for example cities, administrative borders, roads etc.



12.552°,42.992° If river is not on the map, press any key to receive GIS environmental data at this location

Figure 4

User access MOIRA GIS functions with MOIRA GUI. The connection between GUI and GIS is based on the MapInfo Integrated Mapping [MapInfo 1995] and allows to show MapInfo windows directly in MOIRA GUI. Figures 3, 4, 5, 6 are examples of Map windows of MOIRA GUI. With MOIRA GUI Map windows user have the possibility to preview the geodatabases and select the "target" lake or part of the river using the same buttons and layer management menus as in MapInfo.



Target box - 5
Fallout Cs-137 - box(es) : 1 2 3 4 5 6 7 8 9 10

Fallout Sr-90 - box(es) :

Strategy No actions

Sediment removal box(es):
Removal of cont. snow and ice from left catchn

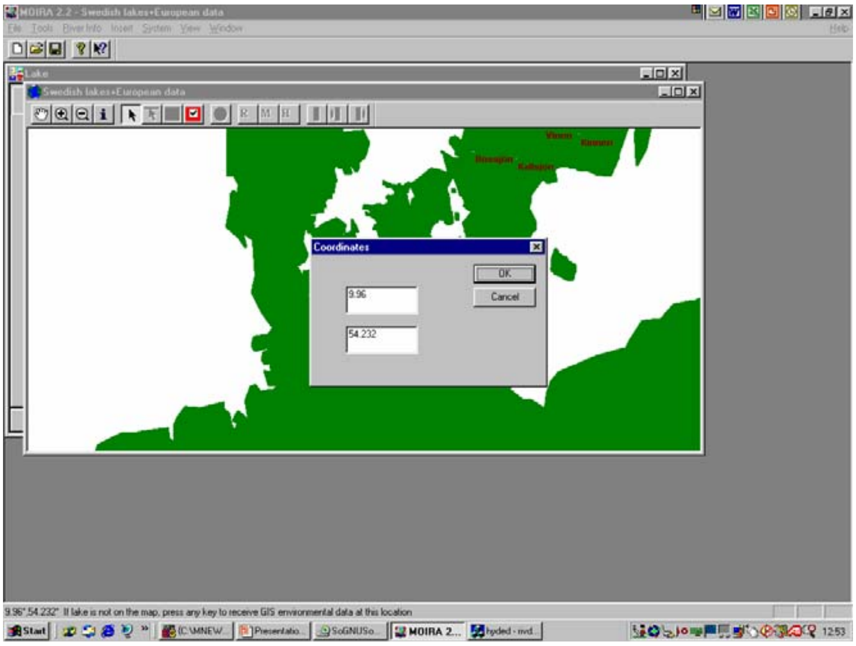
Time (month)	On left catch. (Bq/(m2*month))	On right catch. (Bq/(m2*month))	On box (Bq/(m2*month))	Input rate to box (Bq
Jan 2003	0	0	0	0
Feb 2003	0	0	0	0
Mar 2003	0	0	0	0
Apr 2003	0	0	0	0
May 2003	5000	5000	5000	1000

Simulation	Value
Simul. from 1 Jan (year)	2003
Period of simul. (months)	24

10.226°,43.959°

Figure 5

After selection of the geographical object, the corresponding data are extracted from geodatbases (or estimated) and loaded in the data sets of the solution box. After this the user can change them by MOIRA GUI in the same way as if they was inputted directly. If particular lake or river is not on the map user can obtain corresponding region-specific environmental and population data by providing coordinates of the geographical location.



9.96°,54.232° If lake is not on the map, press any key to receive GIS environmental data at this location

Figure 6

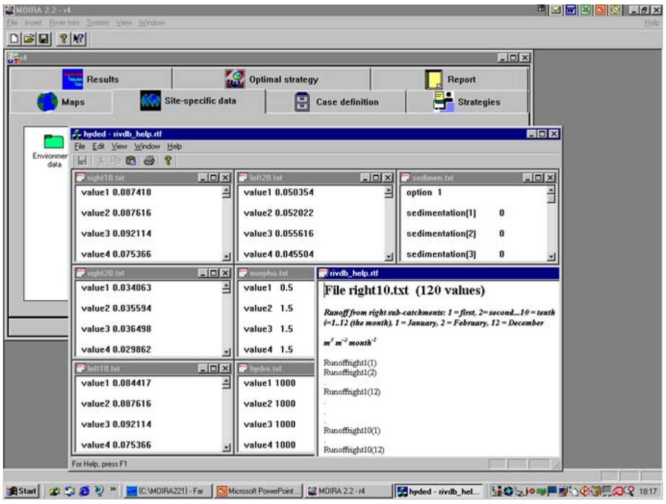
To help user, MOIRA GIS contains the geographical DB with the environmental and population data for the Western Europe, topology of r.Tevere and shapes and characteristics for more 30 lakes in Sweden. These data are distributed as part of the MOIRA installation.

Steps of site-specific customisation of MOIRA DSS are shown in Table 2:

Task	GIS and databases	Instrument	Knowlwge
Implement new lake in MOIRA GIS	MOIRA GIS	MapInfo	Require beginning knowledge in MapInfo
Implement new river in MOIRA GIS	RiverDataBase MOIRA GIS	MapInfo MOIRA GUI	Require beginning knowledge in MapInfo
Provide "background" information	MOIRA GIS		
Implement permanent socio-ecomomic site-specific data	RefDB MOIRA GIS	MapInfo MOIRA GUI	Require beginning knowledge in MapInfo
Site-specific setting for MAA	MAA config. files	MAA GUI, text editor	Require knowledge in MAA module

Table 2

While topology of the river is stored in MOIRA GIS, the characteristics of the river are stored as set of the text files. The customisation of these data is supported by the tool shown in Fig. 7.



```
right10.txt
value1 0.087418
value2 0.087616
value3 0.092114
value4 0.075366
```

```
left20.txt
value1 0.050354
value2 0.052022
value3 0.055616
value4 0.045504
```

```
sedimen.txt
option  1
sedimentation[1]     0
sedimentation[2]     0
sedimentation[3]     0
```

```
right20.txt
value1 0.034063
value2 0.035594
value3 0.036498
value4 0.029862
```

```
morpho.txt
value1   0.5
value2   1.5
value3   1.5
value4   1.5
```

```
left10.txt
value1 0.084417
value2 0.087616
value3 0.092114
value4 0.075366
```

```
hydro.txt
value1 1000
value2 1000
value3 1000
value4 1000
```

File right10.txt (120 values)

Runoff from right sub-catchments: 1 = first, 2= second...10 = tenth i=1..12 (the month), 1 = January, 2 = February, 12 = December

$m^3\ m^{-2}\ month^{-1}$

Runoffright1(1)
Runoffright1(2)
.
Runoffright1(12)
.
.
.
Runoffright10(1)
.
Runoffright10(12)

Figure 7

Set of "default" socioeconomic data (not connected to the specific geographical location) is stored in RefDB and is loaded into the MOIRA GUI tables after selection of the geographical object in the same manner as MOIRA GIS data. MOIRA supplies user with the default values for socio-economic parameters. Modification of these values for the particular site-specific data may be required. The MOIRA GUI supports this modification.

LIANA Model Integration System

The name LIANA Model Integration System is used for both:

- Framework of C++ classes and functions for quick creating of the "shell" for the model-based Environmental Decision Support System (EDSS).
- The resulting general purpose "shell" application constructed with this framework and having the following features:
  - It can be quickly integrated with standalone models or other application such as GIS and databases. On the Windows system, a "model" can be any Windows or DOS .exe application retrieving input and producing output as text files
.
  - It contains a built-in data-centred [Microsoft 1998] user interface allowing data browsing by means of a desktop metaphor and by selection from the map.

The shell for the "real" EDSS is constructed by the extending of the LIANA Model Integration System with the classes and functions reflecting the functionality specific for the models or operating environment. Such shell inherits all the properties of LIANA Model Integration System and can be used as basis for the creating of the new EDSS in the same way as the "basic" LIANA system.

LIANA Model Integration System for Windows had been developed in the frame of MOIRA project and implemented in MOIRA Software Framework (MOIRASF). Further development of MOIRASF has been done both in direction of extending LIANA system with classes and functions reflecting specific of MOIRA and with development of the kernel genral-purpose functionality of LIANA classes and functions.

The following characteristics of LIANA system were evaluated as important during the developement of the MOIRA DSS by distributed international group of the developers in the frame of MOIRA project.

- Limited requirements of the LIANA to the model allowed to integrate the models in the form they are received from developers.

- After the integration the same versions of the models and MAA software was used both in the frame of MOIRA and stand-alone. This allowed developers of the models to test and further develop the models using known software environment without necessity to learn new things related to the MOIRA architecture and functionality. This gives the possibility for the simultaneous and independent development of the models and "kernel" of the DSS.
- The updated versions of the models was integrated just by substituting of the corresponding .exe, .sim or .mbx file. If new data was used or produced by the updated version of the model then in most cases only the changes in data class definition files and configuration files had been required. The GUI appearance had been changed automatically in response to the changes in these files.

The basic principles of LIANA functionality are shown in Fig 8. This functionality is supported by the framework of C++ classes and functions covering most common tasks required for the EDSS (such as managing of scenarios and alternative strategies for each scenario; running of the chain of the models; keeping consistency between changes in scenario data and results; access to data in Explorer-like and GIS-like styles; visualisation of the data with tables and graphs; supporting of the data base of reference values and ranges for the parameters etc.) The simplified class diagram of LIANA is shown in Fig. 9.

Data objects

The key objects for the LIANA system are the objects of the class *Data.*

For the user the EDSS is presented as a hierarchy of *Data* objects. *Data* contains values for one or more parameters related to the description of scenario to be evaluated by EDSS or results of the evaluation of scenario with modelling. In addition to the values of the parameters *Data* contains the information about source of the values (for example "estimated by the GIS", "default value").

From the integration point of view each *Data* contains information necessary to prepare one of the input files of the modes or information imported from one of the output files of the models.

The lifetime of a *Data* object is normally limited to the current function or the lifetime of the user interface object visualising *Data*. The system stores and retrieves content of the *Data* to/from file using methods similar to ones implemented in Document/View architecture [Microsoft 95]. The file used to keep *Data* in persistent form called in LIANA a "data set".

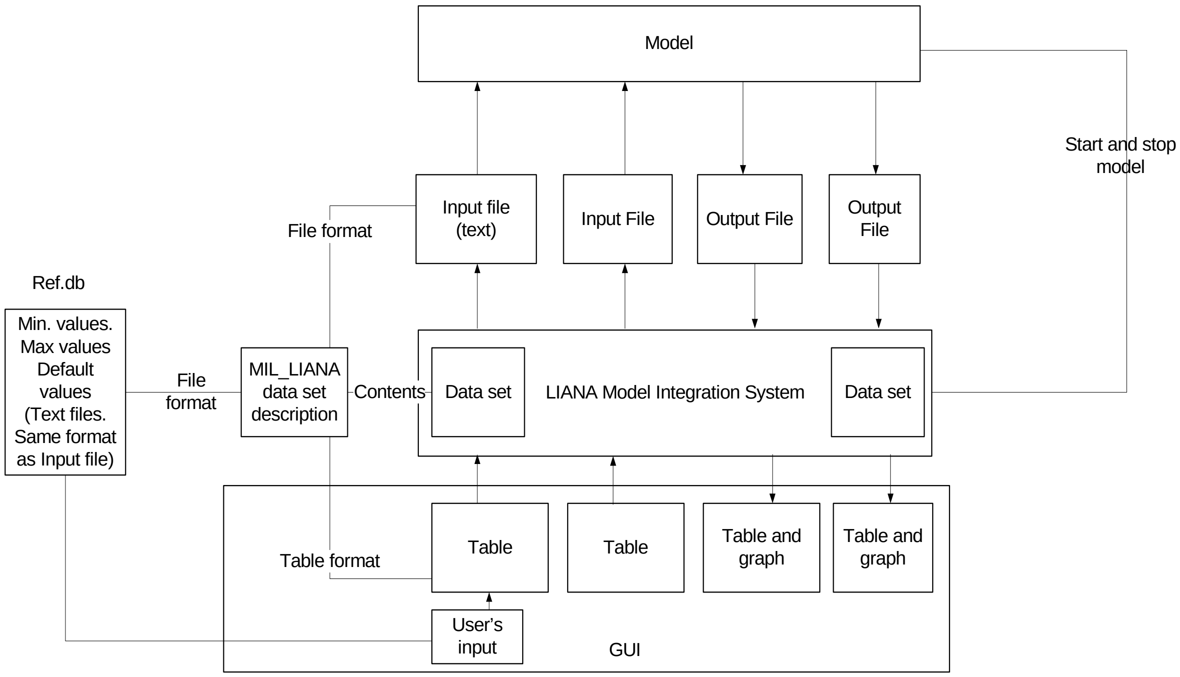
Data classes

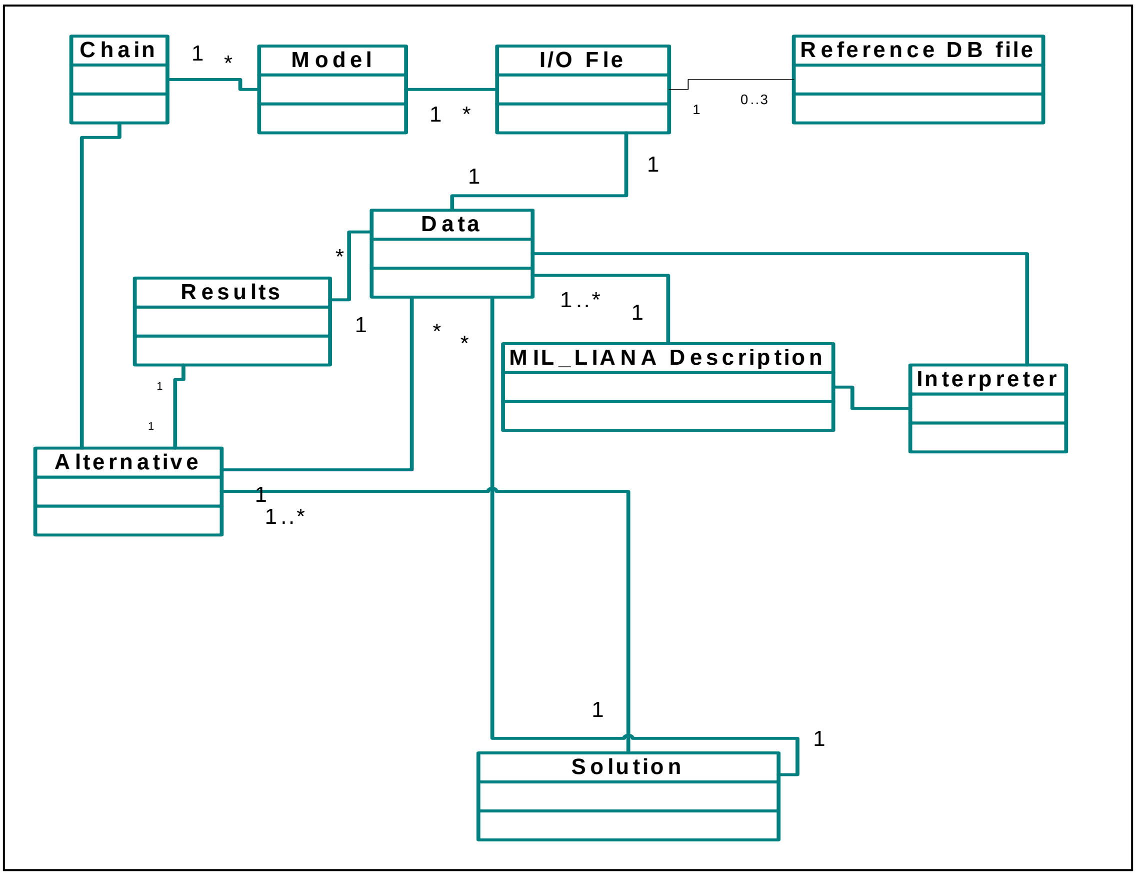
Each data set used in the system has a corresponding "data class definition" which is described using the MIL_LIANA language and contains:

- Type and basic properties of the data set (such as for example "input", "output", "countermeasure", "editable" etc.)
- Types, names and initial values of variables of the data set
- Format of the table presenting the data set in the GUI
- Format specification for importing or exporting a data from/to I/O file of the model

After the first request to data set class definition it is parsed and stored in an internal format, therefore parsing is required only once for each class definition.

Figure 8, Figure 9





Scenarios and alternatives

The objects of classes Solution, Alternative and Results are the lists. They contain filenames and GUI-related run-time information for the data sets. The framework uses serialization mechanisms provided by MFC to load and store these objects at run-time. The configuration files are used to describe the content of each list.

The objects of class *Alternative* keep information about data sets defining alternative strategies (for example alternative strategies of countermeasures that can be applied for the lake contaminated by radionuclides). The content of *Alternative* is dynamic. User can select which data sets are to be included in each *Alternative*. System contains the configuration file describing all possible "countermeasure" data sets and their "compatibility" (some of countermeasures can not be applied simultaneously).

Each *Alternative* has corresponding *Results* containing filenames of data sets related to the results of the evaluation of *Alternative* via modelling. The objects of classes *Model* and *Chain* provide the functionality related to model chain execution and obtaining of results of the simulation.

The *Solution* keeps information about data sets valid for all *Alternatives* (such as site-specific data) as well as references to the *Alternatives*. All data sets related to *Solution* are stored in the separate directory. Data sets directly enumerated in the *Solution* are stored in the root of this directory. A new subdirectory is created for each *Alternative*. LIANA can manipulate *Solution* directories as unit objects (such as it allows to perform operations "Open", "Open last", "Save as…" etc.)

Model integration and EDSS construction

EDSS is constructed by integration of LIANA system with the models or other applications such as GIS or MAA software. The basic requirements to the model or other application to be integrated is minimal – it should be a Windows or DOS .exe file and receive input and provide output as text files. Each I/O file of the model corresponds to one of the data sets. The kernel of the system "knows" about the format of each I/O file of the model by parsing and using the corresponding data class definition. MIL_LIANA definition can describe complex formats of the file with "scalar" data, but it is assumed that a file with time-dependent data has a column-based structure.

The integration means creating of the MIL_LIANA files and configuration files describing content of *Solution, Alternative* and *Results.* During the integration it is also necessary to make a changes in LIANA source code in order to describe:

1. Manipulation with data sets other than import and export to/from the files and time interpolation of the data.
2. Import or export from and to files with very complex format
3. Data query from several sets
4. Relationship between data and models
5. Conditions for the execution of the certain model in the model chain

At present the work to describe the features of the EDSS enumerated above with the data class definitions and configuration files and without necessity to make a changes in the C++ code is in progress.

User interface

LIANA system assumes that content of all lists (such as *Solution, Inputs, Alternative, Results*) is available for the users (via GUI tools) in Explorer-like style as icons (or buttons) or in GIS-like style by the clicking on the map. "Activating" of the certain data set referred in the list (for example by clicking on the icon) may results in:

Data set type	**Data set does not exist**	**Data set exists**
"Input"	Opening the UI tool, showing template and initial values (or "not defined") for the data set and giving the possibility to edit it	Opening the UI tool, showing of the data set content and giving the possibility to edit it
"Output"	Starting the chain of models (via *Alternative* object) to obtain data set information	Opening a corresponding UI tool, showing of the data set content without the possibility to edit it

Table 2

Developers of each model affect the appearance of the GUI of EDSS when decided how to split the model data in different files. For example the input or output data for the particular model can be presented in GUI as one long table (containing all of the parameters) or as number of the short tables each related to one of the parameters. Developers of the model will make the decision about it. Such participation helps to construct the user interface quickly and utilise the broad experience of the developers in a scientific subject and their view on the optimal data presentation for particular model.

The developers of models also supply the information necessary to maintain the database of reference values (RefDB). During the integration each model can be optionally supplied with

- Files with the default values for certain parameters
- Files with the minimum values
- Files with the maximum values

These files should have the same format as the corresponding input file of the model (and thus available for the kernel with the same MIL_LIANA description). Default values for the parameters are available for the user while working with the GUI tables. Range values are utilised to check user's input.

Development of MOIRA DSS in 2002-2004

During the 2002-2004 MOIRA developers group on the voluntary basis had performed the development of the MOIRA DSS. The development was driven by the flowing goals:

- Implement improvements related to end-user evaluation of the system (MOIRA 2.2.1 Release 2) during TRA-RAD-FW course.
- Increase availability of the MOIRA DSS required for the easy evaluation of the system by wide community of experts and in particular by the participants of EVANET-HYDRA project.
- Perform test implementation of improvements suggested during MOIRA evaluation by EVANET-HYDRA users (see WP4 Report 2) in order to take the opportunity to receive quick feedback about the practical realisation of improvements.

Versions released during 2002-2004

New features implemented in the several MOIRA versions are shown in Table 3. These changes are in details described in the on-line documents available at http://user.tninet.se/~fde729o/MOIRA

MOIRA 2.2	February 2003	• Increasing of availability of MOIRA system by the possibility to run system without MapInfo Professional or without need to implement detailed site-specific data • Improvements of the river-related user interface • Simplification of the process of the site-specific implementation of the DSS
MOIRA 2.2.1	April 2003	Improvements in the MOIRA Software Framework, fixing bugs
MOIRA 2.2.1 Release 2	May 2003	Improvements in the MOIRA Software Framework, fixing bugs
MOIRA 2.3.0	September 2003	Modelling of the concentration in biota in MOIRA river models
MOIRA 2.3.1	October 2003	Implementing the possibilities to input and reflect data related to modelling for long time-periods (to have possibility to simulate from the year 86 (Chernobyl) to the present time)
MOIRA 2.3.2	October 2004	Improvements in the MOIRA Software Framework, fixing bugs

Table 3

Components of the future MOIRA release (MOIRA Version 3):

The following changes had been realised during 2004 and demonstrated during the 2-nd "short visit" meeting (Studsvik, Sweden) :

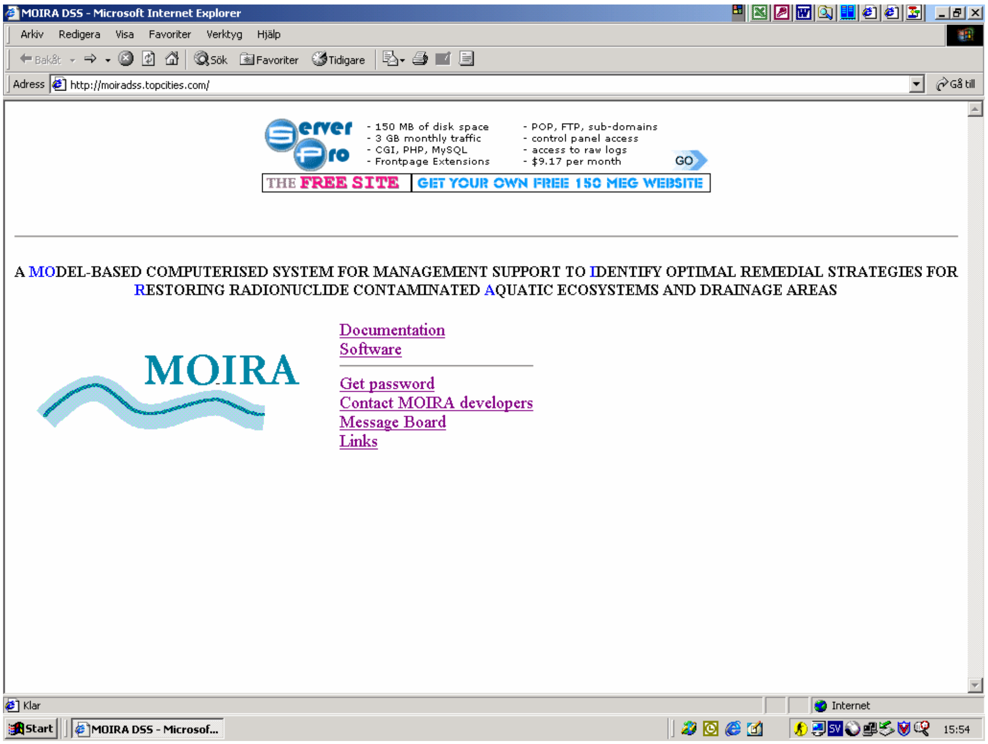
- New version of Cs-137 and Sr-90 river model MARTE. Model comprises 4 sub-models that are aimed at assessing: a) the hydrological behaviour of a complex water body (HYDROAV); b) radionuclide fluxes from sub-catchments to water body (CAT); c) the migration of radionuclide through the water body (MIGRA); and d) the migration of radionuclides from water to biota (BIOL). This new version allows users to simulate the behaviour of any kind of contaminant provided that the main migration pathways are the ones accounted for Cs and Sr.
- Updates in dose assessment model
- Updates in the lake Cs-137 model**.**
- Harmonisation of the models structure and data for the Sr-90 and Cs-137 chains taking into account also future including of the models for new radionuclides.. Prototype version of new model for evaluation of Sr-90 fate in lake water and biota harmonised with the lake Cs-137 model. (by UU and UPM)
- New version of MOIRA Software Framework.

MOIRA web site

In order to increase simplicity of the dissemination of the MOIRA DSS, simplify management of the MOIRA users group and to provide Internet–based tools for the collecting of the users' feedback the web site **http://user.tninet.se/~fde729o/MOIRA** had been developed and become available from the February 2003.

The site contains the web-based tools helping to:

- download the new version of MOIRA software
- obtain documentation
- submit suggestions for the improvements and bug reports



A MODEL-BASED COMPUTERISED SYSTEM FOR MANAGEMENT SUPPORT TO IDENTIFY OPTIMAL REMEDIAL STRATEGIES FOR RESTORING RADIONUCLIDE CONTAMINATED AQUATIC ECOSYSTEMS AND DRAINAGE AREAS

Documentation
Software

Get password
Contact MOIRA developers
Message Board
Links

Figure 10

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Monte L. , Brittain J., Håkansson L., Gallego E., Zheleznyak M., Voitsehovich O., Kryshev I., Marinov Petrov K. . "Implementing Computerised Methodologies to Evaluate the Effectiveness of Countermeasures for Restoring Radionuclide Contaminated Fresh Water Ecosystems. COMETES Project. Final Report". Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA), RT/AMB/2001/28, Roma (Italia), 2002

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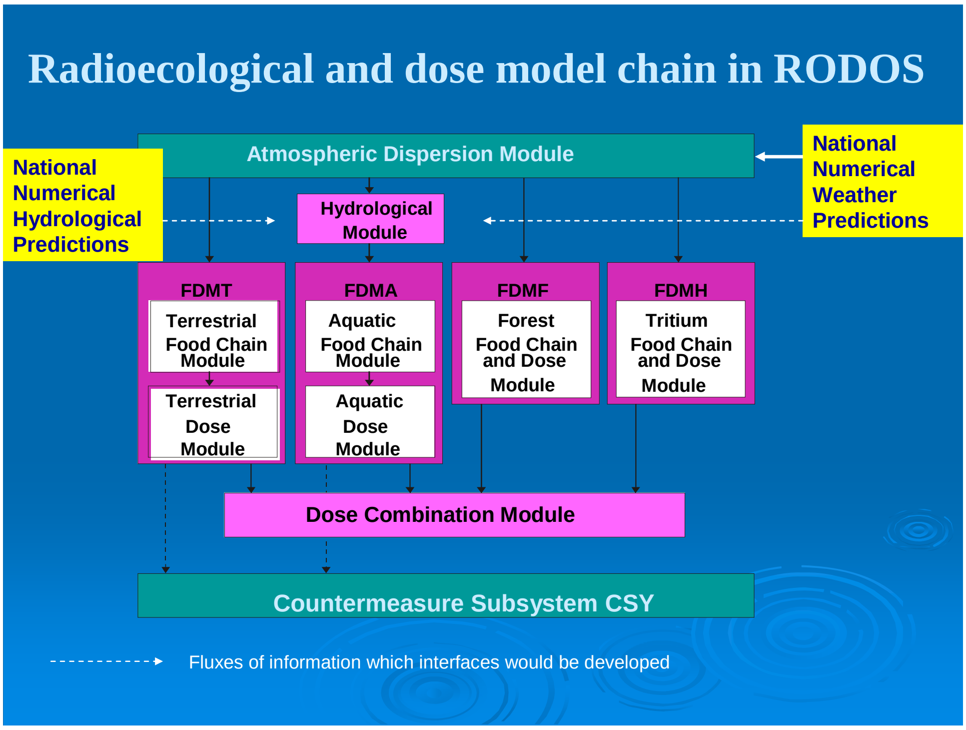
Hydrological Dispersion Module of RODOS (RODOS-HDM)

Designed as a generic tool, the RODOS system will be applicable from very early stages of an accident up to many years after the release and from vicinity of a site to far distance areas. Decision support is provided at various levels ranging from the largely descriptive, with information on the present and future radiological situation to an evaluation of the benefits and disadvantages of different countermeasures' options. The software framework of RODOS provides tools for processing and managing a large variety of different types of information, including meterology, radiology, economy, emergency actions and countermeasures, rules, preferences, facts, maps and statistics.

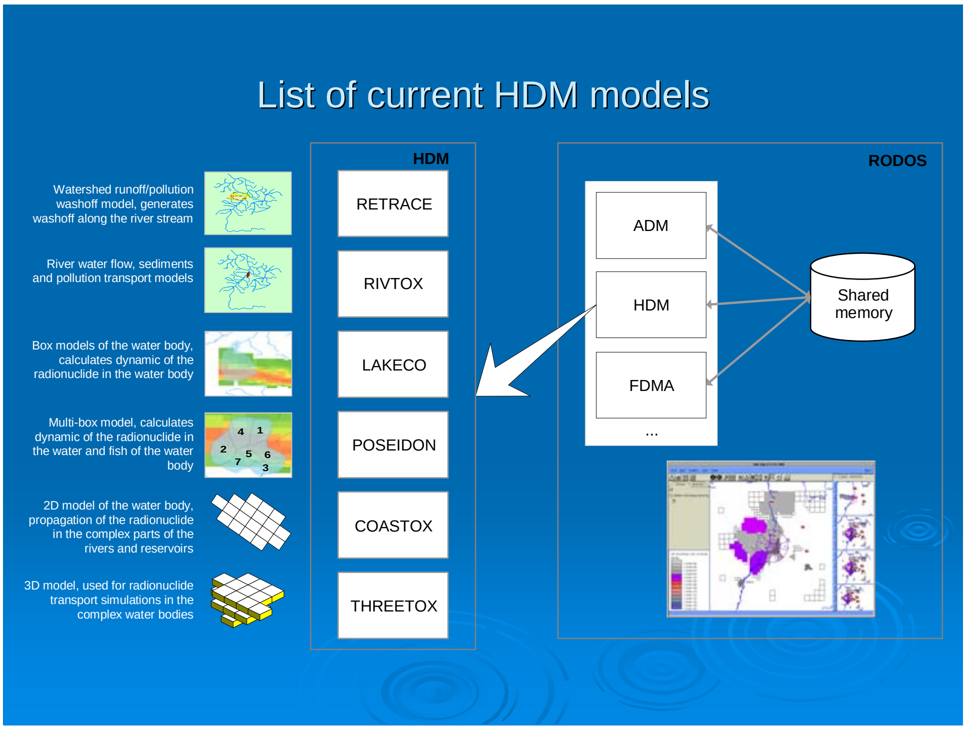
Within the RODOS system, HDM [13,19,21] is the module for simulating the transfer of radioactive material in aquatic environment – watersheds, rivers, lakes, reservoirs, estuaries and groundwater. HDM uses the output fallout from the Atmospheric Dispersion Module of RODOS (ADM) as the input source term. It also could simulate the consequences of the direct radioactive material releases into surface water and ground water. The output of HDM is simulated concentration of radionuclides in water, sediment, fishes to be used by the aquatic foodchain submodel of FDMA- the RODOS' dose module . The results of HDM are used with FDMA to estimate the effect of short and long term countermeasures in order to mitigate the radiation exposure of the public.



Radioecological and dose model chain in RODOS

Fluxes of information which interfaces would be developed

Figure 1

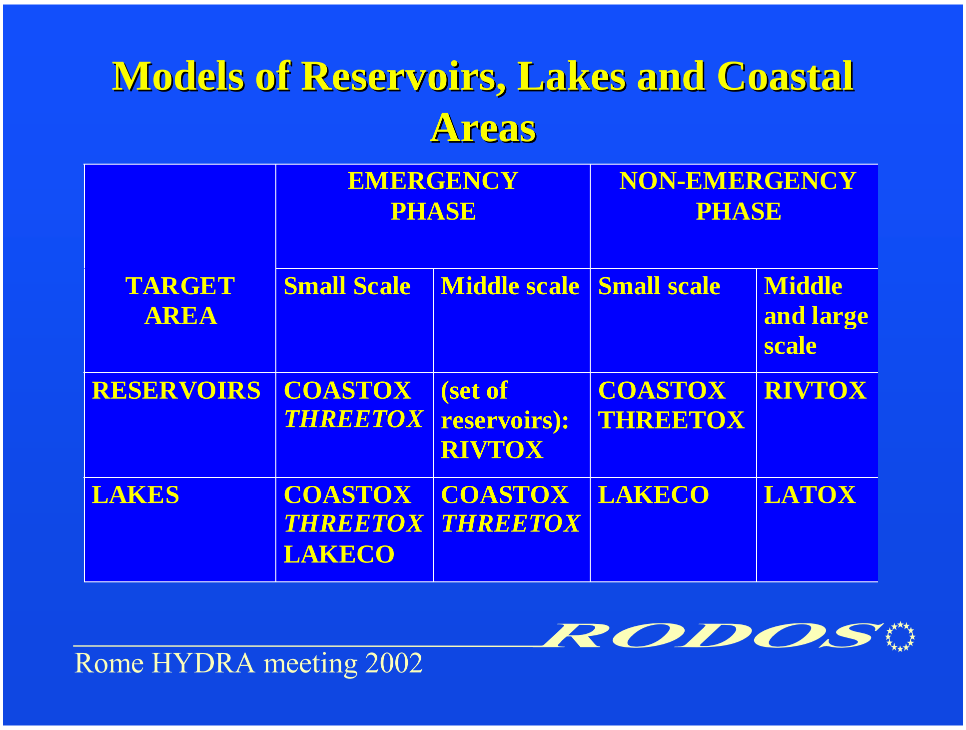


List of current HDM models

	HDM
Watershed runoff/pollution washoff model, generates washoff along the river stream	RETRACE
River water flow, sediments and pollution transport models	RIVTOX
Box models of the water body, calculates dynamic of the radionuclide in the water body	LAKECO
Multi-box model, calculates dynamic of the radionuclide in the water and fish of the water body	POSEIDON
2D model of the water body, propagation of the radionuclide in the complex parts of the rivers and reservoirs	COASTOX
3D model, used for radionuclide transport simulations in the complex water bodies	THREETOX

Figure 2

RODOS HDM includes many models for the aquatic environment (watersheds, reservoirs, lakes, rivers). It was designed for application for both short term (emergency phase) and long term. RODOS HDM models show different degrees of complexity ranging from box models, based on the assumption of homogeneous distribution of radionuclides within a compartment, to three dimensional models assuming spatial variability of radionuclide concentration in abiotic components of waterbodies. RODOS is aimed at assessing the effects of some countermeasures such as restriction on fish and water consumption.



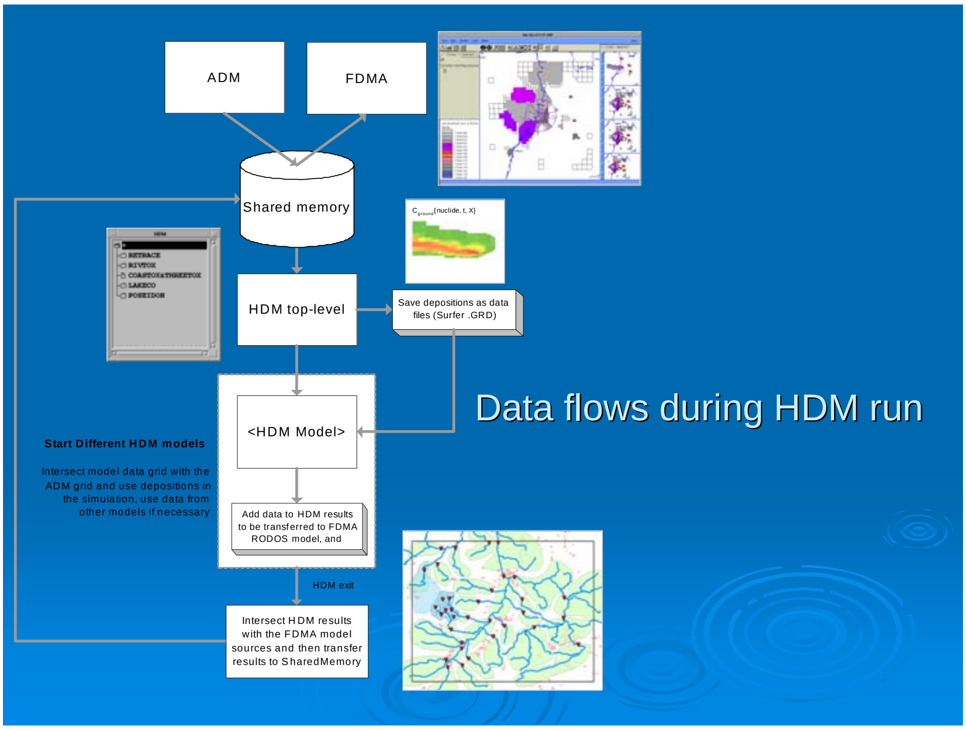
Models of Reservoirs, Lakes and Coastal Areas

TARGET AREA	EMERGENCY PHASE		NON-EMERGENCY PHASE	
	Small Scale	Middle scale	Small scale	Middle and large scale
RESERVOIRS	COASTOX *THREETOX*	(set of reservoirs): RIVTOX	COASTOX THREETOX	RIVTOX
LAKES	COASTOX *THREETOX* LAKECO	COASTOX *THREETOX*	LAKECO	LATOX

RODOS

Rome HYDRA meeting 2002

Figure 3



Data flows during HDM run

ADM

FDMA

Shared memory

HDM top-level

Save depositions as data files (Surfer .GRD)

<HDM Model>

Add data to HDM results to be transferred to FDMA RODOS model, and

HDM exit

Intersect HDM results with the FDMA model sources and then transfer results to SharedMemory

Start Different HDM models

Intersect model data grid with the ADM grid and use depositions in the simulation, use data from other models if necessary

Figure 4

As hydrological chain operates as an individual part of the RODOS System, a user friendly graphical interface [20,21] has been developed to operate the individual models inside the hydrological module. The interface provides the possibility of easily accessing all the information necessary to run the individual models as well as displaying the results in a way decision makers can handle them.

The interface allows:
- to input and to edit data and parameters through a system of
- user configured dialogues and input windows;
- to run models separately or simultaneously with the
- possibility of exchanging data between individual models via shared memory;
- to manage the data base and to create predefined scenarios;
- to present data base information and on-line results of the simulations in graphs and maps (e.g. contamination);
- to receive data from and transfer data to other RODOS modules (e.g. read results of atmospheric dispersion,
- forward concentrations to the foodchain module);
- to support different modes with different user services: two interactive modes for the decision maker - first: “whole chain” (complete model chain starting with the areal contamination), and ”direct release” (COASTOX, RIVTOX, LAKECO); and second: run individual models (also possible with loading of predefined scenarios) and finally the “scenario maker” model for creating scenarios and manipulating data bases

The example of HDM user interface is show on Figures 5 and 6

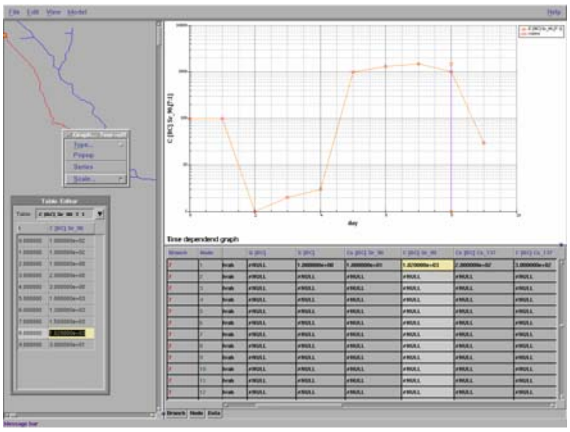


Figure 5

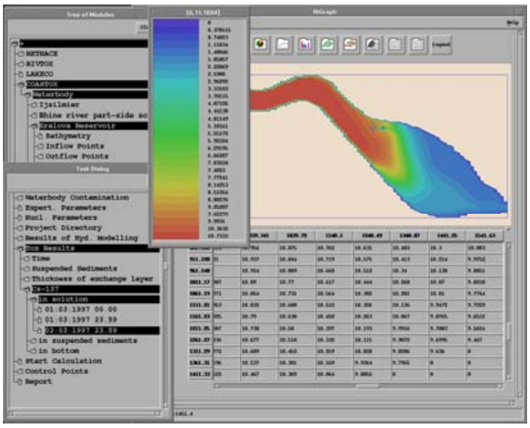


Figure 6

RIVTOX – The object-oriented framework for modelling of pollutant transport in river network

(by G.Donchyts and M.Zheleznyak)

River transport model classes can be divided into three groups: first we should consider Geographical part that describes topology of the river network. Next part is Data classes used to specify physical parameters in the model together with data units. Then it is necessary to introduce classes to store data as values on the river grid, miscellaneous functions (rating curves, time series, etc.). The last part is Numerical classes used to solve numerical equations on the river network grid; these classes mainly represent various numerical algorithms. In [11] it is shown the integration of object-oriented model with GIS system. Here we try to define constraints for different equations via template parameters in order to make possible a replacement of different numerical schemes on the fly, without losing efficiency.

On the class diagrams only the main concept classes of the program are represented. Even without showing attributes and methods explicitly it is easy to catch main ideas.

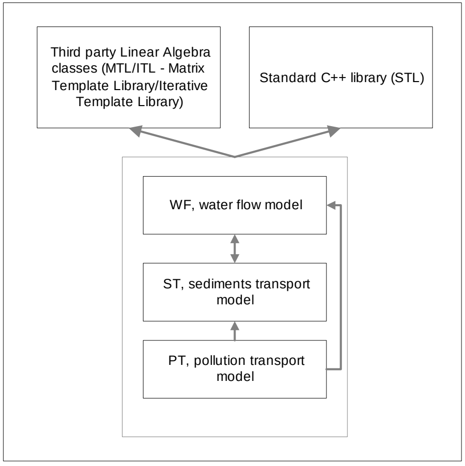


Fig 7. Structure of the model library

To develop a new sub-model it is necessary just to implement several additional classes that contain numerical equation logic. After that the classes can be utilized as template parameters in other parts of the program. Nevertheless, during development one should always balances between efficiency, code size and understandability. Current version of model consists of three submodels (Fig 7).

1.1. River network topology

The main class in this part is a ***River*** i.e. a container for all other spatial object such as ***Node***, ***Crosssection***, etc. On the diagram (Fig 8) an aggregation link between ***River*** and ***Branch/Node*** classes becomes active when we define ***BranchModel*** that depends on a numerical scheme, equation type, etc.

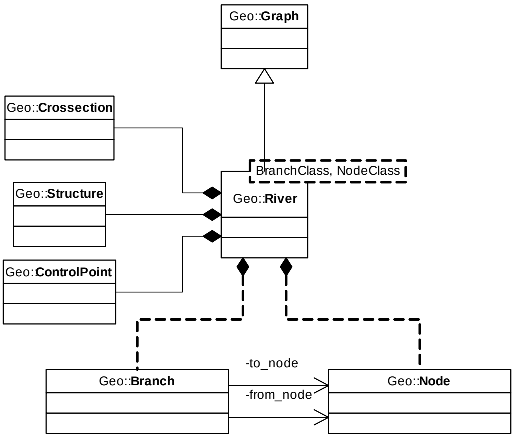


Fig 8. Classes for management of the river topology and geometry

Crossection class describes a shape of cross-section in a certain location on a river. It would be more correct to define it as a class derived from a ***Function*** and ***Vector*** as it stores *W(h),* where *W* is a river width and *h* – its depth, later on in the program this array is recalculated into *A(h)*. ***Structure*** shown on a diagram is more complex in reality, because it is necessary to redefine the algorithm of equation solving for different structures and this should be done in a specific boundary equation. The class ***Structure*** describes the type and parameters of the structure.
River is derived from a more general class ***Graph*** taken from the BGL (Boost Graph Library); the later one has lots of algorithms for solution of different problems on graphs.

1.2 Model data classes

Most of the data in environmental models can be described in a general way as a set of some functions. Model is able to take some parameters as an input, simulate something and produce some results for output. Some data are set onto specific model grid (properties of the bottom, cross-sections, equation variables), some – as a common for the whole program (model parameters). Also there can appear more specific data such as boundary conditions (time series or rating curves). For more complex boundary conditions (structure) it is necessary to define its properties and behaviours.

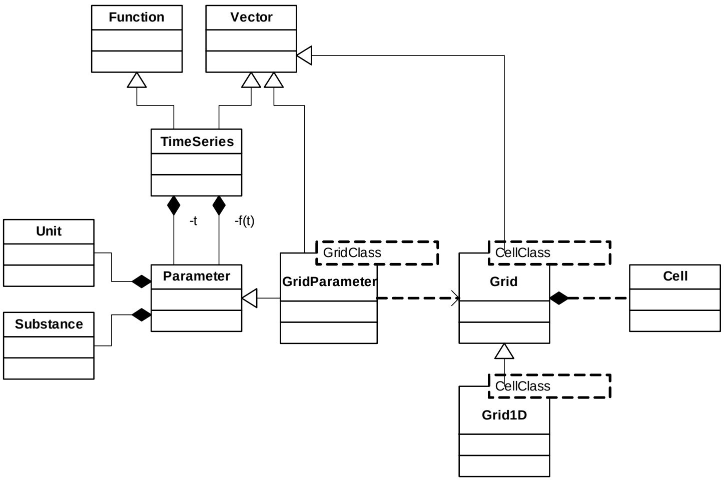


Fig 9. Model data classes responsible for the information about physical parameters, substances, and state vector of some parameter/variable on the model space grid

In the framework the concept of Parameter is introduced as a class that stores information about some physical (but not necessarily) parameter (Fig 9). Additionally there are Units and Substance to define data units of parameter. Substance used to define for example “concentration of Cs-137 in the water”, so in this way it is possible to operate with Parameter “concentration in the water” and Substance identifying pollutant (“Cs-137” or other), plus Units can be set e.g. to Bq/m3.

The Grid class is defined as a class built as a Vector of Cells. Later cell are defined to store some specific information needed by the model. GridParameter class defines value of some Parameter on a one-dimensional model grid. It is used to define values of model variables and parameters that depend on spatial location.

Development of classes for more complex grids for multi-dimensional models is discussed in [2].

1.3 OO Numerics

To construct model of the river transport Model concept is defined as a basis for all classes that can be started for a simulation. The RiverModel class is constructed as a container class for BranchModel class, in this way it is possible to divide complex task of solving equation for the whole river network into a set of solving simple one-dimensional tasks on each branch.

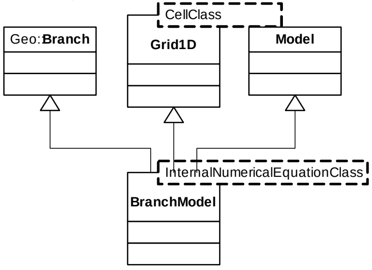


Fig 10. BranchModel class stores logic that is necessary to run one-dimensional model on one branch of the river network using some numerical algorithm/equation

BranchModel is defined as it is shown on diagram (Fig 10). At the same time BranchModel is a model, a branch on the river and a one-dimensional grid. The class also depends on a type of numerical equation given as a template parameter. BranchModel links with numerical equation at the compilation time, so it has no influence on a speed of the program, but gives an opportunity to realize only general methods/properties which are common for all one-dimensional models.

The model classes are based on geographical units, e.g. RiverModel (Fig 11). The numerical schemes are introduced as the template parameters of these classes. Using this approach it is possible to construct any model that simulates river network in a specific way. The Simulation is a container of model classes. It is necessary to create links between different sub-models and develop mechanism of synchronization to exchange data between linked sub-models. Two types of the numerical equations are used.

One type - for the solution of the boundary problem, for this reason the BoundaryNumericalEquation added to the NodeModel as a template parameter and is responsible for setting and solving boundary conditions in the point of connection of several branches. The second class InternalNumericalEquation solves algebraic equations on one-dimensional grid on the branch using some numerical scheme (Fig 12).

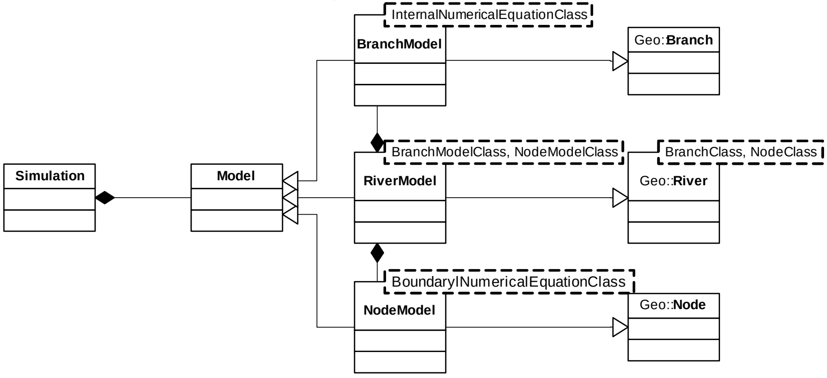


Fig 11. Design of the RiverModel class; program uses this class to make simulation.

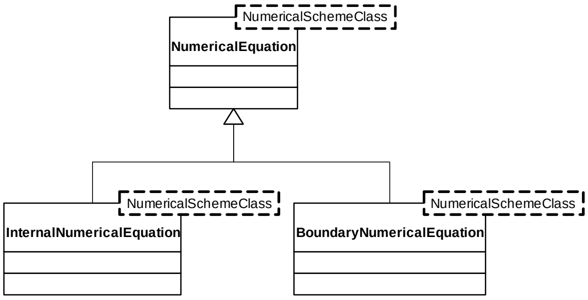


Fig 12. Classes responsible for numerical equation

Numerical scheme for this purpose is defined separately and is used independently from equation. In fact it is hard (and even unnecessary) to separate these concepts as they are very coupled, but we can define in numerical equation classes general properties of equation, such as parameters, variables, general logic of solution etc.

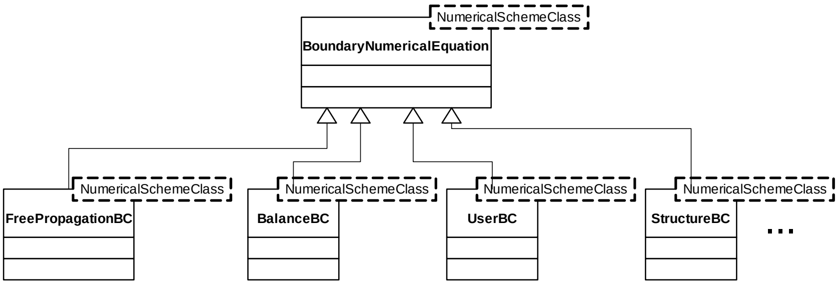


Fig 13. Boundary condition classes

From boundary numerical equation it is possible to build a hierarchy of all possible combinations of boundary conditions (Fig 13). In the river without structures it is necessary to define only several of them. When we introduce different structures it is necessary to develop more concrete classes for each structure or a group of structures.

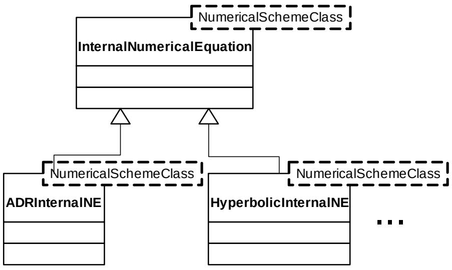


Fig 14. Classes for internal branch numerical equations

Two types of the equations, - the hyperbolic (for water flow model) and parabolic (advection-diffusion transport with reaction) are separated in two classes due to their different properties (Fig 14).

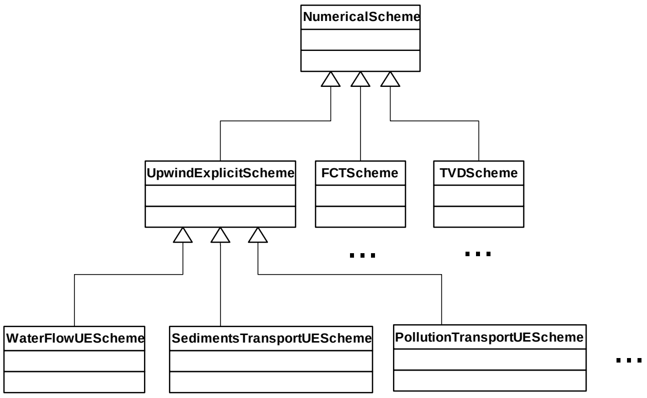


Fig 15. Numerical scheme hierarchy extended by new methods

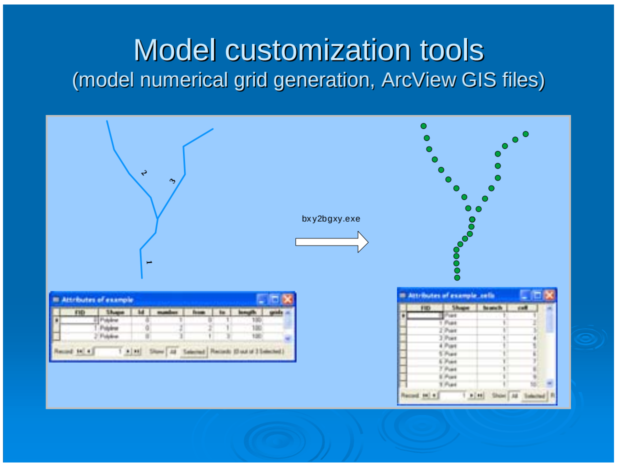
For each type of equation it is necessary to develop a numerical scheme used to calculate model variables on each time step (Fig 15). Then after developing of several numerical schemes for one type of equations it is easy to replace them during constructing of model objects.
Model code is developed using Microsoft Visual C++ compiler and also ported to UNIX platform using GCC compiler. Some minor changes were made during porting due to differences in STL realization.

1.4 Sample results

In this section we provide code samples for solution of an advection equation model. Lets assume that we have simple river network containing 3 branches:

```
... ==== main body of the program
typedef BranchModel<UpwindInternalEQ> AdvectionBranchModel;
typedef RiverModel<AdvectionBranchModel, BaseNodeModel> AdvectionRiverModel;

AdvectionRiverModel r;

r.AddNode(new NodeModel<UserBoundaryEQ>(1));
r.AddNode(new NodeModel<UserBoundaryEQ>(2));
r.AddNode(new NodeModel<BalanceBoundaryEQ>(3));
r.AddNode(new NodeModel<FreePropagationBoundaryEQ>(4));

r.AddBranch(r.GetNode(1), r.GetNode(3));
r.AddBranch(r.GetNode(2), r.GetNode(3));
r.AddBranch(r.GetNode(3), r.GetNode(4));

r.init();

// time loop
for(t=0; t<T; t+=dt)
{
        r.solve();
}

... === definition of a simple model classes
class RiverModel
        ...
        solve()
        {
                ... === call solvers on each Branch and Node
                for(BranchModelIterator b=branch.begin(); b!=branch.end(); b++)
                {
                        b->solve();
                }
                for(NodeModelIterator n=node.begin(); n!=branch.end(); n++)
                {
                        n->solve();
                }
                ...
        }
        ...

class BranchModel
        ...
        solve()
        {
                ...
                // solve InternalEQ on all cells of branch
                solve(cell.begin(), cell.end(), InternalEQ);
                ...
        }
        ...

class NodeModel
        ...
        solve()
        {
                ...
                // solve BoundaryEQ on current node
                BoundaryEQ.solve(this);
                ...
        }
        ...
```

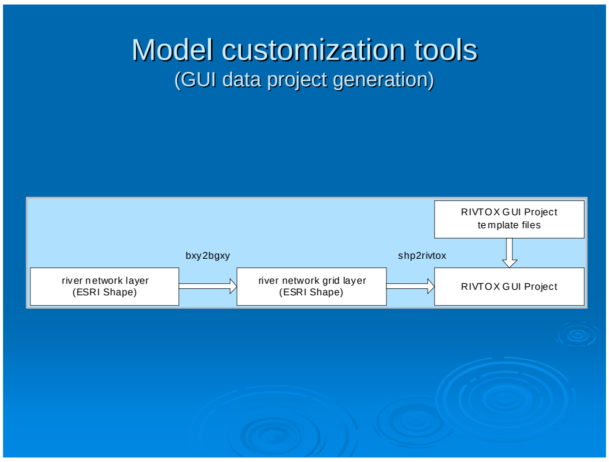
Customisation of RODOS-HDM to site-specific conditions


Model customization tools

(model numerical grid generation, ArcView GIS files)

bxy2bgxy.exe

Fig. 16


Model customization tools

(GUI data project generation)

river network layer (ESRI Shape)

bxy2bgxy

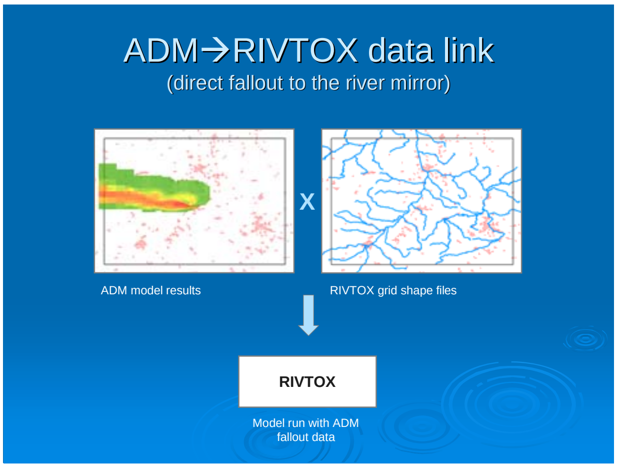
river network grid layer (ESRI Shape)

shp2rivtox

RIVTOX GUI Project template files

RIVTOX GUI Project

Fig. 17


ADM→RIVTOX data link

(direct fallout to the river mirror)

ADM model results

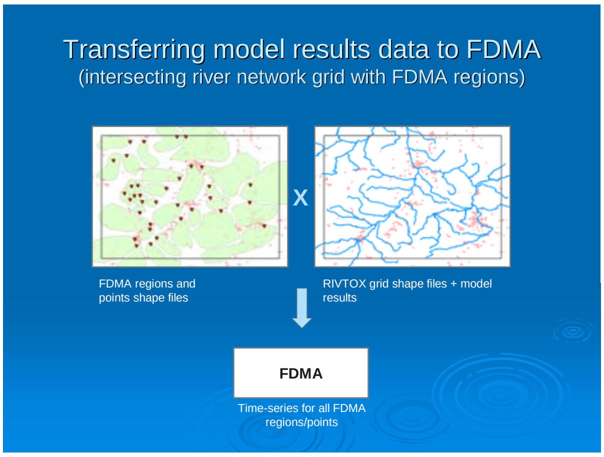
X

RIVTOX grid shape files

RIVTOX

Model run with ADM fallout data

Fig. 18


Transferring model results data to FDMA

(intersecting river network grid with FDMA regions)

FDMA regions and points shape files

X

RIVTOX grid shape files + model results

FDMA

Time-series for all FDMA regions/points

Fig. 19

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22 EVANET-HYDRA 1st plenary meeting 20-22 February 2002, Rome, Italy, Minutes of the Meeting

CASTEAUR

(by P. Boyer)

CASTEAUR (Simplified CAlculation of radionuclides Transfer in Receiving WATER ways) is a project responding to a request for a simplified tool to assess, for short and middle terms (some hours to some days) of both accidental and routine radioactive releases, the radioecological transfer to the main abiotic and biotic components of a river. These components are for the abiotic part water and matters, suspended as well as deposited, and for the biotic aspect phytoplankton, zooplankton, macrobenthos and fish, divided in plancktonivorous and omnivorous [1]. The targets are the radionuclides concentrations in these different components according to space and time.

At present, a first prototype (CASTEAUR v0.0) developed under Visual Basic for Excel is available.

This prototype is organised over a simplified representation of a hydrographic network on which hydraulics, sedimentology, ecology and radioecology are connected and described by simplified models.

General considerations

One-dimensional, the general approach limits the validity domain to the good mixing area downstream a release. The user defines the spatial resolution and the temporal resolution is automatically adapted. The resolution method is based on explicit differences finites numerical schemes. Developed for short and middle terms (some hours to some days), the temporal domain of application can be extended to a hydrological season.

Pollutants sources

The radionuclides implemented in the code are: Ag-110m, Am-241, Co-58, Co-60, Cs-134, Cs-137, Mn-54 and Ru-106. The interface allows the user to add other radionuclides and to specify their parameters.

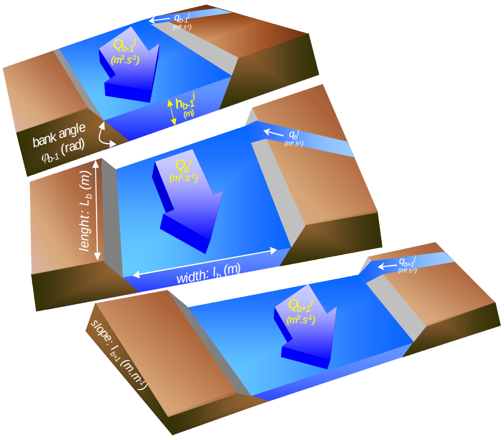
The prototype proposes four kinds of radioactive releases, which can be composed from several radioactive nuclides, combined and distributed along the hydrographical network.

- *Punctual permanent release*
  This is a punctual release characterised by a permanent emission flow ($Bq \cdot s^{-1}$). The mathematical resolution is applied for the permanent condition and gives directly the equilibrium state of the watercourse.

- *Punctual pulse release*
  This release corresponds to an instantaneous punctual addition of activity (Bq) at a given time.

- *Punctual sequential release*
  A punctual sequential release corresponds to a punctual addition for which the emission flow ($Bq \cdot s^{-1}$) can change during a period, defined by its beginning and its end.

- *Linear sequential release*
  Like the previous, this kind of release is associated to a temporal addition, which can change on a period. The difference is that it can be spatially distributed, along a part of a river ($Bq \cdot s^{-1} \cdot m^{-1}$), to allow admitting an eventual contribution of the basin by runoff process or an eventual atmospheric deposit.



Hydrographic model

The river is described by a succession of reaches, constituting a hydrographic network. Each reach represents a homogeneous part of the river, for all its characteristics. It is defined by its length, L_r (m), its slope, I_r ($m \cdot m^{-1}$) and an isosceles trapezium bathymetric section form.

Hydraulics model

The flow conditions are supposed fluvial and permanent. The hydraulics model applied the Manning - Strickler relations, using the flow, the average velocity, the Strickler coefficient and the geometrical parameters, such as the hydraulics radius and the wet cross section, which are deduced from the water column height, the bottom width and the bank angle of each reach.

Sedimentary model

Under hypothesis of permanent conditions, the matter dynamics are mathematically formulated as a function of the (suspended and deposited) matters concentrations, the global longitudinal diffusion coefficient and the rate of deposit. Only the first layer of the bottom sediment is represented by the deposited matters, because they are considered similar to the suspended one. A single kind of matter is considered per run, mineral or phytoplanktonic. Considering that the cohesive matters (diameter < 64 mm) are more reactive with radioactive nuclides, the deposit rate is determined by the relation of Krone, taken into account the settling velocity, the deposit critical shear stress of the matter and the flow shear stress.

Food chain model

Three trophic levels are considered: plankton (both zoo- and phyto-), macrobenthos and fish. Mainly pelagic, the food chain is linked to the superficial bottom sediment through the macrobenthos. From it to fish, the trophic net is linear. Indeed, a realistic choice conduces to divide the fish compartment into juveniles and adults, whose diet includes the three inferior links of the food chain. The case of the phytoplankton is particular, as it is modeled as suspended matters. At each trophic level, the biological relations quantify the exchange rates of an average individual with the other levels and with the environment (alimentation, ingestion, filtration). Theoretically, these physiological parameters are space and time dependent. In a way consistent with the physical approach, they are taken to be constant per reach, and the temporal validity of CASTEAUR v0.0 is thus limited to a season.

Radioecological models

To respond to the operational constraints induced by the situations of routine and/or crisis (data and parameter availability, calculation time delay,...), CASTEAUR v0.0 allows to choose between five radioecological models associated to different hydrosystem compositions.

"Raw water" option

This choice conduces to assess the total volumic activity in water taken as a single component, including suspended matter and taking into account dispersion and radioactive decay.

"Water + suspended matter" option

Considering dispersion, exchanges between dissolved and solid phases and radioactive decay, this model assesses the dissolved and the fixed activities in the water column.

"Water + suspended matter + adult fish" option

Based on the previous selection for the abiotic components, this option adds the fish compartment, through the transfer from dissolved phase to adults.

"Water + suspended matter + deposited matter" option

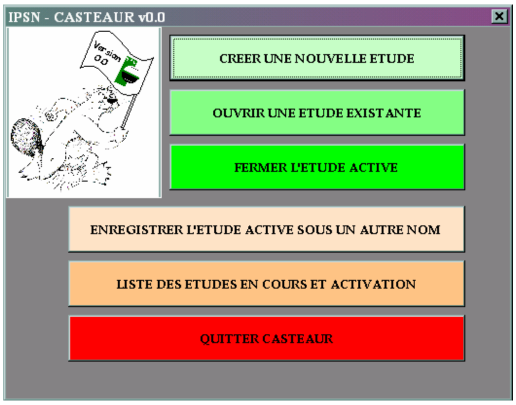
This choice takes into account water, suspended and deposited matters contamination, assessing the transfers by dispersion, exchange (between dissolved and solid phases) and deposition (of the suspended matters).

"Water + suspended matter + deposited matter + food chain" option

This last alternative is the most complete of CASTEAUR v0.0. It includes the previous approach for the abiotic components and adds the transfers in the simplified food chain, considering for fish physio

User interface

The user interface of CASTEAUR v0.0 is built by using advanced possibilities provided by VBA (Visual Basic for Applications) for automation of MS Excel.



It allows the user:

to select the radioecological model:

○ Mode eau brute
○ Mode eau + m.e.s
● Mode eau + m.e.s + sédiment
○ Mode eau + m.e.s + sédiment + trophique

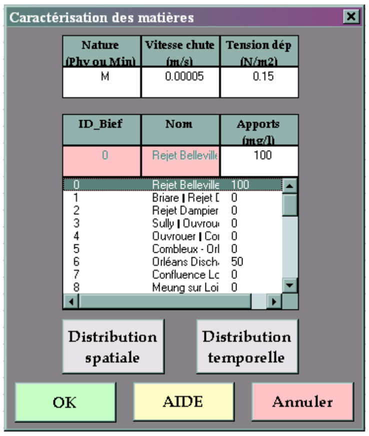
to define the hydrographic network and the hydraulics conditions:

ID	Nom	Type	L (m)	la (m)	fi (rad)	Pente (m/m)	Strickler (m1/3/s)	Q (m3/s)	q (m3/s)	H (m)	U (m/s)	SM (m2)	PM (m)	RH (m)	To (N/m2)	Kx (m2/s)
1	Rejet B	N	17500	235	0.2	0.00051	31.50	195.75	195.75	1.09	0.74	263.12	246.02	1.07	5.35E+	4596.7

1	Rejet Bell	N	17500	235	0.2	0.00051	31.50	195.75	195.75	1.09	0.74	263.12	246.02	1.07	5.35E+
2	Briare - F	N	18720	200	0.14	0.00039	31.50	195.75	0.00	1.30	0.72	272.02	218.63	1.24	4.76E+
3	Rejet Dan	N	12500	320	0.12	0.00053	31.50	195.75	0.00	0.90	0.67	294.29	335.01	0.88	4.56E+
4	Sully - O	N	23000	290	0.13	0.00053	31.50	195.75	0.00	0.95	0.69	283.34	304.70	0.93	4.83E+
5	Ouvrouer	N	20000	360	0.18	0.00058	31.50	195.75	0.00	0.82	0.66	297.77	369.13	0.81	4.59E+
6	Combleu	N	8990	270	0.18	0.00042	31.50	195.75	0.00	1.07	0.66	294.52	281.93	1.04	4.30E+
7	Orléans I	N	5710	270	0.18	0.00042	31.50	203.71	7.96	1.09	0.68	301.77	282.21	1.07	4.40E+
8	Confluen	N	9500	300	0.17	0.00034	31.50	203.71	0.00	1.09	0.61	335.09	312.93	1.07	3.57E+

☑ Détermination automatique du coefficient de diffusion à la ligne sélectionnée

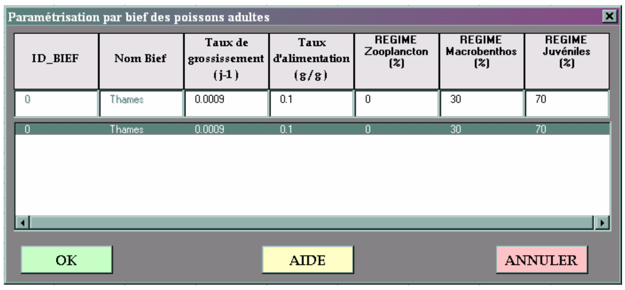
to characterize the suspended matters and the omnivorous fish characteristics



Nature (Phy ou Min)	Vitesse chute (m/s)	Tension dép (N/m2)
M	0.00005	0.15

ID_Bief	Nom	Apports (mg/l)
0	Rejet Bellevill	100

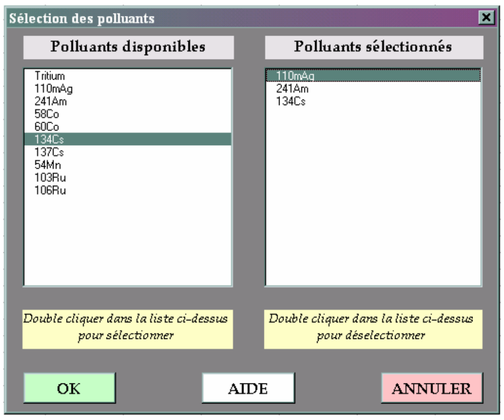
0	Rejet Belleville	100
1	Briare | Rejet D	0
2	Rejet Dampier	0
3	Sully | Ouvrou	0
4	Ouvrouer | Co	0
5	Combleux - Orl	0
6	Orléans Disch	50
7	Confluence Lo	0
8	Meung sur Loi	0



ID_BIEF	Nom Bief	Taux de grossissement (j-1)	Taux d'alimentation (g/g)	REGIME Zooplancton (%)	REGIME Macrobenthos (%)	REGIME Juvéniles (%)
0	Thames	0.0009	0.1	0	30	70

0	Thames	0.0009	0.1	0	30	70

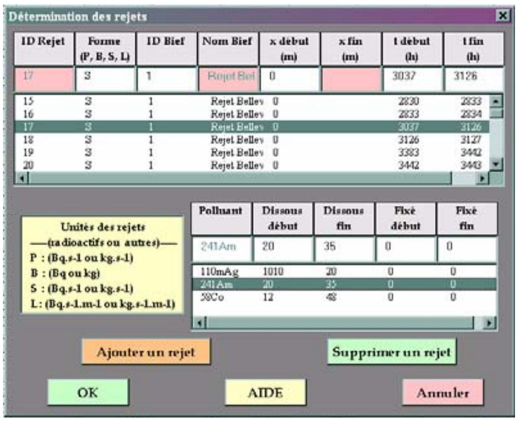
to select the radionuclides and to specify the release conditions:



Polluants disponibles	Polluants sélectionnés
Tritium	110mAg
110mAg	241Am
241Am	134Cs
58Co	
60Co	
134Cs	
137Cs	
54Mn	
103Ru	
106Ru	

Double cliquer dans la liste ci-dessus pour sélectionner

Double cliquer dans la liste ci-dessus pour déselectionner

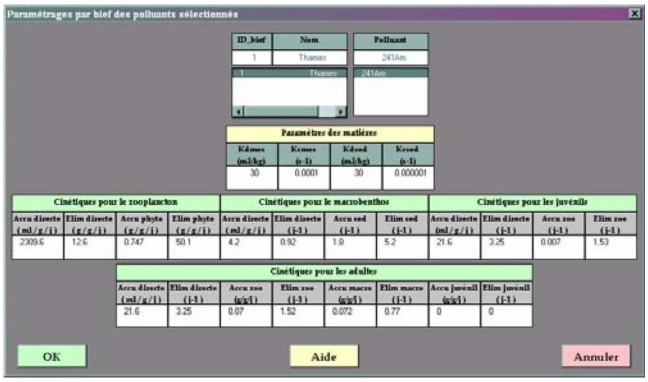


ID Rejet	Forme (P, B, S, L)	ID Bief	Nom Bief	x début (m)	x fin (m)	t début (h)	t fin (h)
17	S	1	Rejet Bel	0		3037	3126
15	S	1	Rejet Bellev	0		2830	2833
16	S	1	Rejet Bellev	0		2833	2834
17	S	1	Rejet Bellev	0		3037	3126
18	S	1	Rejet Bellev	0		3126	3127
19	S	1	Rejet Bellev	0		3383	3442
20	S	1	Rejet Bellev	0		3442	3443

Unités des rejets
—(radioactifs ou autres)—
P : (Bq.s-1 ou kg.s-1)
B : (Bq ou kg)
S : (Bq.s-1 ou kg.s-1)
L : (Bq.s-1.m-1 ou kg.s-1.m-1)

Polluant	Dissous début	Dissous fin	Fixé début	Fixé fin
241Am	20	35	0	0
110mAg	1010	20	0	0
241Am	20	35	0	0
58Co	12	48	0	0

to parameterised the radioecological parameters:



ID_bief	Nom	Polluant
1	Thames	241Am
1	Thames	241Am

Paramètres des matières

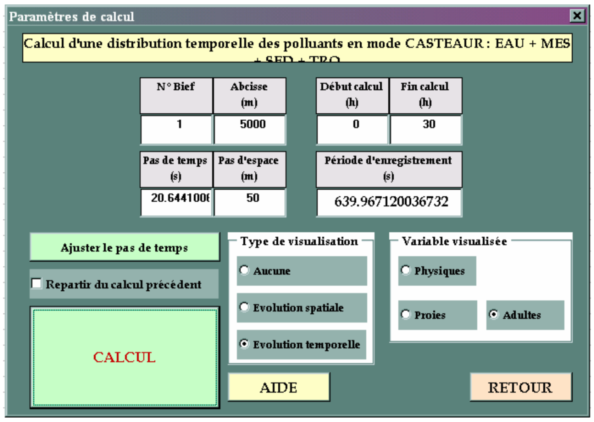
Kdmes (ml/kg)	Kcmes (s-1)	Kdsed (ml/kg)	Kcsed (s-1)
30	0.0001	30	0.000001

Cinétiques pour le zooplancton				Cinétiques pour le macrobenthos				Cinétiques pour les juvénils			
Accu directe (ml/g/j)	Elim directe (g/g/j)	Accu phyto (g/g/j)	Elim phyto (g/g/j)	Accu directe (ml/g/j)	Elim directe (j-1)	Accu sed (j-1)	Elim sed (j-1)	Accu directe (ml/g/j)	Elim directe (j-1)	Accu zoo (j-1)	Elim zoo (j-1)
2309.6	12.6	0.747	50.1	4.2	0.92	1.9	5.2	21.6	3.25	0.007	1.53

Cinétiques pour les adultes

Accu directe (ml/g/j)	Elim directe (j-1)	Accu zoo (g/g/j)	Elim zoo (j-1)	Accu macro (g/g/j)	Elim macro (j-1)	Accu juvénil (g/g/j)	Elim juvénil (j-1)
21.6	3.25	0.07	1.52	0.072	0.77	0	0

to run the calculations:



Calcul d'une distribution temporelle des polluants en mode CASTEAUR : EAU + MES + SED + TRO

N° Bief	Abcisse (m)	Début calcul (h)	Fin calcul (h)
1	5000	0	30

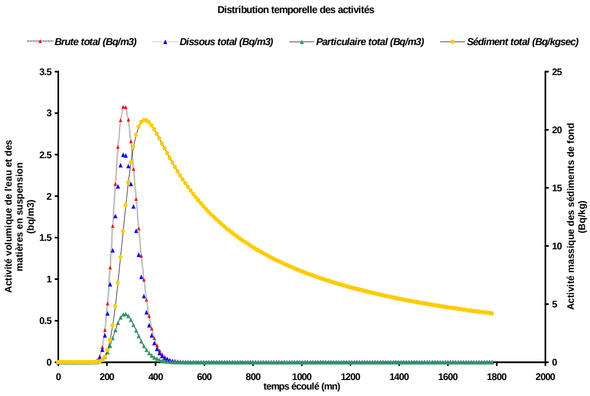
Pas de temps (s)	Pas d'espace (m)	Période d'enregistrement (s)
20.6441006	50	639.967120036732

☐ Repartir du calcul précédent

Type de visualisation
○ Aucune
○ Evolution spatiale
● Evolution temporelle

Variable visualisée
○ Physiques
○ Proies
● Adultes

to visualized the results:



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AQUASCOPE

(by J. Smith)

AQUASCOPE is the set of simplified models for predicting
131I, 89,90Sr, 134,137Cs in water and fish of rivers, lakes and reservoirs. A key aspect of the models are that they are based on a very large database of field measurements of radionuclides in surface waters in a wide range of European countries. Long time series measurements of radionuclides in surface waters were collated from the European Commission AQUASCOPE project and from previous projects. These

measurements were complemented by data from literature studies. Thus far, data has been collected for 25 lakes and 30 rivers in Belarus, Russia, Ukraine, UK, Finland, Italy, The Netherlands and Germany. The measurements span a long time period after fallout from atmospheric nuclear weapons testing and following the Chernobyl accident.

On the basis of this extensive empirical data set we have developed and tested these simplified models for prediction of radionuclide activity concentrations in both rivers and lakes. The target variables were radioactivity concentration in water (dissolved phase) and in fish (for radiocaesium output is given for predatory and non-predatory species separately). Predictions are made for whole fish, though in the case of strontium (where flesh and skeleton activity concentrations are very different), corrections may be made for activity concentrations in the flesh or bony parts separately.

The AQUASCOPE modelling package consists of models for

- Rivers
- "Open" lakes or reservoirs
- "Closed" lakes

where open lakes are defined as all lakes with water residence time < 1 year or mean depth > 7 metres and closed lakes are all lakes with water residence time > 1 year and mean depth <7 metres. The division is important since it has been observed that closed lakes retain much more residual radiocaesium and radiostrontium in water and fish than open lakes. Closed lakes have relatively low rates of inflow and outflow of water (long water residence time), hence radioactivity is cycled more effectively within the lake system. For obvious reasons, it is highly unlikely that any reservoir would be defined as closed.

The river model may be applied in situations where there is a distributed atmospheric fallout of radioactivity onto the river and its catchment. It should not be applied to predict the effects of direct discharges of radioactivity to the river. The model predicts the activity concentration in water (dissolved phase) and fish (predatory and non-predatory) at any point in the river network. Input data requirements are given in Table 1.

Model domain and input data requirements

River model

Table 1. Input data requirements of river model.

Target variable	Input data required
Radiocaesium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the catchment upstream of the point of estimation. 2. Fraction of the catchment which is covered by organic, boggy soils.
Radiocaesium activity concentration in fish (whole fish)	In addition to water (dissolved) phase parameters: 1. Potassium concentration of the water (μM l^{-1})
Radiostrontium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the catchment upstream of the point of estimation. 2. Classification of catchment into predominantly "organic" or "mineral".
Radiostrontium activity concentration in fish (whole fish)	In addition to water (dissolved)phase parameters: 1. Calcium concentration of the water (μM l^{-1})
Radioiodine activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the catchment upstream of the point of estimation.
Radioiodine activity concentration in fish (whole fish)	None in addition to parameters required for water (dissolved) phase.

Open lake model

The open lake model may be applied in situations where there is a distributed atmospheric fallout of radioactivity onto the lake and its catchment. It may also be applied where there is a direct input of radioactivity either to the lake or to the catchment. The model predicts the mean activity concentration in water (dissolved phase) and fish (predatory and non-predatory) in the lake. Input data requirements are given in Table 2.

Table 2. Input data requirements of the open lake model.

Target variable	Input data required
Radiocaesium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the catchment. 2. Mean surface deposition (Bq m^{-2}) of radioactivity to the lake. 3. Fraction of the catchment which is covered by organic, boggy soils. 4. Lake mean depth (metres) 5. Lake water residence time (years) <u>or</u> net annual rainfall and catchment area.
Radiocaesium activity concentration in fish (whole fish)	In addition to water (dissolved) phase parameters: 1. Potassium concentration of the lake water (μM l^{-1})
Radiostrontium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the catchment. 2. Mean surface deposition (Bq m^{-2}) of radioactivity to the lake. 3. Classification of catchment into predominantly “organic” or “mineral”. 4. Lake mean depth (metres) 5. Lake water residence time (years) <u>or</u> the net annual rainfall and catchment area.
Radiostrontium activity concentration in fish (whole fish)	In addition to water (dissolved) phase parameters: 1. Calcium concentration of the lake water (μM l^{-1})
Radioiodine activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of I-131 to the catchment. 2. Mean surface deposition (Bq m^{-2}) of I-131 to the lake. 3. Lake mean depth (metres) 4. Lake water residence time (years) <u>or</u> the net annual rainfall and catchment area.
Radioiodine activity concentration in fish (whole fish)	None in addition to parameters required for water (dissolved) phase.

Closed lake model

The closed lake model may be applied in situations where there is a distributed atmospheric fallout of radioactivity onto the lake. It may also be applied where there is a direct input of radioactivity to the lake. The model predicts the mean activity concentration in water (dissolved phase) and fish (predatory and non-predatory) in the lake. Input data requirements are given in Table 3. The catchment generally has little influence on closed lake radionuclide dynamics, so it is ignored in this model.

Table 3. Input data requirements of the closed lake model.

Target variable	Input data required
Radiocaesium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the lake. 2. Lake mean depth (metres) 3. Lake water residence time (years) or the net annual rainfall and catchment area.
Radiocaesium activity concentration in fish (whole fish)	In addition to water (dissolved) phase parameters: 1. Potassium concentration of the lake water (μM l^{-1})
Radiostrontium activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of radioactivity to the lake. 2. Lake mean depth (metres) 3. Lake water residence time (years) or the net annual rainfall and catchment area.
Radiostrontium activity concentration in fish (whole fish)	In addition to water (dissolved) phase parameters: 1. Calcium concentration of the lake water (μM l^{-1})
Radioiodine activity concentration in water (dissolved phase)	1. Mean surface deposition (Bq m^{-2}) of I-131 to the lake. 2. Lake mean depth (metres) 3. Lake water residence time (years) or the net annual rainfall and catchment area.
Radioiodine activity concentration in fish (whole fish)	None in addition to parameters required for water (dissolved) phase.

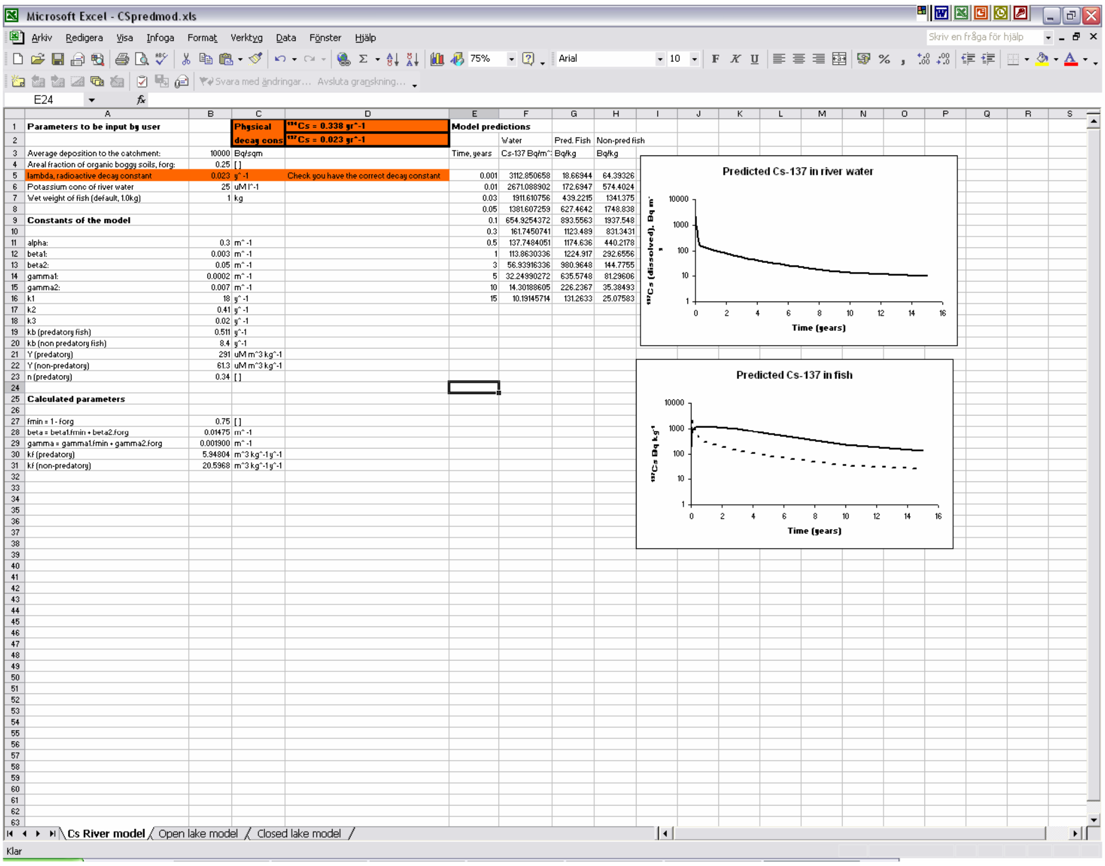
Using the models

The models are implemented in EXCEL spreadsheets, in separate files for the different radionuclides: CSpredmod.xls, SRpredmod.xls and I131predmod.xls. Each file contains different worksheets for the river, open lake and closed lake models.

Each worksheet is divided into "Parameters to be input by the user", "Constants of the model" and "Calculated parameters". The constants of the model may be changed, but this is not recommended unless you are an expert user. The "Calculated parameters" are parameters calculated from the input parameters and model constants and may be ignored. Each of the two lake worksheets also has a "Water residence time calculator" and a "Kappa calculator". These are to aid the user in calculating the lake water residence time and radionuclide removal rate, Kappa (see below).

The user input parameters are simply entered into the spreadsheet with care taken that the correct units are used. The output is given in the relevant columns for water, large predatory fish (1 kg wet weight of fish) and non-predatory fish for different times in the years after fallout. For predatory fish it is known that there is a significant effect of size on uptake of radiocaesium, so a large fish is specified. For non-predatory fish this effect is much less obvious, so no fish size is specified. For radiostrontium and ^{131}I no differentiation between different fish types is made.

Some model workings are shown in grey coloured cells: these may be ignored. Model output is also given in graphical form. The graphs and time points may be amended by the user to suit requirements. Note that if a logarithmic scale is used in the graphs, the first calculation time point must be greater than zero.



	A	B	C	D	E	F	G	H
1	**Parameters to be input by user**		**Physical**	**^{134}Cs = 0.338 yr^-1**	**Model predictions**			
2			**decay cons**	**^{137}Cs = 0.023 yr^-1**		Water	Pred. Fish	Non-pred fish
3	Average deposition to the catchment:	10000	Bq/sqm		Time, years	Cs-137 Bq/m^:	Bq/kg	Bq/kg
4	Areal fraction of organic boggy soils, forg:	0.25	[ ]					
5	lambda, radioactive decay constant	0.023	y^ -1	Check you have the correct decay constant	0.001	3112.850658	18.66944	64.39326
6	Potassium conc of river water	25	uM l^-1		0.01	2671.088902	172.6947	574.4024
7	Wet weight of fish (default, 1.0kg)	1	kg		0.03	1911.610756	439.2215	1341.375
8					0.05	1381.607259	627.4642	1748.838
9	**Constants of the model**				0.1	654.9254372	893.5563	1937.548
10					0.3	161.7450741	1123.489	831.3431
11	alpha:	0.3	m^ -1		0.5	137.7484051	1174.636	440.2178
12	beta1:	0.003	m^ -1		1	113.8630336	1224.917	292.6556
13	beta2:	0.05	m^ -1		3	56.93916336	980.9648	144.7755
14	gamma1:	0.0002	m^ -1		5	32.24990272	635.5748	81.29606
15	gamma2:	0.007	m^ -1		10	14.30188605	226.2367	35.38493
16	k1	18	y^ -1		15	10.19145714	131.2633	25.07583
17	k2	0.41	y^ -1					
18	k3	0.02	y^ -1					
19	kb (predatory fish)	0.511	y^-1					
20	kb (non predatory fish)	8.4	y^-1					
21	Y (predatory)	291	uM m^3 kg^-1					
22	Y (non-predatory)	61.3	uM m^3 kg^-1					
23	n (predatory)	0.34	[ ]					
24								
25	**Calculated parameters**							
26								
27	fmin = 1 - forg	0.75	[ ]					
28	beta = beta1.fmin + beta2.forg	0.01475	m^ -1					
29	gamma = gamma1.fmin + gamma2.forg	0.001900	m^ -1					
30	kf (predatory)	5.94804	m^3 kg^-1 y^-1					
31	kf (non-predatory)	20.5968	m^3 kg^-1 y^-1					

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EVANET-HYDRA 1st plenary meeting 20-22 February 2002, Rome, Italy, Minutes of the Meeting

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AQUASTAR

(by J. Smith)

- Simplified assessment model for short term accidental and regulated releases to rivers.
- Radionuclides of interest:
    - H-3, C-14, P-32, Co-60, Zn-65, Sr-89,90, I-125,131, Cs-134,137
    - Am-241, Isotopes of Pu, U.
- Sites of interest:
    - River Colne (Amersham), River Thames (Aldermaston, Harwell)

- Target variables:
  - Maximum and time integrated activity concentrations in water, fish and sediments within a 10km reach downstream of the discharge.
- Longitudinal advection and dispersion of the plume at different volumetric flow rates;
- Transverse dispersion of the plume;
- Different release times: 5 min, 30 min, 3, 12, 24 h
- Transfers to sediments;
- Dynamics of uptake by predatory fish (trout) as a function of water temperature.

Model is available as an EXCEL spreadsheet based on the US Geological Survey (USGS) (Jobson, 1997). The model can also be used as a series of look-up graphs (Smith et al., 2000).

References

Jobson H E (1997) *Predicting travel time and dispersion in rivers and streams*. J. Hydraulic Engineering, Vol. 123, 971-978.

Smith, J.T., Konoplev, A.V., Bulgakov, A,A, Comans, R.N.J., Cross, M.A., Khristuk, B., de Koning, A., Kudelsky, A.V., Madruga, M-J., Voitsekhovitch, O.V., Zibold, G. (2001) AQUASCOPE Technical Deliverable: Simplified models for predicting ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{131}I in water and fish of rivers, lakes and reservoirs. European Commission project IC15-CT98-0205, 43 pp.

RIPARIA

(by S.Lepicard)

RIPARIA is a "compartmental-modelling" computer code for assessing the radiological consequences of radioactive releases into rivers [1]. This code was developed and tested by CEPN for the French Rhône river in the framework of the ExternE study [2], and its parameters have been adjusted to the Dnieper cascade in the context of a recent study [3]. In particular the modelling of the sedimentation processes has also been modified, on the basis of the European Methodology report RP72 [4].

The major assumption inherent to this compartmental modelling is the homogeneity of each reservoir with respect to its parameters (i.e. suspended sediment load, sedimentation rate,depth, etc.), and an equal distribution of the activity within the volume of the compartment. Exchanges between compartments are expressed in terms of an average annual transferred volume of water. Seasonal variations (of water flows for example) are not considered in the modelling. The impacts of such seasonal variations of water flows were estimated and considered in the variability study of dose assessment results [6]

RIPARIA is a calculation code compiled in FORTRAN. It has a command line interface. Inputs/outputs are performed *via* exchange files (.DAT); results are provided in text files (.OUT). The .OUT files have such format that they could be easily opened in Excel for the proposes of preview and presentation of data as graphs. Detailed format and description of RIPARIA I/O data is presented in [5]

The input data required for the running of RIPARIA are given below, through an example of input file.

======

1	number of periods of releases
4	number of calculation times (times where activities/doses have to be calculated)
10	total number of boxes for the selected river system
evanet	name of the river system (cf name of the sub-directory \RIPARIA**xxxxxx**\
Sr-90	radionuclide (a single radionuclide for each run)
8	n° of the compartment in which the release occurs
1.14E-03	duration of each period of release (in years)
---	file separator (compulsory)
1.00E+00	first calculation time (in years)

1.00E+01	second calculation time (in years)
1.00E+02	third calculation time (in years)
1.00E+03	fourth calculation time (in years)
1	individual dose calculations (0-NO / 1-YES)
Groupe1	name of the selected reference group for individual calculation (cf description in <Grpref.dat> file)

======

Release rates are fixed in an additional input file, RIPA_REJ.dat. An example is provided below.

======

1.00E+05 0.00E+00	first column: total activity released over the corresponding release period on dissolved form (in Bq); second column: total activity released over the corresponding release period on adsorbed form (in Bq)

======

A description of outputs from RIPARIA are given below. Individual and collective doses are provided for each exposure route considered.

Individual dose (in Sv/year over the time period between 2 calculation times)
Collective doses (person-Sv/year over the time period between 2 calculation times)

References

1. RAFFESTIN, D., LEPICARD, S., MICHOU, P., RIPARIA: Logiciel d'évaluation de l'impact radiologique associé au relâchement de matières radioactives en milieu fluvial, Rapport CEPN n° 237, 1995.
2. M. DREICER, V. TORT, P. MANEN, Nuclear fuel cycle: estimation of physical impacts and monetary valuation for priority pathways, Rapport CEPN N°234, 1995.
3. LEPICARD S., Chernobyl dyke on the Pripyat river: collective dose reduction and cost-benefit analysis, Report CEPN n°265, 1999.
4. EUROPEAN COMMISSION, Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment, RP 72, EUR 15760, 1995.
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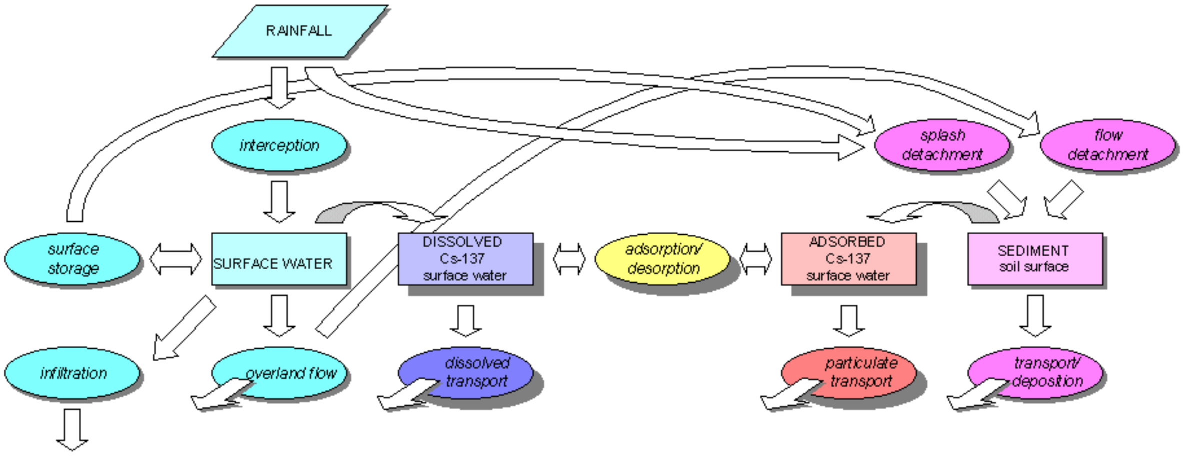
SPARTACUS

(by M. van der Perk)

In August 1998, the SPARTACUS project (EC DGXII INCO-COPERNICUS Programme) was initiated to improve the methodology for spatial modelling of radionuclide redistribution within catchments and to incorporate this methodology in GIS for further development of rehabilitation approaches after environmental radioactive contamination. The main aim of the project is to develop a set of distributed models for assessment of the spatial redistribution of radiocaesium within catchments. For this purpose, the stand-alone RUNTOX application was developed, a physicallybased model accounting for radionuclide transport through runoff, unsaturated flow, and groundwater flow at the event scale. In addition, GIS-based models have been developed using the spatio-temporal modelling language of PCRaster to predict soil erosion, event-based soluble and particulate ^{137}Cs wash-off, long-term ^{137}Cs redistribution as a result of both overland flow induced soil erosion and soil translocation due to tillage. The implementation of the models into PCRaster enables a straightforward integration into the existing environmental decision support system that was developed in the framework of the RESTORE project. For the SPARTACUS project, the ^{137}Cs redistribution models were tested and applied to the Mochovce catchment in Slovakia. A comprehensive GIS database was compiled to feed the models and an extensive soil sampling campaign was carried out to map the spatial distribution of ^{137}Cs inventories in soil in the Mochovce catchment (Van der Perk et al., 2002).

Development of simulation procedures and GIS-based models

The SPARTACUS ^{137}Cs redistribution models predict the changes in ^{137}Cs inventories in soil at two time scales, namely at the event scale (hours) and the long-term scale (years). The basic input for both models is a map of initial soil contamination by radiocesium, a digital elevation model (DEM), and maps of soil type and land use. The event-based radiocesium redistribution model has been based on the existing LISEM soil erosion model (De Roo et al. 1996). The LISEM model accounts for rainfall, interception, surface storage, infiltration, overland flow, detachment by rainfall and throughfall, detachment by overland flow, and transport capacity of overland flow. Radiocesium exchange processes between the dissolved and adsorbed phase in both top soil and overland flow have been incorporated based on a distribution coefficient (Kd) approach. The figure below shows the structure of the model. At the event time scale, it can be assumed that Kd is constant for the different sediment types and equilibrium is reached instantaneously. The Kd is estimated based on sediment type and time since initial deposition. Radiocesium exchange processes between the top soil and runoff water are modeled assuming an active layer of 5 mm. The initial radiocesium contamination values usually expressed as Bq/m2 are converted to activity concentrations in this active layer (Bq/kg) using soil bulk density and a standardized depth distribution of radiocesium that depends on time as a result of vertical advective and diffusive transport and ploughing. Besides the changes in soil radiocesium inventories, the model yields also rates of both dissolved and particulate radiocesium transport from the model area.



Schematic overview of the event-based radiocesium redistribution model.

The long-term radiocesium transport model is a simplified spatial version of a soil erosion and deposition model presented by Govers et al. (1993) and accounts for rill-erosion and transport capacity. A relative measure for potential soil erosion was derived using:

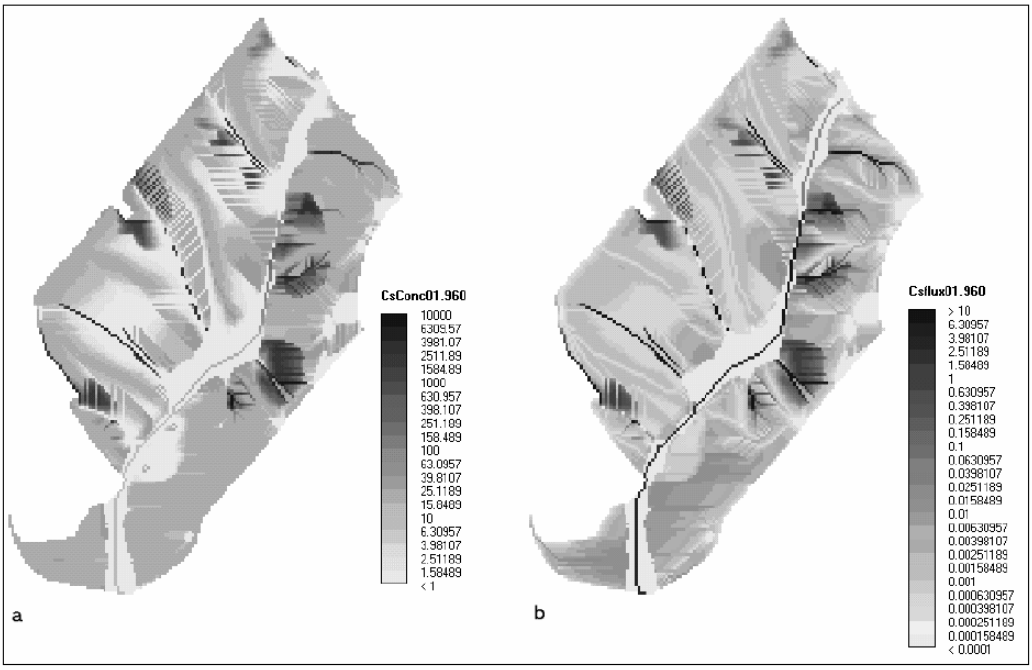
$$E_r = f_{soil} f_{lc} L^n S^m$$

where E_r = the relative potential erosion rate per unit area, f = a factor (-), L = the slope length (m), S = the sine of the slope gradient, and n and m are exponents. Note that the model only estimates the relative soil erosion rate. The sediment transport capacity (T_r) on a given location in the catchment was considered to be proportional to the potential for erosion (Govers *et al.*, 1993):

$$Tr = gt\, E_r$$

Where g_t = the transport capacity coefficient. The amount of eroded sediment and sediment-associated P per gridcell is transported downstream over the drainage network, as long as it does not exceed the transport capacity. The surplus is deposited. The ^{137}Cs in the deposited sediment was calculated as a weighted average of eroded soil ^{137}Cs and the ^{137}Cs in transported sediment in the upstream gridcells.

The model adopts a time step of 1 year. The predicted soil erosion and deposition rates are used as input for a radiocesium mass-balance, for which the radiocesium activity concentration of the eroded sediment equals the activity concentration of the active layer (see above) and the activity concentration of the deposited sediment equals a weighted average of the activity concentration of eroded sediment from the upstream grid cells. Each time step, the radiocesium inventory in the top 25 cm of the soil profile is redistributed to simulate homogenization due to ploughing.



Results of the event-based ^{137}Cs redistribution model for the rainfall event on 10-11 July 1999: a) total 137Cs activity
concentrations in the runoff water (Bq/m3) and b) 137Cs fluxes (Bq/s) during simulated peak discharge (time step 1960 = 11 July 1999 1:39 AM).

A more detailed description and application of both models to the Mochovce catchment in Slovakia can be found in Van der Perk and Slávik (2003). The models were implemented in the PCRaster environmental modelling language, a computer language for construction of iterative spatio-temporal environmental models (PCRaster 2004). It runs in the PCRaster interactive raster GIS environment that supports immediate pre- or post-modelling visualisation of spatio-temporal data. The PCRaster environmental modelling language is a high level computer language: it uses spatio-temporal operators with intrinsic functionality especially meant for construction of spatio-temporal models. Compared with low level computer languages (e.g. C, Pascal) this has the advantage that models are programmed and structured according to the way of thinking applied in spatial-temporal sciences such as geography or geology. It allows researchers in these fields to construct models by themselves in a relatively short period of time, even when they do not have experience in programming.

Models constructed in the PCRaster Environmental Modelling language can easily be changed or extended and the results can immediately be evaluated using visualisation routines linked to the language. This interactive approach of model building is not possible with models constructed in a low level computer language. Changing such models mostly means rewriting the whole computer code which implies time consuming programming. In addition such models must be linked to separate software packages for visualisation of model output with results in clumsy data exchange.

Annex 6 gives the detailed evaluation of the software features of the software developed in the frameworks of the SPARTACUS project done by its developers in the form of the answers to EVANET-HYDRA questionnaire.

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Van der Perk, M., A.A. Svetlytchnyi, J.W. den Besten, and A. Wielinga (eds.)(2000) SPARTACUS - Spatial redistribution of radionuclides within catchments: Development of GIS-based models for decision support systems, EC Contract No. ERB IC15 CT98 0215; Final Report. Utrecht: Utrecht University, 165 pp. + 1 Annex (CD-ROM). Available online at http://globis.geog.uu.nl/Users/Perk/Projects/Spartacus/report.html.

Van der Perk, M., O. Slávik, and E. Fulajtár (2002) Assessment of spatial variation of 137Cs in small catchments. Journal of Environmental Quality 31, 1930-1939.

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PRANA-DSS

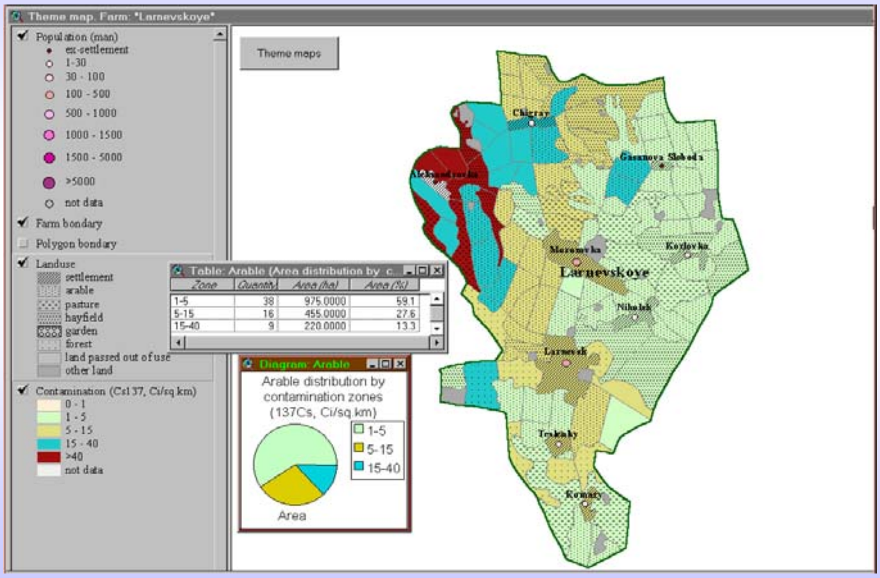
(by B. Yatsalo and O. Mirzeabassov)

In order to reflect current state of the art in the development of the GIS-based DSS and explore the potential links the demonstration of PRANA DSS (which is not a DSS for the predicting the migration of radionuclides in the aquatic environment) had been also performed during EVANET-HYDRA meetings. PRANA has been developed with the use of GIS technologies, comprises all the main territories of Russia subjected to radioactive contamination as a result of the Chernobyl accident and includes all the tools necessary for RBLM and CMs optimisation both on local and regional levels.

Despite continual improvement of the radiological situation for the 16 years after the Chernobyl accident, the latest monitoring data and assessments demonstrate that the situation on the contaminated territories of Bryansk region (Russia) is far from satisfactory. Fraction of milk for 5 districts of Bryansk region with contamination above formal action level exceeded in 2001 20% (for Novozybkov district - 60%); about 50% of the rural population live in settlements with a mean dose above 1 mSv/y (formal dose level for exemption from intervention). As a rule, contamination of private agricultural produce, which constitutes the majority of foodstuffs of the local population, substantially exceeds contamination of farm produce. In this condition implementation of up-to-date information technologies for decision-making support on Risk Based Land Management (RBLM) and optimisation of countermeasures CMs) within the programmes on rehabilitation and sustainable development of contaminated territories is more than actual.

PRANA is a unique Decision Support System (*DSS*) developed with the use of GIS technologies which comprises all the main territories of Russia subjected to radioactive contamination as a result of the Chernobyl accident and includes all the tools necessary for RBLM and CMs optimisation both on local and regional levels.

PRANA-AV : ^{137}Cs contamination, farm "Larnevskoye”, 1996 y., Krasnogorsky district



Zone	Quantity	Area (ha)	Area (%)
1-5	38	975.0000	59.1
5-15	16	455.0000	27.6
15-40	9	220.0000	13.3

The main blocks of the *PRANA DSSs* are:

- libraries of electronic maps of *landuse* for all contaminated districts of Bryansk region (more than 30000 polygons of vector digital maps);
- databases (radioecological, ecological, economic, demographic and other monitoring data and model parameters, including attributive information of vector electronic maps);
- model blocks for assessing: contamination of agricultural produce, doses to the local population and risk and corresponding results of CMs implementation;
- evaluation of CMs effectiveness and decision-making support (local and regional levels- from separate settlement/field up to group of settlements/farms and region as a whole).

The following ‘risk indices’ (monitoring data and/or model assessments) are considered:
surface density contamination (^{137}Cs, ^{90}Sr);

- contamination of agricultural produce (plant growing and animal husbandry, farm and private production);
- external and internal doses to the local population (for different age and occupational groups of each settlement for region under consideration);
- radiological risks caused by irradiation of the population;
- and also expenses associated with CMs implementation and rehabilitation procedures.

Ranking fields, farms, settlements and districts has been carried out with the use of several criteria: surface density contamination, contamination of a given product, dose to the local population and percent of exceeding corresponding DILs by indicated values.

Several versions of *PRANA DSS* have been developed: for practical use within rehabilitation of radioactive contaminated territories of Bryansk region and for research and for training and education. This work has been carried out by a team of Russian scientists within the ISTC project.

SECTION 2. END-USERS EXPERIENCE WITH THE SOFTWARE.

Introduction

Evaluation of the practical users' experience with the software included in the frame of EVANET-HYDRA project was performed through:

- Demonstrations, discussion meetings and practical exercises with the participation of both software developers and potential users.
- Distribution of the most recent versions of the software and documentation to both current and potential users of DSSs (both participants and non-participants in the EVANET-HYDRA network). Necessary consultancy for the DSSs implementation was provided. Development of a web-site (http://user.tninet.se/~fde729o/MOIRA) for support of MOIRA DSS software and documentation download and evaluation.
- Test implementation of the software undertaken by end-users – participants of EVANET-HYDRA (in cooperation with WP5) as well as collecting the experience gained by MOIRA and AQUASCOPE implementations by organisations not involved in the network activities.
- Test implementation of decision support systems to EVANET-HYDRA scenarios undertaken by developers

A summary of the results of the EVANET_HYDRA exercises regarding software implementation as well as collected information from other software users are presented in Table 2.1.

DSS	**Lake**	**Organisation**	**Developers/users**	**Presentation**	**Selected suggestions**
AQUASCOPE	Lake Balaton	CEH	Developer	1st topical meeting	Modelling of tritium
MOIRA 2.1	Lake Balaton.	NRG, UPM,UU	Developers	1st topical meeting	Using MOIRA and RODOS as complimentary tools. MOIRA predicts the outflow on the basis of algorithms related with the geographical and morphological properties of a lake and its catchment. An improvement of MOIRA could be is that the user cannterfere via the user interface to overrule these predictive submodels. Modification for modelling closed lakes by implementing the possibility to set the outflow to zero for closed lakes, even when a significant inflow is calculated by a sub-mode
HDM (LAKECO, TREETOX)	Lakes Balaton, Uruskul, Svyatoe	NRG	Developer	1st topical meeting	The refinement of the User Guides and development of the Customisation Manuals; Possibilities for multi-level data input; Appropriate model chain definition; Scenarios for model testing; Connection of HDM to national hydrological forecasting systems
MOIRA 2.1	Lakes in Chernobyl area	UHMI, Ukraine	User (organisation is not directly involved in EVANET-HYDRA)	1st coordination meeting	MOIRA needs to have possibility to start from measured data of concentration in the water (sediments) starting the modelling of concentration in water at the end of given data ; System need the possibility to use time-dependent discharge data; Importing/exporting functions need to be improved; Start from initial contamination data (data assimilation procedures)
MOIRA 2.2	Lake St. Kumlan	Studsvik, UPM, UU, UO, ENEA, NRG.	Developers	Meeting with the participation of SSI (Sweden) and SRV (Sweden) in the frame of 1std "short visit" meeting	Introducing the possibilities to use MOIRA in the distributed network environment where MOIRA will run on a server in emergency preparedness organisation and a client software with data preparation and results visualisation possibility only will be installed in the county administration organisations to connect this server.
MOIRA 2.2	River Po Scenario 2 of EVANET 2nd topical meeting	Studsvik	Developer	2nd topical meeting	Procedure of definition of relationship between MapInfo segments and numbers of boxes in MOIRA river model need to documented.
AQUASCOPE	River Po Scenario 2 of EVANET 2nd topical meeting	CEH	Developer	2nd topical meeting	

MOIRA 2.2 – 2.3.1	Lakes Cernavoda area	IFIN, Romania		EVANET 2nd topical meeting 3-rd plenary meeting	Have the possibility to prepare all site-specific data in the format of one of the popular GIS
MOIRA 2.2 – 2.3.1 RODOS-HDM (PV RODOS 5.0) AQUASCOPE	River Danube	IFIN, Romania	User	EVANET 2nd and 3rd topical meetings , 3rd plenary meeting	The modelling of a river like Danube has to pay a special attention from the developers, in order to address in a better way the real topology, containing loops and multiple outlets. It is recommended to have a manual for RODOS and MOIRA explained how to make the customization of the systems including the addition of new radionuclides. It could be useful to recommend a set of default values for each radionuclide. As the RETRACE module needs a number of parameters difficult to calibrate without a big amount of experimental data, it should be better to replace this in the future with a grid assessment procedure of the wash-off in the watersheds. For the further customisation of HDM modules in case of the complex hydrology of the Danube Delta, containing a mixture of lakes and channels, there is a need for simplification, due to the large amount of hydrological data required. We also note that since tritium is a very important radionuclide in case of accidental CANDU NPP releases in Danube river, it should be included in the RODOS-database The development of LCMA in RODOS system similar to MOIRA. For the future a common emergency exercise for both systems (RODOS and MOIRA) could be useful in comparison of results between end-users and developers.
MOIRA 2.3	River Pryp'at EMRAS Prip'at floodplain scenario	Studsvik	Developer	EMRAS-EVANET joint meeting	
MOIRA 2.3	Lake Svyatoe	UPM	Developer	2nd plenary meeting EVANET	See chapter 1.3.3 for the description of the exercise.

RODOS-HDM	River system Vah-Dudvah	VUJE, Slovakia		EVANET 2nd plenary meeting and 3rd topical meeting, , 3rd plenary meeting	RIVTOX: Develop special SW tool for: facilitating a change of the created river net (add, remove tributaries,, now it is a laborious procedure); conversion of 2D to 1D cross section data for river reservoirs; performing basic testing procedures for complex river nets (summing rule, water flow continuity, ...) . Adopt available GIS and hydrostatistical data to facilitate initial customisation of the model (make the use of RIVTOX more user friendly, cheaper and not requiring so much hardly available input data)
MOIRA 2.3.1	Lake Lago Maggiore	Fachhochschule Ravensburg-Weingarten	User (organisation is not directly involved in EVANET-HYDRA)	See [2]	Misprint in the unit presented in the heading of the column “Concentration I sedments” in MOIRA tables.
MOIRA 2.3.1	Lake Svyatoe	UPM	Users other than persons involved in development of MOIRA	2nd “short visit” meeting	Improvements in the sytem keeping consistency between input data and results (warnings before deleting of the inconsistent data are required)
MOIRA 2.3.1 In addition to test implementation of MOIRA 2.3.1, □-version of MOIRA 2.3.2 had been successfully tested with the same scenario	River Danube	National Research Institute for Radiobiology and Radiohygiene, Hungary	User	3rd plenary meeting	The Help of the software should be completed with the following topics: meaning of the data in the chemistr.txt file; instructions on how to fill the River Database in case of less than 20 boxes; meaning of the „Reload RiverDataBase data to the user interface” menu. Some parameters should be more clearly defined/explained. The River Database could be a bit more user friendly.

Table 2.1

Experiences and Tests in Customization of Aquatic DS Systems in Romania

(by D. Slavnuicu and D. D. Gheorghiu)

During the 2-nd topical meeting of EVANET-HYDRA National Institute of R&D for Physics and Nuclear Engineering of Bucharest (IFIN-HH) has presented an exercise of customisation of MOIRA 2.2 to river Danube and several lakes in Romania . The customisation had been done via:

- The customization of the program for Romanian hydrological GIS database:
    - The lake database was extended by merging the lakes workspace from Cernavoda area to the basic layer (fig 1)
    - The hydrological and topological data were transformed to a convenient format;
    - The preparation of Danube river workspace with main tributaries (fig.2);
- Test simulation for an accident scenario in Cernavoda area

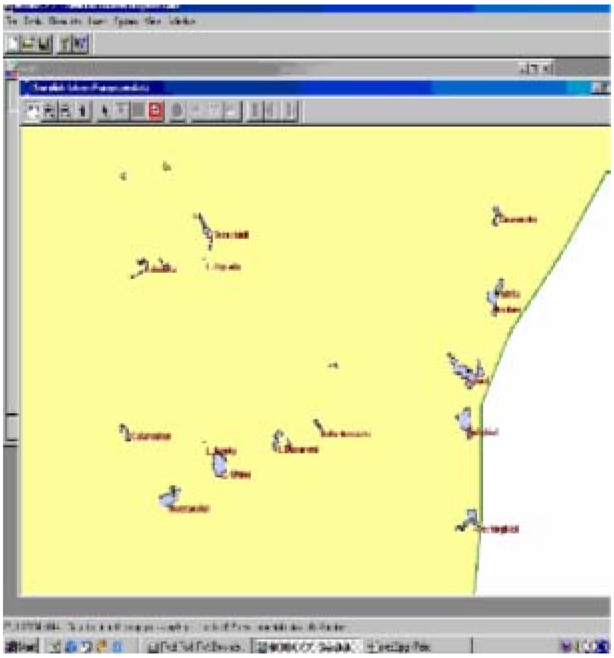


Figure 1

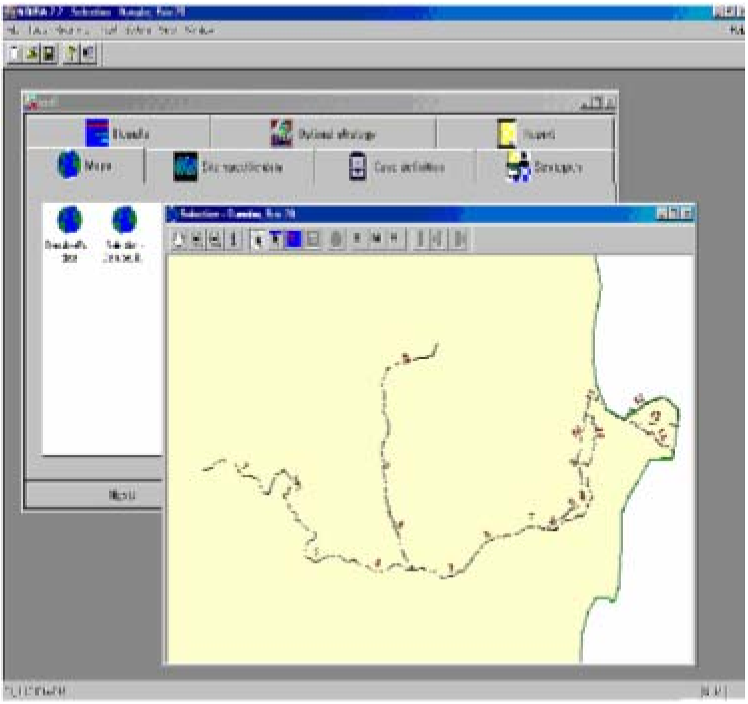


Figure 2

The application has confirmed the possibility of quick customisation of MOIRA data by the advanced users. It was recognised that documentation describing how to implement new rivers according to their shape features (such as forks and loops) needs to be prepared. It was also suggested that possibility to prepare all the river data in the environment of one of the popular GIS packages would be useful alternative (for the users experienced in GIS) to the current system based on the text files.

For the customisation of the RODOS-HDM with the collaboration of the National Institute of Meteorology and Hydrology IFIN collected the data following for the main rivers and tributaries located in a square area of 100 x 100 km centered on Cernavoda NPP:

- Geographic position of hydrometric stations; GIS representation of the hydrological network

  -Water body characteristic (daily average discharge, daily mean depth)

-Transversal hydrological profile for each month of the year

- Hydrological network (one way topology) with node database
- Suspended particles flow for each month of the year and size of suspended particles where available

The localization of the rivers and of the hydrometric stations are given in Fig. 3. All the parameters were collected on a daily or monthly basis for year 2000, considered as representative.

During the TRAC-RODODS course IFIN has presented the results of the cusomisation of RODOS-HDM and improved results of MOIRA customisation to the Danube river.

For RODOS-HDM due to the complicated topology of Danube in Cernavoda segment a simplified model of flow was adopted to take into account the tree model of RIVTOX which does not allow loops and multiple outlets. By application of special tools (bxy2bgxy.exe and shp2rivtox.exe) provided by developers of HDM module the necessary files of Danube project for RIVTOX was created, for Cernavoda segment. As an alternative to shp2rivtox.exe to build the Data .Table file it was used the SQL facilities of Arc View 3.2 to fulfill the database with all necessary items and export it in ASCII fix format required by Data .Table file.

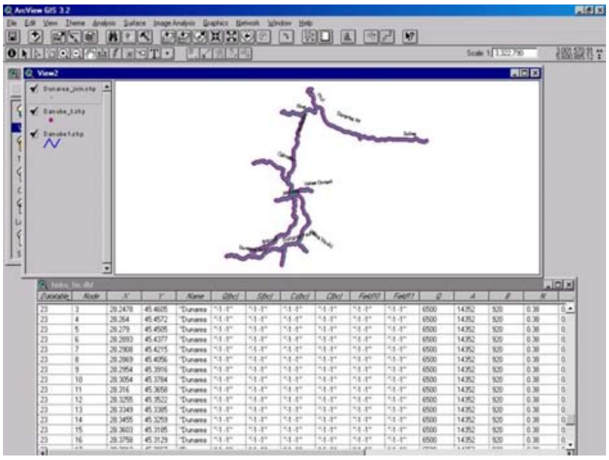
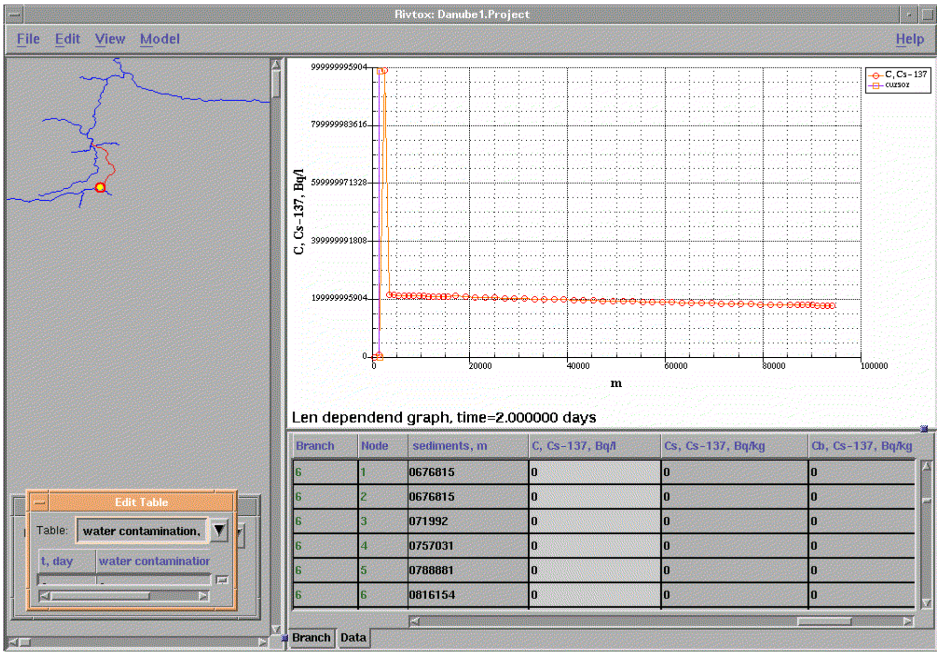


Figure 3

The advantage of this method:

- the database is complete
- subsequent changes in database are very easy to do

By using a fictitious source term (Cs-137) and direct inflow, the main results of RIVTOX as time dependent of concentration in a point and the concentration versus distance were obtained in Cernavoda segment (Figure 4).

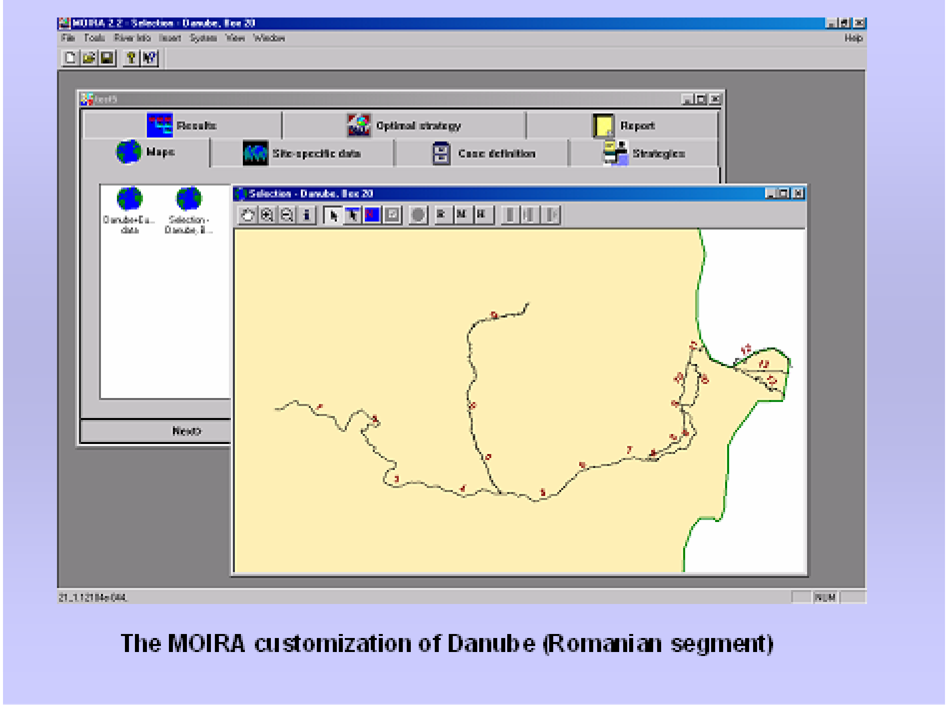


Len dependend graph, time=2.000000 days

Branch	Node	sediments, m	C, Cs-137, Bq/l	Cs, Cs-137, Bq/kg	Cb, Cs-137, Bq/kg
6	1	0676815	0	0	0
6	2	0676815	0	0	0
6	3	071992	0	0	0
6	4	0757031	0	0	0
6	5	0788881	0	0	0
6	6	0816154	0	0	0

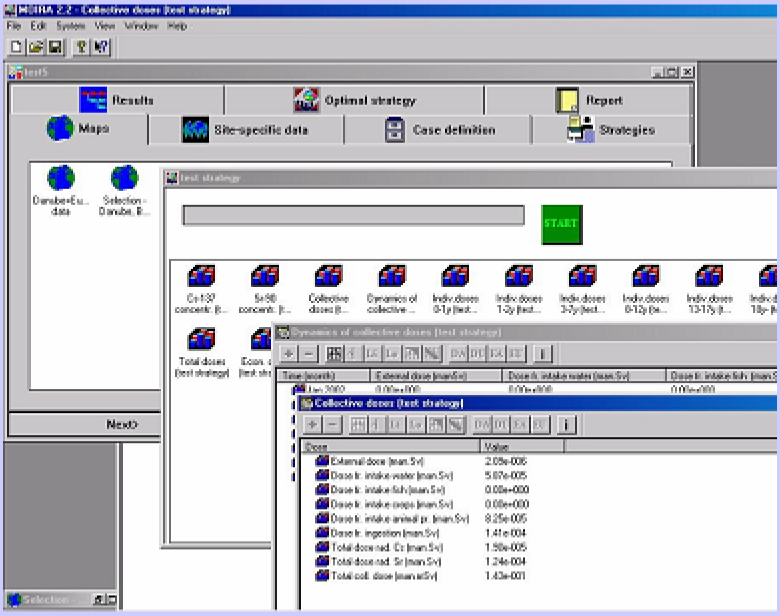
Figure 4. Concentration in solution on a branch after 2 days

To run MOIRA, a simplified model for Danube was applied also in this case. The MOIRA GUI and some results are presented.



The MOIRA customization of Danube (Romanian segment)

Figure 5



Dose	Value
External dose [man Sv]	2.05e-006
Dose fr. intake water [man Sv]	5.07e-005
Dose fr. intake fish [man Sv]	0.00e+000
Dose fr. intake crops [man Sv]	0.00e+000
Dose fr. intake animal pr. [man Sv]	8.25e-005
Dose fr. ingestion [man Sv]	1.41e-004
Total dose rad. Cs [man Sv]	1.58e-005
Total dose rad. Sr [man Sv]	1.24e-004
Total coll. dose [man mSv]	1.43e-001

Some results of MOIRA system for Danube (Romanian segment)

Figure 5.1

Problems encountered during customization:

- (HDM and MOIRA) The modeling of a river like Danube has to pay a special attention from the developers to approach as better as possible the real topology.
- (HDM) The need of changing of some parameters by using some dedicated windows: e.g. time parameters, name of the river in Run.dat file.
- (HDM) The Dynamic.Grid generation for the HDM2FDMA, and setting of the Bounding Box of the DSAA (Surfer export ASCII) grid for Danube area.
- (HDM) The FDMA module did not run even in default case.
- (HDM) The impossibility to display results for previous hydro tests

During the 3-rd topical meeting of EVANET-HYDRA IFIN had demonstrated the results of the exercise in application of RODOS-HDM, MOIRA and AQUASCOPE to the Romania conditions. The results of this implementation are presented in [4] and shown below:

The Hydro DSS and programs that have been tested for Romanian conditions are :

1. RIVTOX (RODOS-Hydro submodule)
2. MOIRA Decision Support System - for river
3. AQUASCOPE Program - for river

The following steps have been made:
a) The loading and the running of the systems on default version.
b) The collection of necessary hydrological data to develop a specific database for RIVTOX and MOIRA
c) The tests of the programs based on accident scenario specific to CANDU NPP.
d) The comparison of the results and the recommendations for the best use of each system
e) The encountered problems during the running of the systems and the notification to the developers

Data input for the programs:
a. The running of ECDHB (Early Core Disassembly with Hydrogen Burn) scenario in ADM - RODOS (Prognosis Mode).
ADM - Atmospheric Dispersion Module
b. Meteorological scenario :

- wind velocity - v= 1m/s
- wind direction - from east to west
- stability - D
- no rain and rain - 10 mm/h

c. The ground deposition (ADM) in no rain case was used as input data for RIVTOX, and the greater values for the Danube branch nearer to NPP were used in rain case to run all programs and to compare the results.

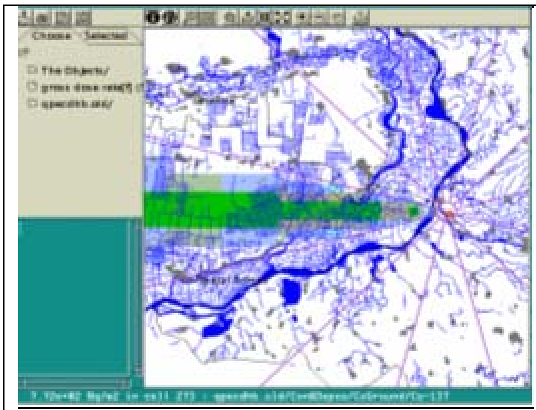
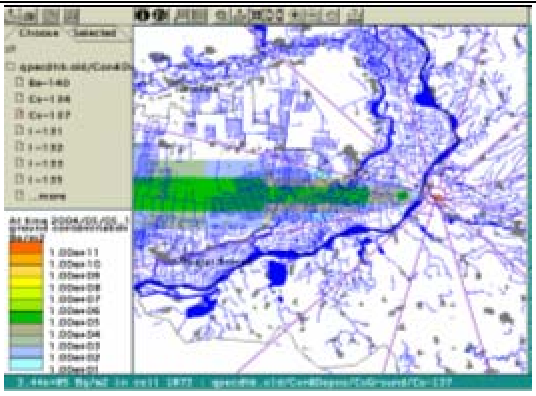
	

Fig 6. Cs-137 ground deposition on cell 273 in no rain case	Fig.7 Cs-137 ground deposition on cell 1073, no rain case

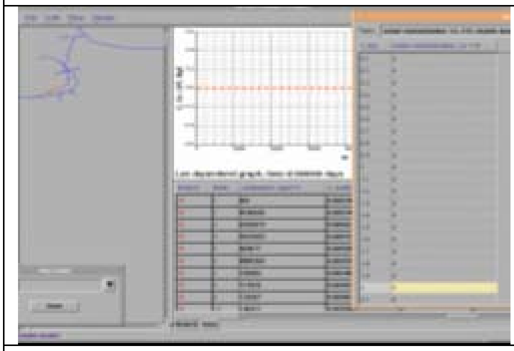
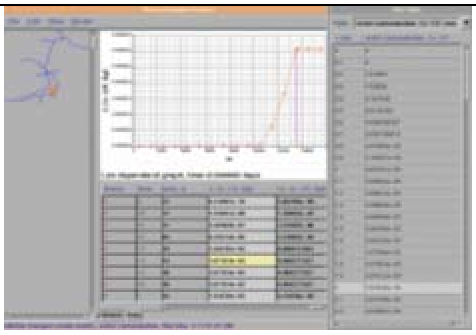

	

Fig.8 Cs-137 concentration in water, branch no.11 , no rain case	Fig.9 Cs-137 concentration of in water, branch no.7, no rain case

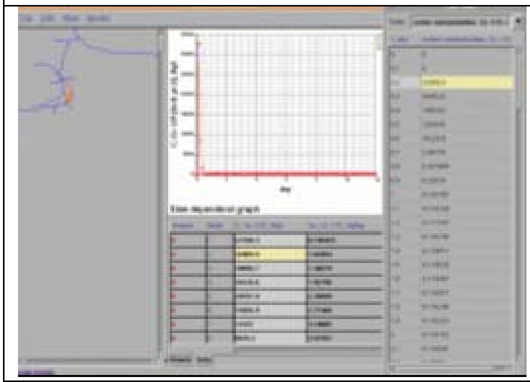
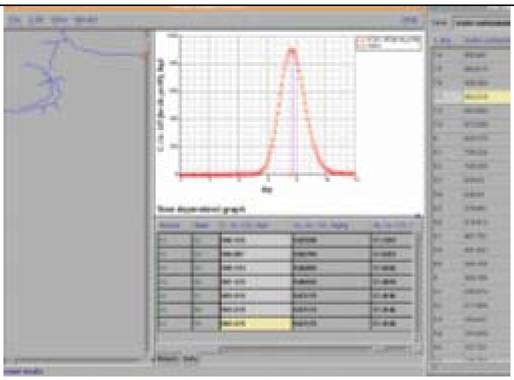

	

Fig.10 Cs-137 concentration in water on branch no.8, rain case	Fig.11 Cs-137 Concentration in water, branch no.24, rain case

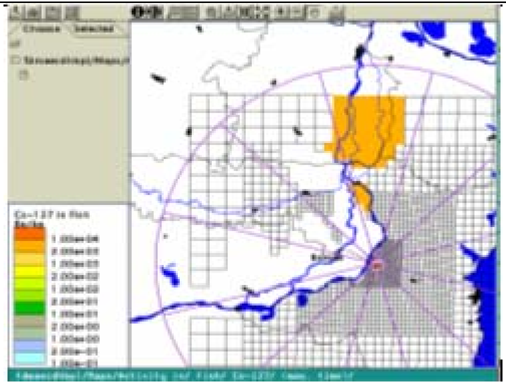
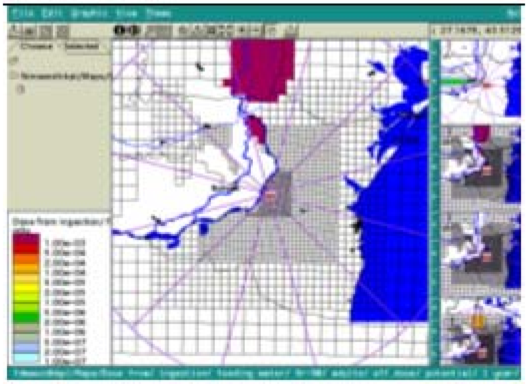
	

Fig.12 Cs-137 activity in fish, rain case	Fig.13 Dose from ingestion for Sr-90, rain case

Table 1. Cs-137 concentration (Bq/l) in water for maximum deposition on river area (cell 274-RODOS)

Duration (days)	RODOS	AQUASCOPE Mean value	AQUASCOPE Maximum value	AQUASCOPE Minimum value	MOIRA
0.2	3.20 E+04				1.18E+03
0.3	7.79 E+03	1.55 E+04	7.75 E+04	3.10 E+03	
0.4	1.32 E+03				
0.5	1.94 E+02	1.53 E+04	7.65 E+04	3.09 E+03	
0.6	2.77 E+01				
0.7	4.18				
0.8	0.93				
0.9	0.48				
1.0	0.41	1.49 E+04	7.45 E+04	2.98 E+03	
3.0	0.37	1.34 E+04	6.70 E+04	2.68 E+03	
5.0	0.37	1.20 E+04	6.00 E+04	2.40 E+03	
10.0	0.36	9.27 E+03	4.64 E+04	1.85 E+03	
30.0		2.83 E+03	1.42 E+04	5.66 E+02	5.83 E+02
60.0		8.83 E+02	4.42 E+03	1.77 E+02	1.50 E+02
90.0		3.39 E+02	1.70 E+03	6.68 E+01	5.79 E+01
120.0		3.06 E+02	1.53 E+03	6.12 E+01	2.40 E+01
150.0		2.64 E+02	1.32 E+03	5.28 E+01	1.26 E+01
180.0		2.49 E+02	1.25 E+03	2.99 E+01	7.85

Table2. Sr – 90 Concentration in water (Bq/l) for maximum deposition on river area (RODOS (cell 274) and MOIRA)

Duration (days)	RODOS RIVTOX – submodule	MOIRA
0.2	1.93 E+04	7.28 E+02
0.3	4.92 E+03	
0.4	8.74 E+02	
0.5	1.36 E+02	
0.6	2.02 E+01	
0.7	2.97	
0.8	0.49	
0.9	0.13	
1.0	0.08	
3.0	0.07	
5.0	0.07	
10.0	0.06	
30.0		3.13 E+02
60.0		6.86 E+01
90.0		2.45 E+01
120.0		1.04 E+01
150.0		6.18
180.0		5.05

Table2.1 . Sr – 90 Concentration in water (Bq/l) for maximum deposition on river area (AQUASCOPE)

Duration (days)	AQUASCOPE Mean value organic	mineral	AQUASCOPE Maximum value organic	mineral	AQUASCOPE Minimum value organic	mineral
0.2						
0.3	3.14 E+04	3.03 E+04	1.57 E+05	1.53 E+05	6.28 E+03	6.06 E+03
0.4						
0.5	3.11 E+04	3.01 E+04	1.56 E+05	1.51 E+05	6.22 E+03	6.02 E+01
0.6						
0.7						
0.8						
0.9						
1.0	3.04 E+04	2.94 E+04	1.52 E+05	1.47 E+02	6.08 E+03	5.88 E+03
3.0	2.77 E+04	2.67 E+04	1.39 E+05	1.34 E+05	5.54 E+03	5.34 E+03
5.0	2.53 E+04	2.43 E+04	1.27 E+05	1.21 E+05	5.06 E+03	4.86 E+03
10.0	2.02 E+04	1.92 E+04	1.01 E+05	9.60 E+04	4.04 E+03	3.84 E+03
30.0	8.53 E+03	7.53 E+03	4.27 E+04	3.77 E+04	1.71 E+03	1.51 E+03
60.0	3.01 E+03	2.04 E+03	1.51 E+04	1.02 E+04	6.02 E+02	4.08 E+02
90.0	1.70 E+03	7.39 E+02	8.50 E+03	3.70 E+03	3.40 E+02	1.48 E+02
120.0	1.44 E+03	4.88 E+02	7.20 E+03	2.44 E+03	2.88 E+02	9.76 E+01
150.0	1.31 E+03	3.69 E+02	6.55 E+03	1.85 E+03	2.62 E+02	7.38 E+01
180.0	4.27 E+02	3.39 E+02	2.14 E+03	1.70 E+03	8.54 E+01	6.78 E+01

The results

a. In the case of no rain, RIVTOX gives for Cs-137 concentration in water zero values in the Danube branch (no.11) further away from NPP, even the ADM results show a greater value for Cs-137 deposition (3.44 105 Bq/m2, cell 1073) on this place than the nearest branch (no.8) (7.72 102 Bq/m2, cell 273) (Fig.6-Fig.9) where the results of concentration have significant values.
b. In the case of rain when the deposition is much greater, the maximum ground deposition on branch no.8 for all tests have been used. The results for RODOS - HDM - RIVTOX are shown in Fig.10 and Fig.11.and some results of FDMA module are presented in Fig.12 and Fig.13.
c There are results presented for all programs used for Cs-137 and Sr-90 in Table 1, Table 2 and Table 2.1. One can see that AQUASCOPE gives the results for aquatic contamination from early stage to late stage of the accident (2 month), the HDM - RODOS can be used more properly for early stage and MOIRA for late stage (months)

Remarks

a. RODOS (PV5.0) gives the same values for Cs-137 and Sr-90 in exchange rates, decay coefficient, etc.
b. For time intervals grater than one day it is recommended to run also RETRACE submodule (in RODOS) to take into account the catchment area.
c. MOIRA uses the month deposition on ground and the release duration of this accident scenario is for ½ hour and the deposition reaches the maximum in 3-4 hours.
d. It is recommended to have a manual for RODOS and MOIRA explained how to make the customization of the systems including the addition of new radionuclides (for CANDU NPP, tritium is very important)
e. For the future a common emergency exercise for both systems (RODOS and MOIRA) could be useful in comparison of results between end-users and developers.
f. The AQUASCOPE gives the concentration in predatory and non-predatory fish, RODOS provides the concentration in fish in FDMA module.
g. It could be useful to recommend a set of default values for each radionuclide.
h. FDMA has to present the feedstuff and foodstuff only for radioecological selected region
i. The development of LCMA in RODOS system similar to MOIRA.

Future proposals and intentions of Romanian team for using DSS hydro systems:

- Having in mind that many NPP , potential nuclear pollutants, are situated on Danube river and its tributaries a complete stream of river is needed. A special database has to be developed by participation of all countries that are passed by the river and to solve the peculiar problems (dams, delta). This will allow to estimate the nuclear pollution whenever and wherever an accidental release could happen.
- A source term database for direct inflow of radionuclides from NPP could be developed
- The assessment of tritium accidental release consequences in Danube river has to be implemented in DSS hydro systems, as CANDU NPP is an important source of tritium. A first proposal was presented by Dr.D.Galeriu in Bucharest (EVANET-HYDRA 2nd Topical Meeting on “Rivers and Catchments
- The operation of DSS hydro systems in Nuclear Emergency Center and the connection with INMH for supplying the hydro data in real time.
- The analysis of opportunity to use RODOS – HYDRO DSS or MOIRA DSS in drills, exercises or accidental release depending on accident scenario or real situation for consequence assessment to support the decision makers.

References

1. EVANET-HYDRA 2nd “Topical meeting” 7-9 May 2003, Bucharest, Romania,(6th meeting of the network), Minutes of the Meeting
2. Customization of Aquatic Systems to Romanian Conditions, Dan Slavnicu, T.Craciunescu, D.Gheorghiu, IFIN-HH, ROMANIA,
3. Customization of DSS Aquatic Systems to Danube river – Romanian Segment , Dan Slavnicu, T.Craciunescu, D.Gheorghiu, IFIN-HH, ROMANIA , TRAC-RODOS course CD
4. EVANET-HYDRA. Experiences and Tests in Customization of Aquatic Systems in Romania. Dan Stelian Slavnicu, Dorina Gheorghiu National Institute of R&D for Physics and Nuclear Engineering “Horia Hulubei” IFIN - HH Romania. Presentation on EVANET-HYDRA 3-rd topical meeting, Sopot, 2004.

Experience with HDM customization in Slovakia

(by O. Slavik)

The RODOS-HDM consists of a number of interconnected hydrology modules. Each of them requires extensive sets of input data and model parameter adaptation describing specific initial and boundary condition characterizing the local site specific hydrological and radionuclid contamination related conditions. Moreover, the system works with spatial objects and areas such as river net, reservoir, irrigated areas, water withdrawal points on rivers that have to be geographically localised in a real geography space. In some cases outputs of one model in a specific location are used as input data for another HDM model and all such interconnection between modules have to be clearly defined.

Preparation of necessary input data and adaptation of model parameters describing specific site specific conditions, their integration into respective HDM modules together with testing and verification of the adapted HDM models were the basic tasks for HDM models customisation under site- specific geography and hydrology conditions in Slovakia. The customisation of RODOS HDM model in Slovakia was concentrated on part of river system in the catchments of Váh, Hron and Danube rivers affected by operation of the both Slovakian nuclear power plants (NPP): the Bohunice (EBO) and Mochovce (EMO) NPPs and the models: RIVTOX, RETRACE-D, COASTOX and LACECO. All the customisation steps carried out in Slovakia is documented in a detailed customisation report. The difficulties concerning RODOS-HDM model customisation under given national site-specific conditions are discussed here as well.

The highest number of tributaries were adopted by means of RIVTOX model in close vicinity of the mentioned NPPs in order to describe as close as possible the surface water runoff from lands around NPP contaminated by a possible post nuclear accident fallout. Two dimensional modelling of radionuclide transport by COASTOX model was focused on customisation of Králová Reservoir conditions on the Váh River, where the reservoir water is used for irrigation of nearby agricultural lands. Lake and fish ponds modelling by LAKECO model is concentrated to Mochovce NPP vicinity where small fish ponds are located in close distance to the NPP and also to affected subcatchments drained into respective ponds.

The RODOS hydrological modules assume establishment of a river network with respective geographical coordinates and hydrology parameters. In this context the fundamental of customising the hydromodules is to develop this river network and hydrological objects with site-specific geographical coordinates and associated hydrology parameters.
The basic module in the RODOS-HDM system is the 1D river channel network radionuclide transport model, RIVTOX. To this, a river basin runoff and radionuclide washoff model RETRACE-D is interconnected. By the river network coordinates, the associated river basin is geographically determined, as well. Therefore, very important is to generate a project database file necessary for starting the RIVTOX-RRETRACE graphical user interface (GUI) and the mentioned models itself, as well.

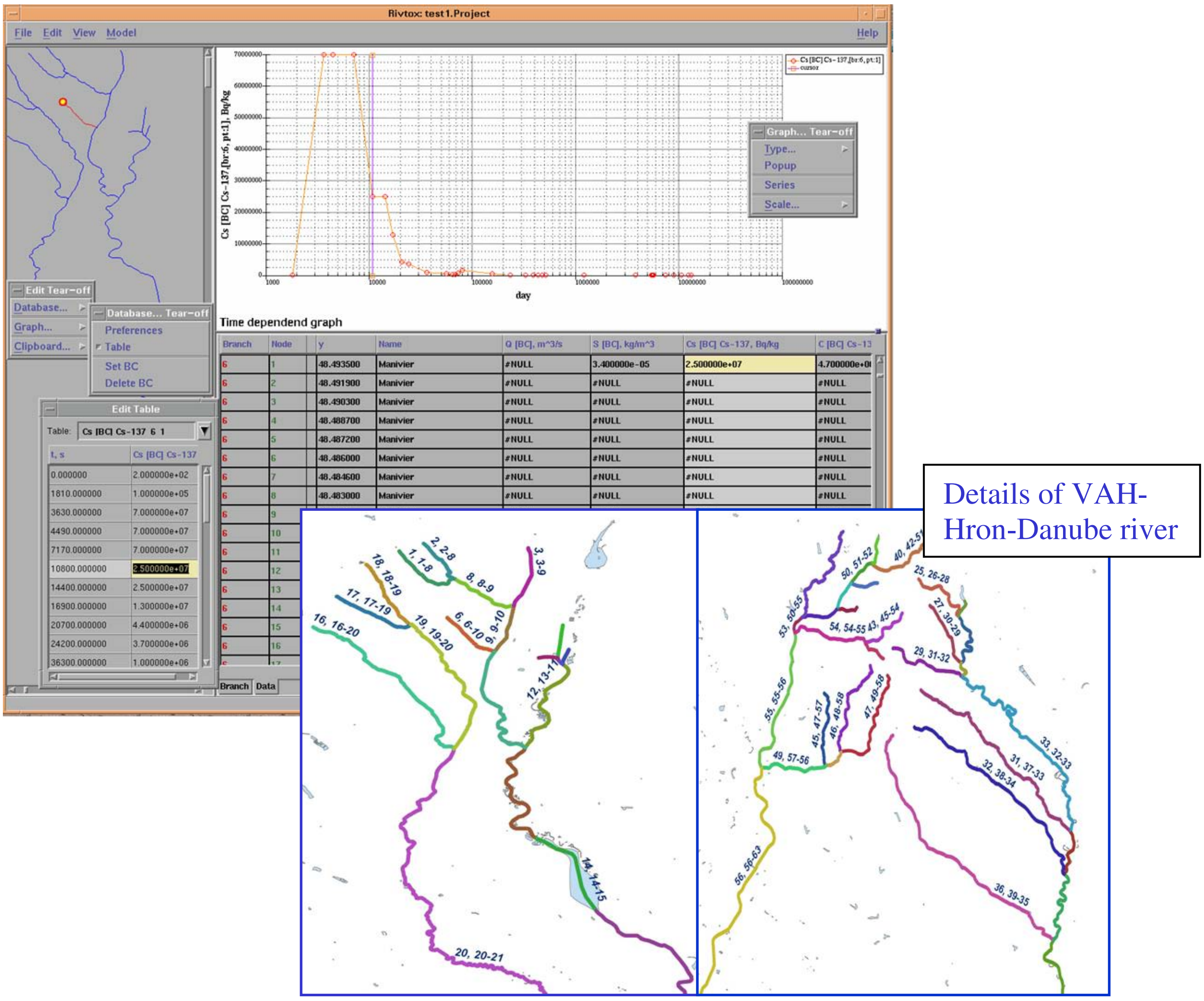
In the case of the RETRACE-D model, the situation is more complicated as a crucial change in the RODOS washoff modelling approach occurred during last development of the RODOS version 5.0 system. RETRACE developers instead of the original physical model RETRACE-2 (ver. 4.0) used a completely different conceptual model RETRACE-D based on the MIKE 11 water runoff model from DHI (Danish Hydrology Institute) and a newly re-evaluated radionuclide washoff model from Tajfune Co., Obninsk, RF. The consequence of these changes is the change in the approach to customisation of this model itself. A lack of required extensive input database for the RETRACE module customisation is typical. Therefore, it was necessary, firstly, to prepare the missing input databases and to integrate them into the RODOS database system together with adopted RIVTOX database. The most problematic part of this step is the creation of databases describing the interconnection between the river network and the particular parts of the river basin with respective water runoff and radionuclide washoff characteristics.
In the case of LAKECO model for radionuclide dispersion in lakes and its biotic and abiotic components, the customisation objective for this time period was only to prepare adequate input data and propose and test the procedures for their integration into the RODOS-HDM system. The POSEIDON models for shore parts of hydrosphere and THREETOX for 3D modelling of radionuclide transport in deep, or shore waters belong also to the hydromodels of RODOS, however, their adaptation was not planned, as these models are neither too much relevant, nor significant for Slovak conditions.
The objectives for addressing all these customisation tasks were to prepare necessary RODOS-HDM (PV 5.0) input databases, develop procedures for their integration to the system, and to test the electronical data generated and HDM-models adopted to site-specific Slovakian conditions.
The customisation task as a whole can be subdivided into a sequence of individual customisation steps. The following basic steps and partial activities were sequentially carried out during customisation of RODOS-HDM models in Slovakia:

1. Preparation of databases (for river net geography, topology, hydrology, sedimentology, meteorology) consisting of two stages:
    - data collection,
    - data formatting and conversion.
2. Integration of geographical data into RODOS system
    - geographical definition of applied river net and hydro objects (points, regions,)
    - model localisation (geography) with unit or default model parameters.
3. Integration of model parameter data into RODOS system
    - adaptation of model parameter (hydro, river topology, sediments, radionuclide sorption),
    - definition/adoption of basic initial and boundary conditions.
4. Testing of model databases and model functions by
    - overviewing via GUI,
    - reviewing continuity of displayed model data, ect.,
    - test model running with various scenario parameters.
5. Verification of model prediction results that requires:
    - definition and set of verification scenario with source term and boundary conditions (time step, scenario duration, type and dumping of release, mean or instantenous discharges on main channels and tributaries, sediment amounts, …
    - running and overviewing of verification scenario in GUI,
    - reviewing results, comparison with expected data (dilution, steady state conditions.for sorption, .ect.

In line with the previously collected databases, the RODODS PV 5.0 hydro models RIVTOX, RETRACE and COASTOX were adapted to the site-specific conditions at river basin of the created river network, Váh-Dudváh-Hron-Žitava-Danube, and the Kráľová Reservoir on the Váh River. Subsequently, testing of the

RIVTOX and COASTOX and FDMA modules was performed by means of a set of hypothetical unit parameters. Also verification of the RIVTOX and COASTOX models was carried out on the basis of comparison between simulated data and physically expected one for the model and site given. In the case of FDMA certain problems in identifying radio-ecological regions were identified and fixed during the testing effort.

The verification done in 2003 highlighted the fact that the results of calculations strongly depend on the values of certain model parameters for which no exact data are available - e.g., the value of sediment deposition rates (COASTOX, RIVTOX), the average amount of bottom sediments in the river bed (RIVTOX). These parameters were set for the Dudváh River on the basis of existing empirical data obtained during monitoring an accidentally elevated 137Cs discharges from the Bohunice Nuclear Power Plant (NPP) A1 (being under decommissioning). These values for the other then Dudvah river sections (e.g. Hron river) can be set more accurately only on the basis of processing and evaluation of future accidental monitoring data. Proper data assimilation techniques using the initial phase of an accidental data sequence seems to be appropriate for such adjusting of the mentioned model parameters.



Time dependend graph

Branch	Node		y	Name	Q [BC], m^3/s	S [BC], kg/m^3	Cs [BC] Cs-137, Bq/kg	C [BC] Cs-13
6	1		48.493500	Manivier	#NULL	3.400000e-05	2.500000e+07	4.700000e+0
6	2		48.491900	Manivier	#NULL	#NULL	#NULL	#NULL
6	3		48.490300	Manivier	#NULL	#NULL	#NULL	#NULL
6	4		48.488700	Manivier	#NULL	#NULL	#NULL	#NULL
6	5		48.487200	Manivier	#NULL	#NULL	#NULL	#NULL
6	6		48.486000	Manivier	#NULL	#NULL	#NULL	#NULL
6	7		48.484600	Manivier	#NULL	#NULL	#NULL	#NULL
6	8		48.483000	Manivier	#NULL	#NULL	#NULL	#NULL
6	9							
6	10							
6	11							
6	12							
6	13							
6	14							
6	15							
6	16							

Edit Table

Table: Cs [BC] Cs-137 6 1

t, s	Cs [BC] Cs-137
0.000000	2.000000e+02
1810.000000	1.000000e+05
3630.000000	7.000000e+07
4490.000000	7.000000e+07
7170.000000	7.000000e+07
10800.000000	2.500000e+07
14400.000000	2.500000e+07
16900.000000	1.300000e+07
20700.000000	4.400000e+06
24200.000000	3.700000e+06
36300.000000	1.000000e+06

Fig. 1 Vah-Hron-Danube project.file as seen in RODOS-RIVTOX GUI, PV5.0

Suggestions for future development of RIVTOX:

- Develop special SW tool for:
  - facilitating a change of the created river net (add, remove tributaries,, now it is a laborious procedure);
  - conversion of 2D to 1D cross section data for river reservoirs;

    - performing basic testing procedures for complex river nets (summing rule, water flow continuity, ...) .

- Performing basic testing procedures for complex river nets (summing rule, water flow continuity, ...) .

- Adopt available GIS and hydrostatistical data to facilitate initial customisation of the model (make the use of RIVTOX more user friendly, cheaper and not requiring so much hardly available input data)

References:

1. Experience in RODOS-HDM v. 5.0 customisation in Slovakia,*Slavik O.,* TRAC-RODOS-HDM Training course, Arnhem, the Nethwerlands, 2003
2. Slávik, O., Miceková P., Integration of Databases into RODOS Hydrological Dispersion modules undre the Slovakian conditions, DAONEM FIKRT-CT-2000-005 project report RODOS(RA5) -TN(04)-03.

Experience with MOIRA as applied to the Hungarian section of the Danube

(by G.Kocsy and A. Kerekes)

Since the Danube is the most important river in Hungary, moreover, the Hungarian NPP uses its water for cooling, we adapted MOIRA to the Hungarian section of the Danube as a tool of decision support for a nuclear accident.

The first step was to define the separate segments of the river and to determine the runoff values and the catchment areas to each of them. The river was divided into 13 segments as shown in Fig. 1.

The runoff values and catchment areas were determined using the above map, taking into account the topographical features of the territory, so that each segment has a more or less well defined subcatchment. The result is shown in Fig. 2 and Fig. 3.

The morphological data of the Danube were provided by the Water Resources Research Centre (VITUKI), where cross sections of the river at every 1-2 km as well as linear sections are recorded. The average width of each segment was determined using the cross sections, while the average depth was determined from the linear sections as shown in Fig. 4.

The morphological characteristics of the segments are shown in Table 1.

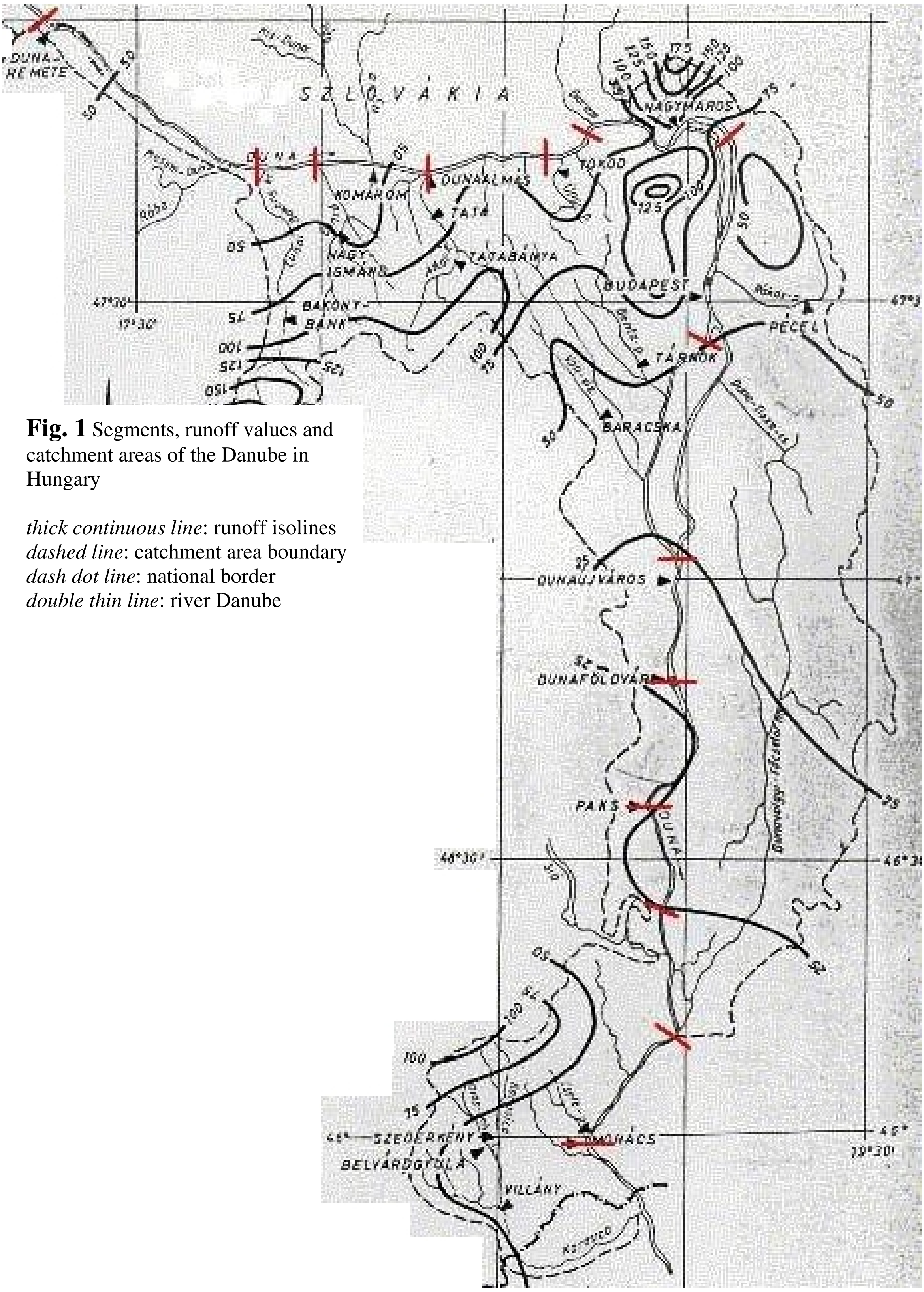


Fig. 1 Segments, runoff values and catchment areas of the Danube in Hungary

thick continuous line: runoff isolines
dashed line: catchment area boundary
dash dot line: national border
double thin line: river Danube

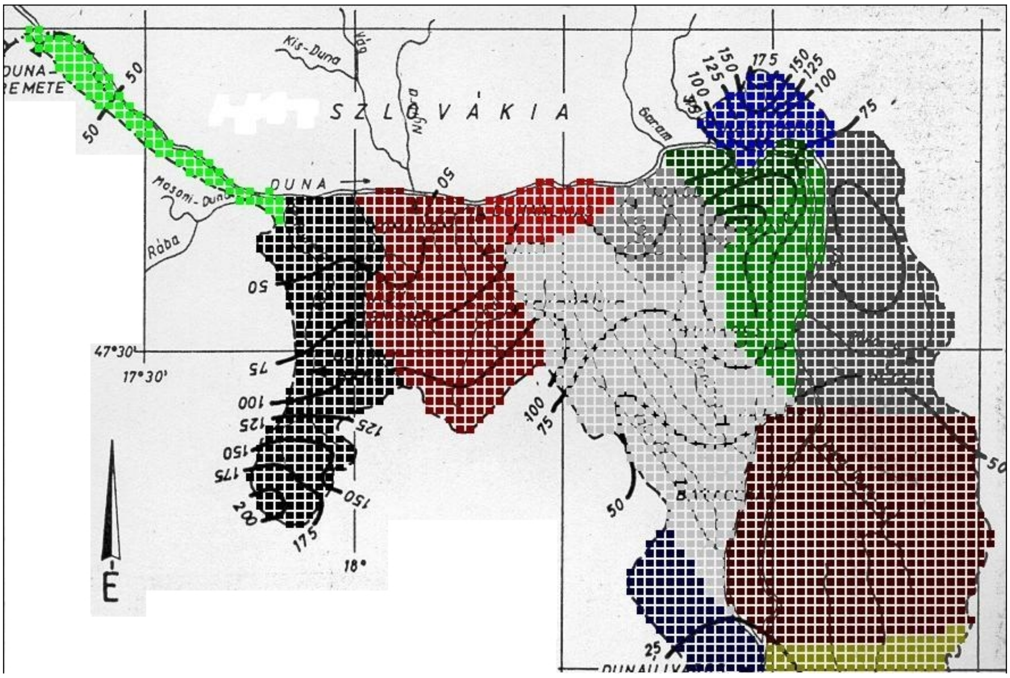


Fig. 2 The catchment areas of the northern segments of the Danube

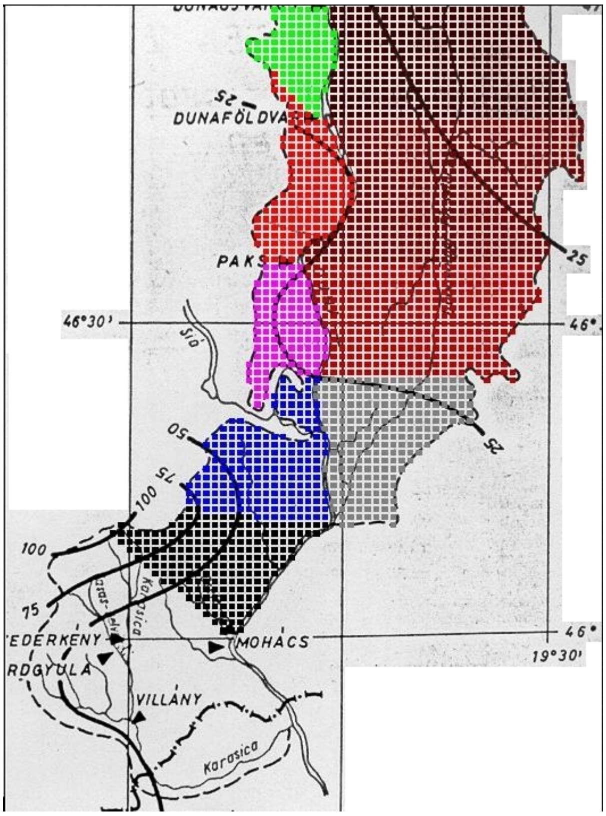


Fig. 3 The catchment areas of the southern segments of the Danube

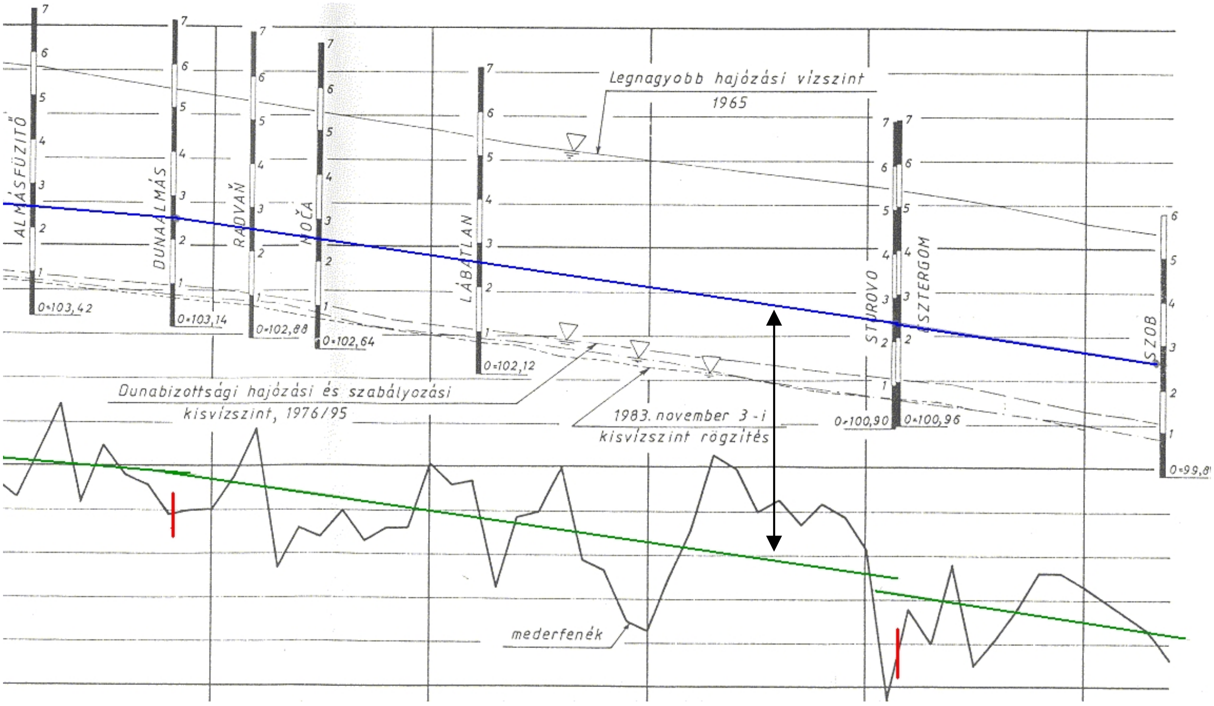


Fig. 4 A short linear section of the Danube, the mean depth of the segment is shown by the arrow (red line: segment boundary, blue line: mean water level, green line: parallel line to the mean water level that best fits into the river bed)

Table 1 The morphological characteristics of the segments

	length (km)	width (m)	depth (m)	left catchment (km^2)	right catchment (km^2)
1st segment	57.1	900	5.5	0	231
2nd segment	14.6	430	6.5	0	902
3rd segment	24.9	485	6	0	911
4th segment	23.6	500	6	0	190
5th segment	9.7	670	6	0	303
6th segment	39	510	6	240	225
7th segment	42.6	400	6.5	955	451
8th segment	50.7	460	6	1673	1525
9th segment	25.6	450	5.5	1267	590
10th segment	29.3	480	6	1371	433
11th segment	24.6	450	8	997	338
12th segment	28.1	440	9	682	564
13th segment	31.8	440	9.5	0	602

Since the spring of the Danube is not in Hungary, we applied the water flow at the beginning of the first box, which was $1.18 \cdot 10^9$ m^3/month. Other environmental data were also provided by VITUKI. Socioeconomic data were found in the reports of the Central Office for Statistics.

As a realistic scenario we estimated the contamination of the Danube after the Chernobil accident. Therefore we chose 1986 as the simulation time and we applied fallout data from that year. Fallout data for May are shown in Table 2 (fallout for any other months was taken as zero). We chose direct input rate to be zero for all the boxes and months. (It probably leads to underestimation as the fallout in some parts of Germany and Austria was significant, too.)

The results of the simulation is shown in Fig. 5. The peak value of about 0.3 Bq/L is in the region of the measurement data for Danube following the accident.

The individual and collective doses to the population on the total catchment area of the Danube in case of „No actions" are summarized in Table 3 and 4.

Table 2 Fallout data after the Chernobil accident in May 1986 (Bq/m^2/month)

	left catchment area	river	right catchment area
1st segment	3200	3200	3200
2nd segment	3200	3200	3200
3rd segment	3200	3200	3200
4th segment	3200	3200	3200
5th segment	3200	3200	3200
6th segment	5700	5700	5700
7th segment	5700	5700	5700
8th segment	5700	5000	4400
9th segment	1700	3000	4400
10th segment	1700	1500	1200
11th segment	1700	1500	1200
12th segment	1700	1500	1200
13th segment	1500	1500	1500

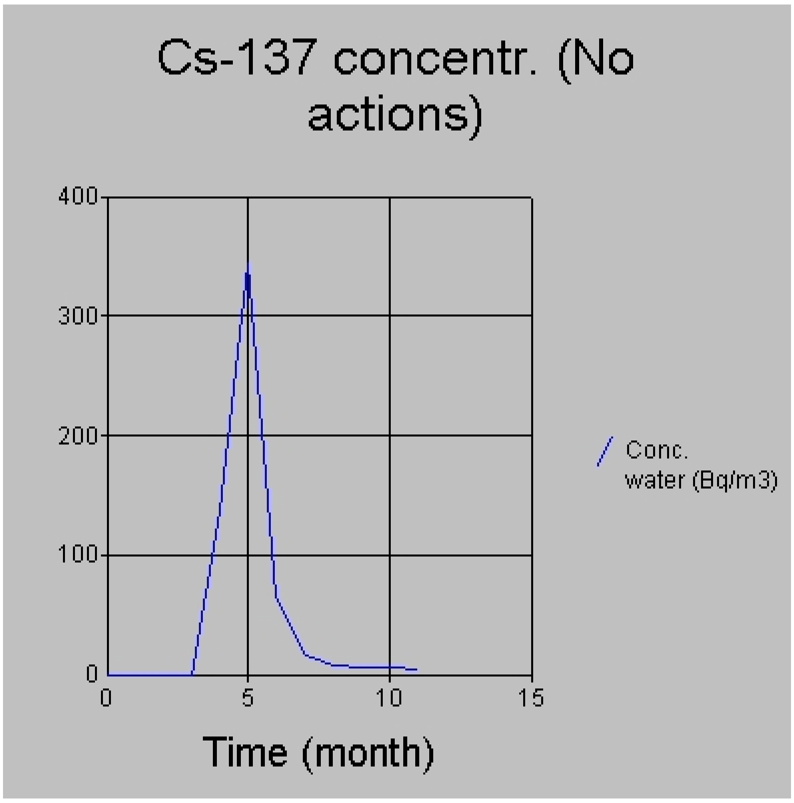


Fig. 5 Cs-137 concentration in the 13th box in case of „No actions" strategy

Table 3 Collective doses (No actions)

External dose (man.mSv)	35.4
Dose from intake water (man.mSv)	441
Dose from intake fish (man.mSv)	2.78
Dose from intake crops (man.mSv)	54.2
Dose from intake animal pr. (man.mSv)	0.636
Dose from ingestion (man.mSv)	498
Total dose Cs (man.mSv)	534

Table 4 Total doses (No actions)

Dose to critical individuals (mSv)	3.75e-003
Total collective dose (man.mSv)	534
Maximum dose to fish (mGy)	0.276

Recommendations

The Help of the software should be completed with the following topics:

- meaning of the data in the chemistr.txt file
- instructions on how to fill the database in case of less than 20 boxes
- meaning of the „Reload RiverDataBase data to the user interface" menu

Some parameters should be more clearly defined/explained:

- runoff values – do they mean the average values or the values right at the bank of the river?
- ice cover – does this refer to the average thickness of the ice cover?
- yield of animal products – which area of land should be in the denominator?
- water treatment and fish processing limits
- input for poultry consumption data is missing.

Also, the River Database could be a bit more user friendly.

Recommendations received as result of DSS software demonstrations during EVANET-HYDRA meetings

During the 1-st topical meeting of the EVANET_HYDRA the following improvements for the MOIRA lake models with the corresponding changes on the MOIRA user interface had been identified :

- "MOIRA predicts the outflow on the basis of algorithms related with the geographical and morphological properties of a lake and its catchment. An improvement of MOIRA could be is that the user cannterfere via the user interface to overrule these predictive submodels. Modification for modelling closed lakes by implementing the possibility to set the outflow to zero for closed lakes, even when a significant inflow is calculated by a sub-model".

Answering to questionnaire distributed after 1-st topical meeting the potential users has expressed interest to the using of EVANET software as possible systems for both operative use and training of the personal.

The following improvements for the HDM had been suggested:

- The refinement of the User Guides and development of the Customisation Manuals

- Possibilities for multi-level data input
    - The requirements for the input data should be formulated in HDM on the multi-level approach:
    - Level 1: – the requirements for the data sets providing the most efficient operation of a model.
    - Level 2: - simplified data sets with the maximum use of the default parameters and relations to be used in situation of a lack of the resources to collect the full data set as indicated in Level 1.
    - The model interfaces should contain the possibility to utilise the default and simplified data of the level 2.
- Appropriate model chain definition
- Scenarios for model testing
    - The users should receive together with HDM software well-developed scenarios, which will illustrate all possibilities of the HDM models and the operation of the model chain.
- Connection of HDM to national hydrological forecasting systems

After the 1-st topical meeting the questionnaire had been distributed among users – participants of EVANET-HYDRA. The following improvements to the software had been suggested as the answers to questionnaire:

- MOIRA

- Providing expert guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario (ranked as very important)
- Providing possibility to start simulation taking into account time-series describing experimental data for some of the parameters such as contamination in the lake water (ranking as important)
- Include tritium in the list of calculated radionuclides
- Providing additional formats of the summary report (now HTML only) such as MS Word document and PDF document

- RODOS-HDM
    - Nuclide group calculated in HDM should correspond to the RODOS default nuclide group
    - Ag-110m need to be calculated
    - Guidelines for HD modules adaptation to specific scenarios need to be prepared
    - Detailed description of the necessary (and optimum) local data sets for the COASTOX model need too be prepared
    - Quick guideline which enables to start negotiations which potential local data providers need to be prepared

- AQUASCOPE.

    - Add tritium to the list of radionuclides calculated by AQUASCOPE.

During the 1-st “short visit” meeting (Sweden) MOIRA (Version 2.2) and web-site http://user.tninet.se/~fde729o/MOIRA had been demonstrated to the representatives of Swedish Radiation Protection Board (SSI) and Swedish Rescue Board (SRSA). The tools received positive evaluation by the potential end-users.

The following end-user suggestion had been noticed:

- ”It has been generally recognised that an important short-term issue in the case of a nuclear emergency is the management of water supply”.

- According to the SRSA in case of future use of MOIRA in Sweden a possible “configuration” could provide the use of MOIRA software by SSI, while County Administrative Boards could supply the data related to the accident and obtain, in return, suggested recommendations .

Configuration of MOIRA proposed by SRSA may require development of the distributed system based on the main “MOIRA – server” and multiple “MOIRA-client” interfaces to prepare data and preview the MOIRA reports.

References:

EVANET-HYDRA Technical Report on First Topical Meeting "Lakes and Reservoirs"

EVANET-HYDRA 1st “Short visit” 13-14 February 2003, Nyköping, Sweden, (4th meeting of the network), Minutes of the Meeting

Suggestions for MOIRA improvement by Ukrainian Hydrometeorological Institute

(by O.Voitsehovich and S.Todosiyenko, Ukrainian Hydrometerological Reserach Institute, Kiev,Ukraine)

The suggestions of the MOIRA users of Ukrainian Hydrometeorological Institute can be summarised as follows:

- MOIRA need to have possibility to start from measured data of concentration in the water (sediments) starting the modelling of concentration in water at the end of given data
- System need the possibility to use time-dependent discharge data
- Importing/exporting functions need to be improved
- Start from initial contamination data (data assimilation procedures)

These suggestions had been presented during bilateral meeting between Studsvik and UHMI in Kiev and reported to EVANET-HYDRA members during 1-st EVANET-HYDRA coordination meeting.

References:

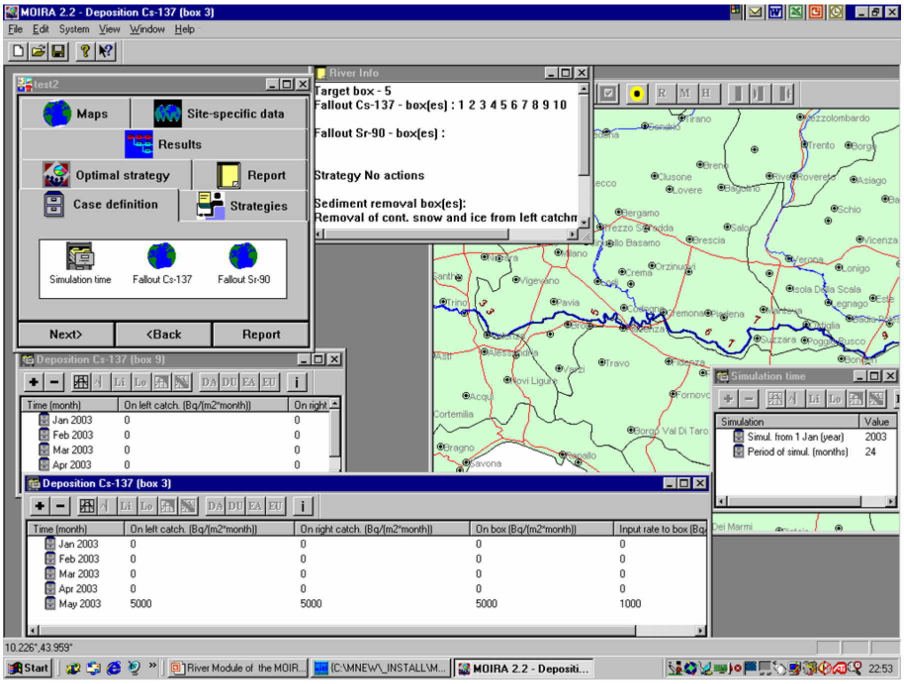
EVANET-HYDRA 1st Coordination Meeting 23-24 October 2002, Madrid, Spain,(3rd meeting of the network), Minutes of the Meeting

Exercises in customization of MOIRA DSS performed by its developers

During EVANET-HYDRA project Studsvik and ENEA has performed and presented the implementation (using only tools and methods available for end-users) in the MOIRA software:

- of test scenario 2 of EVANET-HYDRA 2nd topical meeting (Figure 1)
- Prp’at scenario (joint meeting EVANET-EMRAS) . (Figure 2)

Geographical data for the River Po and Prip’at river had been included in the MOIRA GIS and connected with the morphometrical, hydrological and run-off data described for the "test" rivers. The “World map” data set has been used in order to get MapInfo map with the river topology and background information. During the implementation the map of the river had been sent as .gif file to ENEA in order to identify the boundaries of the “river model boxes”. The problems encountered during the customisation was that boundaries of the suggested “boxes” sometimes was bigger or smaller that segments presenting river in MapInfo database. In this case redrawing of the segment polyline had been used.



Target box - 5
Fallout Cs-137 - box(es) : 1 2 3 4 5 6 7 8 9 10

Fallout Sr-90 - box(es) :

Strategy No actions

Sediment removal box(es):
Removal of cont. snow and ice from left catchn

Deposition Cs-137 (box 9)

Time (month)	On left catch. (Bq/(m2*month))	On right
Jan 2003	0	0
Feb 2003	0	0
Mar 2003	0	0
Apr 2003	0	0

Simulation time

Simulation	Value
Simul. from 1 Jan (year)	2003
Period of simul. (months)	24

Deposition Cs-137 (box 3)

Time (month)	On left catch. (Bq/(m2*month))	On right catch. (Bq/(m2*month))	On box (Bq/(m2*month))	Input rate to box (Bq
Jan 2003	0	0	0	0
Feb 2003	0	0	0	0
Mar 2003	0	0	0	0
Apr 2003	0	0	0	0
May 2003	5000	5000	5000	1000

Figure 1

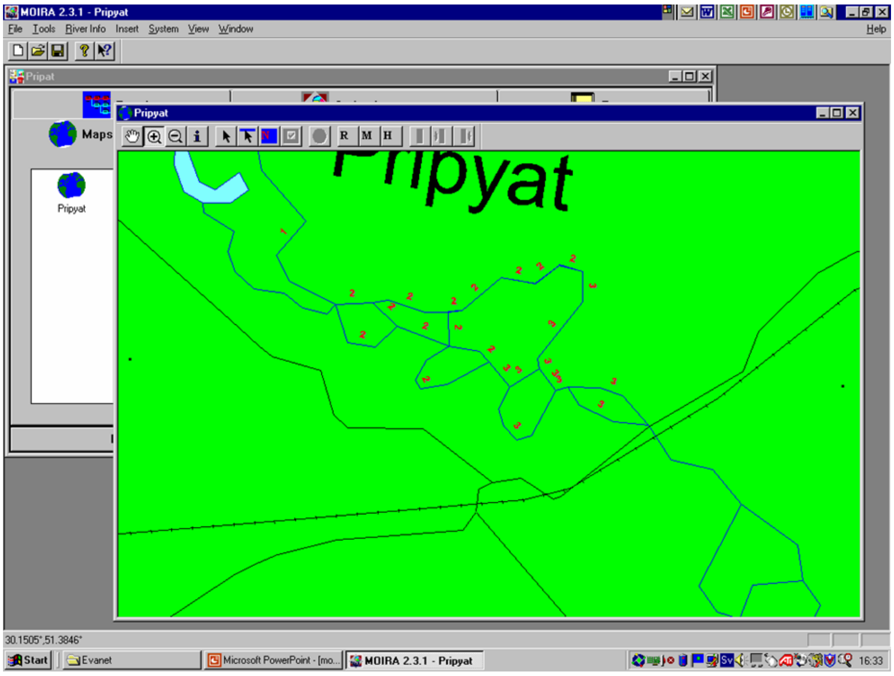


Figure 2

During the preparation of the exercise preformed by UPM during 2-nd plenary meeting of EVANET-HYDRA is was recognised that it is necessary to introduce in MOIRA the possibility to reflect results and input countermeasure data for the more than 200 month period (in order to implement realistic scenario flowing Chernobyl fallout to lake). This feature was realised by Studsvik in MOIRA 2.3.1 used for the exercise.

Further tests performed by UPM on user level (and reported during the 2-nd “short visit” meeting of EVANET-HYDRA) demonstrated the necessity of revising of the mechanism for the keeping consistency between input and output data in order to make it user-friendlier.

SECTION 3. PLANNING OF IMPROVEMENTS IN THE DSS SOFTWARE

General considerations

The main sources of the planned improvements in the DSS software were user suggestions, summarised in Table 2.1.

In order to identify long-term improvements necessary for the DSS the questionnaire aimed to help in ranking of the importance of the different aspects and features of the software according to the practical needs of the users. The questionnaire was based on criteria identified in the document. “Assessment by the user of the software for management of contaminated fresh-water systems” (Annex 1). The questionnaire did not include references to the particular software – the features are enumerated using evaluation criteria, current common features of the “EVANET’s” software, possible future software features based on the analysis of the state-of-art. Answering the questionnaire, the users “constructed the ideal DSS” by ranking (0-2) the importance of proposed features or selecting one of the possible alternatives. These answers were useful for the planning further development of the DSS as they specify users preferences and their vision concerning optimal architecture, appearance and performance of EDSS software. The Tables showing the results of questionnaire are presented in Annex 2

The main suggestions of the users can be categorised as follows:

- Increasing the number of radionuclides taken into account into DSS
- Increasing help in decision support via implementation of modules for built-in uncertainty and sensitivity analysis of the results
- Increasing the volume of information presented by DSS to the users
- Decreasing the time required for the DSS site-specific and scenario-specific data implementation, in particular decreasing of the volume of data required for DSS site- and case- specific implementation
- Decreasing the time and costs required for the DSS setting-up and installation.
- Further development of the DSSs GUI as tool for the presentation both static and dynamic information
- Increasing of models speed performance
- Development of a common basis for easy communication between different DSSs both on local computers and via networks.
- Providing constant documentation and internet-based support for the users

During discussion and presentation of EVANET-HYDRA the following general suggestions were applicable for all DSS had been selected to fulfil the requirements:

Decreasing the time and costs required for the DSS installation may be attained by:

- Using (as GIS and modelling engines) open source software or commercial software already available for most users.
- Adapting software for the widely distributed hardware platforms and operating systems
- Increase end-user possibilities to customise all aspects of the DSS
- Applying easy installation procedures

Decreasing the time required for the DSS site-specific data implementation may be attained by:

- Supporting DSS with collection of default values and ranges for input parameters
- Automated receiving of data from GIS-based data sources (MapInfo and ArcView) available for the end-user

Decreasing the time required for the case-specific data implementation may be reached with:

- Direct transfer of time-dependent data (such as fallout and countermeasures data) from popular applications such as MS Excel
- Improvement of the friendliness of input of long time-series
- Getting real-time data from on-line sources

Improvements planned in MOIRA DSS

The production of MOIRA Version 3 was planned during the EVANET second "short visit" meeting (Studsvik). MOIRA 3 will be based on the significant updates in software and models done by MOIRA developers during 2004 and reported during the 2nd "short visit" meeting of EVANET-HYDRA.

The following long-term improvements had been planned for MOIRA DSS:

- Modelling long-lived radionuclides other then Cs-137 and Sr-90
- Improvements in MOIRA software and manuals in order to increase friendliness of the procedure of site-specific customisation for river scenarios, in particular further development of the GIS-like user interface tools for the visualisation and editing of the spatially distributed data related to the river scenarios
- Increasing MOIRA availability by producing own redistributable GIS and modelling engines
- Further developments of the LIANA Model Integration System (the kernel software of MOIRA Software Framework) to allow quick and easy integration of different types of models
- Further development of MOIRA in order to support the exchange of data with other applications both locally and by networks.
- Introducing of the built-in tools for uncertainty analysis and data assimilation

To simplify future possible expansion of MOIRA with new models it is planned to transform MOIRA Software Framework (MOIRASF) into a "shell" application allowing the integration of new model completely without making changes in the framework's source code – only by means of the description and configuration files. This is achieved [Hofman 2004] in particular by substitution of MIL_LIANA data sets descriptions used in MOIRASF at present time to data class definitions on LIANA language [Hofman 1999]. Data class definition in LL can contains the following sections:

Produces – class members available for access from other Data objects. Only these values will be saved to the data set.

Private – class members not available for access and not stored in persistent form.

Needs – the other objects (data sets), which must be prepared before execution of the command described in *Realization*. Conditional creating of the certain data objects can be specified by using "if" statement. Creating of an object described by the LL class (with the non-empty *Needs* section) will automatically construct the necessary chain of models.

Realization – command which starts external model. The output file of this model contain the data defined in section *Produces*. Alternatively, *Realization* can contain a message issued to the user or statements for pre-processing data from other data sets (specified in *Needs*) followed by SAVE command.

Represented – LL statements or a MIL_LIANA format specification for exporting or importing data set information (given in *Produces* section) to or from I/O file of the model.

Table – MIL_LIANA format of the table presenting a given data set in the user interface.

New classes related to implementation of LL and their associations with present classes of LIANA Model Integration System (see (Section 1, MOIRA, Fig. 9) are shown in Fig. 1.

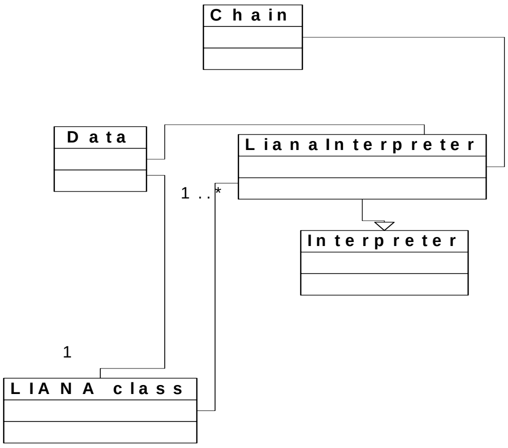
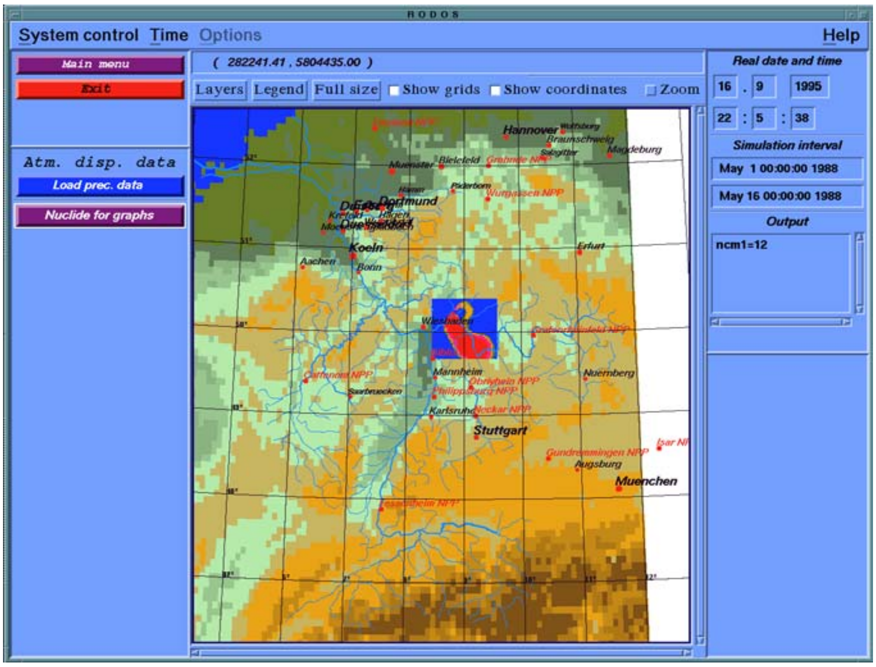


Figure 1

In modern IT word where data are distributed over local and global networks it is necessary to develop the possibilities of MOIRA for network-based exchange of the data. Such a development will require to extend MOIRASF with the possibility to import and export data in XML format, import GIS data in formats issued by OpenGIS consortium, as well as support of COM, CORBA, Web Services and emerging OpenMI [Blind, Gregersen 2004] standards.

HYDROD framework [Gofman, 1995, Marinets et. al. 1996, Hofman 1996] (Fig. 2) demonstrated during EVANET-HYDRA “short visit” meetings was evaluated as potential basis for the future development of the MOIRA own GIS engine. It can be used to eliminate usage of MapInfo package in MOIRA DSS as according to communication with the users they are not always able to bye a MapInfo Pro. Further development of HYDROD as general-purpose open source GIS and GUI system for the EDSS is evaluated by D.Hofman. The HYDROD code was designed for Unix platform supporting X-Windows. It had been developed using C language and uses only X-Window and Motif libraries so transfer between HP platform where it was originally developed and other available Unix-based OS (such as Linux or Solaris) should not be difficult. Using and further development of HYDROD on Windows platform (in particular as GIS system for the MOIRA DSS) is available with the support of free software Cygwin.



(282241.41 , 5804435.00)

Real date and time: 16 . 9 1995 22 : 5 : 38

Simulation interval: May 1 00:00:00 1988 – May 16 00:00:00 1988

Output: ncm1=12

Figure 2

References

Gofman D., Zheleznyak M. Development of the user interfaces for the decision support systems for protection of syrface water against radioactive contamination “AQUATORY” and “RIVTOX”. In: Computational technologies, Novosibirsk, Institute of Computational Technologies RAS, 1995, v. 4 N10, pp. 141 - 148 (in Russian).

Marinets A., Gofman D., Zheleznyak M. Using GIS for modelling radionuclide transport in complex river-reservoir network. In: HydroGIS 96: Application of Geographical Information Systems in Hydrology and Water Resources Management (Proc. of Vienna Conf. 1996) – IAHS Publ. – 1996 – N 235, pp. 325 – 330

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Hofman , D. LIANA Model Integration System - architecture, user interface design and application in MOIRA DSS. 2004, Advances in Geoscience. In press

Improvements planned in RODOS-HDM

The short-term development of the several features of RODOS-HDM is planned in the frame of EURANOS project [1]:

Deliverables Phase 1 (2005)

A Development of a new version of the coastal model POSEIDON-R which includes a dynamic foodchain model

- Functional specification document of the dynamic marine foodchain model for the integration into POSEIDON
- Dynamic marine foodchain model, integrated into POSEIDON-R at month 12
- Technical report on validation of POSEIDON with test data for chosen seas (Baltic Sea, North Sea, Black Sea)
- Modified POSEIDON model integrated into RODOS PV 7

B Interfacing with national hydrological models

- Functional specification document of the software tools for the interfaces with the national hydrological models
- Database with the possibility to exchange information between the HDM and national hydrological models
- Prototype version of RIVTOX model with separated hydrodynamics and radionuclide transport modules
- Technical reports about the functionalities of national run-off models and the possibility to couple national run-off modules with the HDM of RODOS
- Technical report about the comparison study between the two possibilities of using national hydrological models or the models integrated into RODOS as basis for the calculation of the transport and dispersion of radionuclides in rivers

C Improvement of the operability of the hydrological model chain of RODOS

- Functional specifications document of the improved models, GIS-based customisation tools, new numerical algorithms and graphical user interfaces
- Prototype software to allow an easy customisation of the transport models and the watershed characteristics for the run-off model
- Prototypes of the revised transport modules with the full Saint Venant equation and code for shallow water movement
- Integration of the new version of RIVTOX into RODOS PV 7.0
- Integration of the new version of COASTOX into RODOS PV 7.0
- Integration of the new customisation tools into RODOS PV 7.0

Deliverables Phase 2 (2006 and later)

B Interfacing with national hydrological models

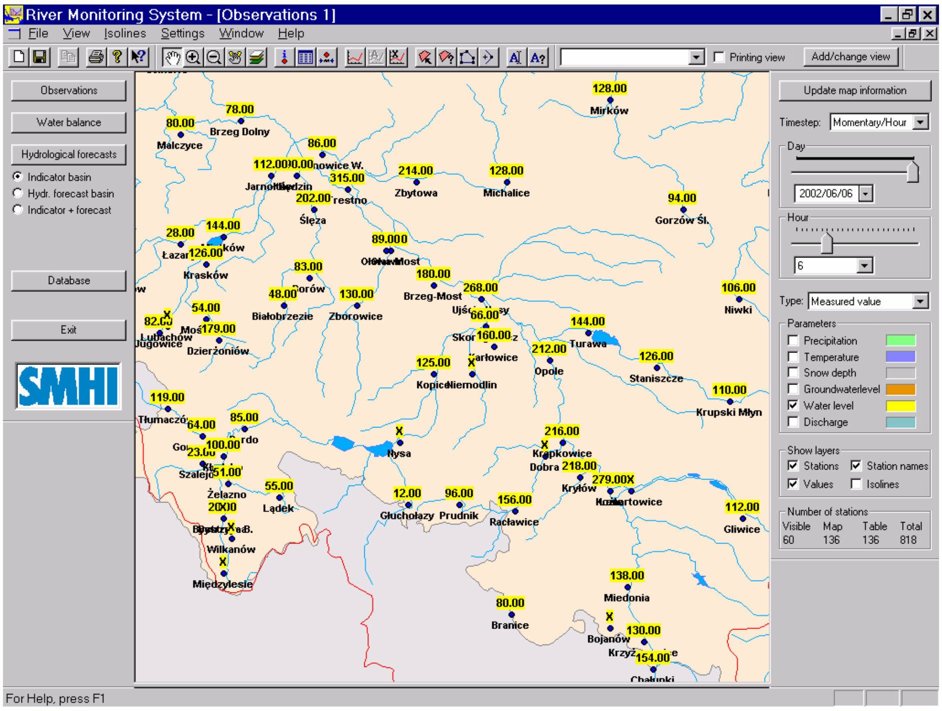
- Functional specifications document of the data interfaces and software tools to access and use data from the JRC ECIS
- Functional specifications document of the software tools for interfacing of the RETRACE-DR with the distributed water balance model LISFLOOD of the JRC EFAS
- Database with the possibility to exchange information between the HDM and European Catchment Information System
- Prototype software to allow the use of the distributed water balance model LISFLOOD of the JRC European Flood Alert System as basis for the models of radionuclide transport in rivers

C Improvement of the operability of the hydrological model chain of RODOS

- Functional specifications document of the refined THREETOX model
- Prototypes of the revised 3-D model TREETOX for estuaries
- Technical report on HDM testing for transboundary basins
- Functional specifications document of the extensions and redesign of the HDM GUI for Linux OS and Web-based RODOS environment
- Updated graphical user interface for Linux and the Web based RODOS environment

- Improved GUI for the presentation of results in the emergency centre (after the demonstration)
- Integration of new HDM models and software tools into Rodos PV 8

According to [2] the important goal of HDM-RODOS development in FP6 is defined as development of software tools for HDM coupling with national hydrological forecasting systems (Figure 1) and with EFFS/EFAS (Figure 2) data bases and models.



Timestep: Momentary/Hour

Day: 2002/06/06

Hour: 6

Type: Measured value

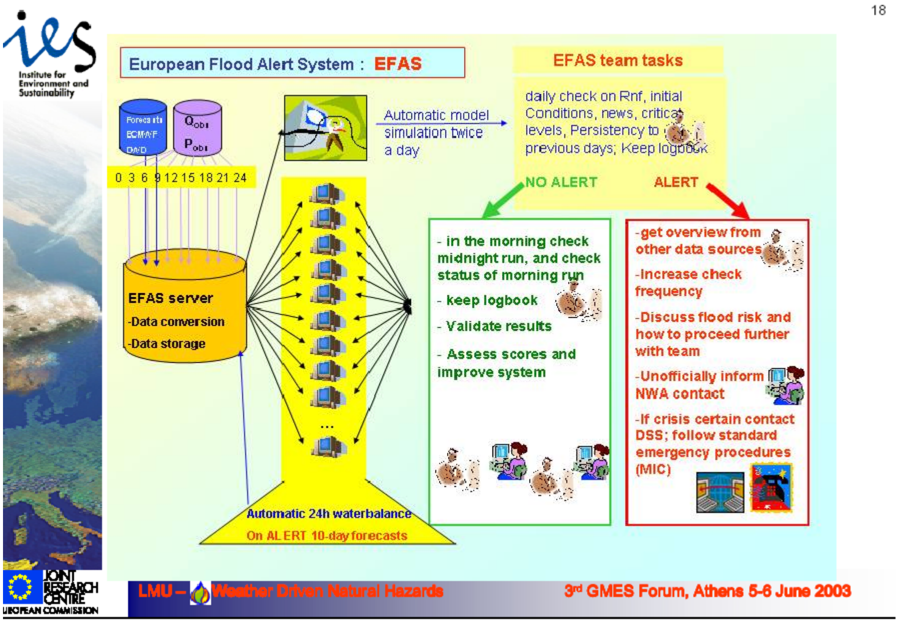
Parameters
☐ Precipitation 🟩
☐ Temperature 🟦
☐ Snow depth ⬜
☐ Groundwaterlevel 🟧
☑ Water level 🟨
☐ Discharge 🟦

○ Indicator basin
○ Hydr. forecast basin
○ Indicator + forecast

Show layers
☑ Stations ☑ Station names
☑ Values ☐ Isolines

Number of stations			
Visible	Map	Table	Total
60	136	136	818

Figure 1. Polish River Monitoring System [3]



European Flood Alert System : EFAS

Automatic model simulation twice a day

EFAS server
-Data conversion
-Data storage

Automatic 24h waterbalance
On ALERT 10-day forecasts

EFAS team tasks

daily check on Rnf, initial Conditions, news, critical levels, Persistency to previous days; Keep logbook

NO ALERT
- in the morning check midnight run, and check status of morning run
- keep logbook
- Validate results
- Assess scores and improve system

ALERT
-get overview from other data sources
-Increase check frequency
-Discuss flood risk and how to proceed further with team
-Unofficially inform NWA contact
-If crisis certain contact DSS; follow standard emergency procedures (MIC)

Figure 2 European Flood Alert System

Among other advantages receiving of the hydrological data on-line can help to satisfy user requirements enumerated in the Section 2 by decreasing of the number of parameters required to perform site-specific customisation and to introduce new scenario data and by increasing of the models speed performance.

There are a set of improvements planned in HDM software kernel and user interface . These improvements are intended to advance the current status of the system:

- Standalone version of models
  - RIVTOX
  - RETRACE
  - LAKECO
  - THREETOX
  - COASTOX
- XWindow user interface
- Interaction with RODOS system (ADM/FDMA)
- File-based data projects

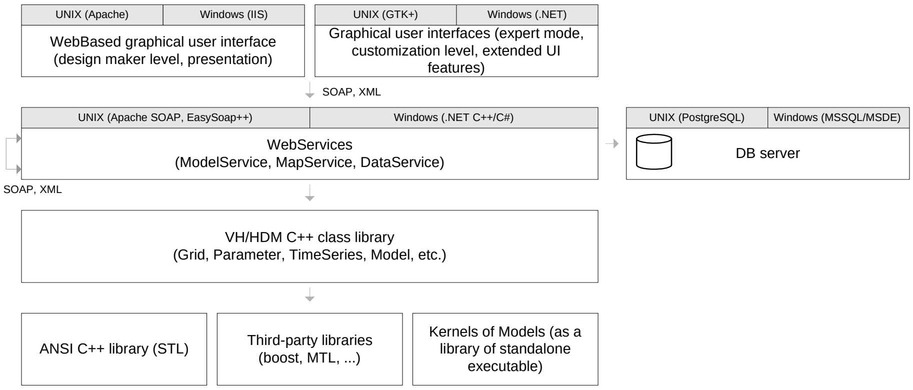
and resolve the following problems currently present in the system:

- Lack of the common DB
- Usage of different approaches for graphical interfaces of different models
- Complicated customization of models
- Complex interaction between models
- Only XWindow, desktop-style graphical user interface

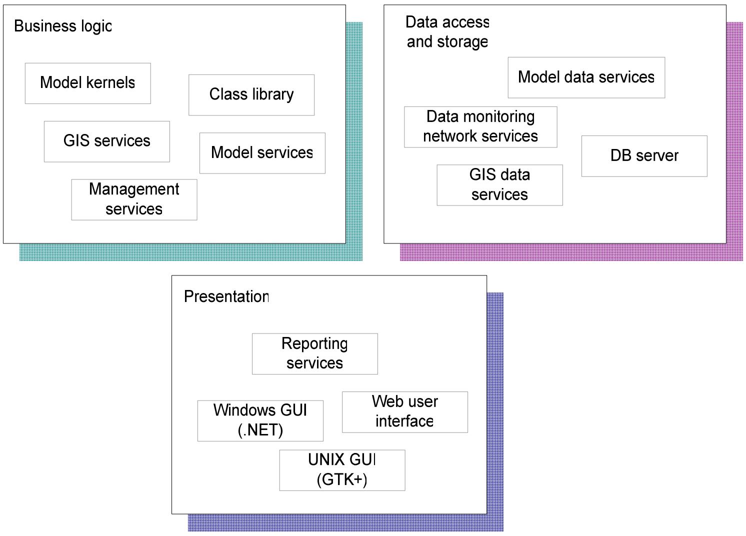
The flowing improvements are planned

- Creation of portable common class library for common logic such as models data manipulation, grids logic (creation, intersection, data manipulation), time series, etc.
- Development of common system Database and use it for monitoring, models, environmental data storing and management
- Usage of the distributed technologies on the base of SOAP architecture for creation of system components/services
- Usage of the XML for interaction between service components and system
- Development of Windows/UNIX GUI tools for services management, models customization
- Creation of design-maker level Web-based tools to work with models, view results

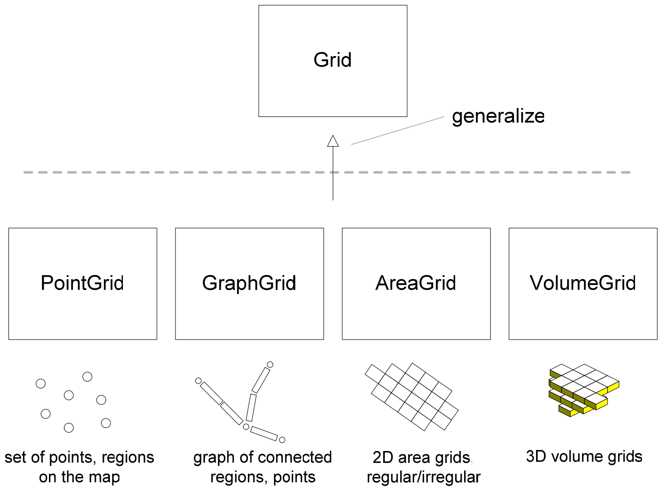
System architecture



Main system components, architecture levels



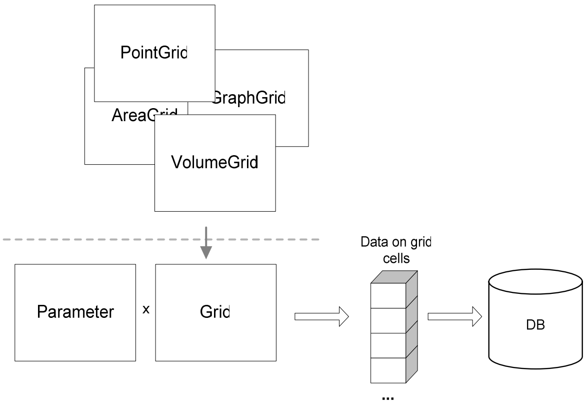
Development of common components for different grids of models



Unification of data and models manipulation

- Usage of unified methods to store and manage input/output data of different models as value of some **Quantity** on some **Element** (model mesh element) of some spatial **Grid** of the model
- Use the same system components and methods to work with different **Models** which work on some **Grids**
- Unify interaction between different models and make it possible to define and use different scenarios of model chains

Data storing for some parameters of some models



Plans for development

- System class library
- DataBase design and implementation
- WebServices for models, system, data, GIS

- Model specific components/services, models integration
- UNIX/Windows based GUI/tools development
- Web-based GUI development for reporting and monitoring

Another improvements planned in the RODOS-HDM is the introducing of advanced build-in GIS possibilities in the HDM user interface. This is in particular connected with the evaluation of the possibilities of using open source tool PostGIS.

References

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2. L.2. Introduction into Hydrological Modelling, *M. Zheleznyak, Materials of TRAC-RODOS-HDM course, Arnhem, the Netherlands, 2003*
3. Hydrological data available in Poland for RODOS-HDM, *A. Kadłubowski, Materials of EVANET-HYDRA 3-rd topical meeting* Spot, Poland, 2004

Improvements planned in CASTEAUR

The prototype version (CASTEAUR v0.0), developed under Visual Basic for Excel, proposes a simplified one-dimensional model dedicated to short and average terms assessments (some hours to some days). Some improvements are proposed in the new version (CASTEAUR v0.1) currently developed (this software had been demonstrated during 2-nd plenary meeting (Arnhem)). The objectives are to extend the domain of application and to improve the interface functionalities and the performances as, for example, the calculation times.

Extension of the domain of application

The application domain is extended to medium- and long-term periods (from several days to several years) and a doses model will be implemented. For longs temporal scales the sediment plays a fundamental role on the radionuclides transfers. In function of the local and hydraulic conditions, this compartment can accumulate (deposition), rapidly be released (flood event), slowly exchange (diffusion) or definitively stock (consolidation) radionuclides. So, CASTEAUR v0.1 proposes a dynamic box model (currently developed in the framework of a PH D work) including a strong coupling between hydraulics, sedimentary dynamics and radionuclides transfers. For the biotics components the model stay quasi-similar to this of the prototype.
Always in the context of long-term assessments, the filiations processes could become non-negligible for some radionuclides. These processes are also included in the model.

To maintain the capacities of this new version in the range of the short and average terms assessments, CASTEAUR v0.1 will propose also a one-dimensional model based on an extension of this box model. This extension will consist mainly to add the dispersion processes to obtain finest spatial and temporal resolutions.

Technical improvements

CASTEAUR v0.1 is developed with a C++ language and an oriented object structure where the main functionalities (data managements, calculations functions and results analysis) are implemented in independent classes. This structure will make easier the implementation of the futures developments.
The performances are improved by the use of a C++ language and the implementation of implicit numerical schemes.
About the interface, the experience return of the prototype has allowed to identify some improvements and to provide high level of the user friendliness.

Improvements planned in AQUASCOPE

A new version of the AQUASCOPE software will be produced in March 2005, with the following improvements:

1. Improvement in sediment sub-model
2. Improvement in fish uptake sub model for strontium
3. Revision of User Manual
4. Improvement in presentation of graphical output. Removal of bug which produces a spurious error message.

Design principles for the establishing of the network of the integrated DSS for the management of radionuclide contaminated aquatic areas

As result of the evaluation done in the frame of EVANET-HYDRA, a new issue, **integration** has become apparent. It was emphasised that the users would like to use **MOIRA and RODOS-HDM as the complimentary decision support systems** using RODOS-HDM as the short-term assessment and MOIRA for the long-term assessment and countermeasure evaluation. In this case of using both systems in the same emergency centre establishing of the automated network data exchange between them can simplify decision making and data input procedures for the users. Realisation of such an exchange will require introducing of new modules in MOIRA and RODOS HDM supporting the general-purpose data exchange middleware such as sockets or Web Services or software specially designed for EDSS model integration such as OpenMI [Argen 2004, Bling, Gregersen 2004].

In broader view (taking into account flexible methods of model integration implemented in MOIRA and RODOS-HDM) such a connection will give a unique possibility to implement transparent data exchange, not only between MOURA and HDM, but also between all the DSS evaluated in the frame of EVANET-HYDRA. This will both help to establish **network of the integrated DSS for the management of radionuclide contaminated aquatic areas** allowing user to select proper tool for each task and increase possibilities of each individual DSS by easy on-line accessing of data, models and tools which are not available in standalone mode.

In the frame of WP 4 the prototype schema for the software architecture necessary for DSS linking was designed (Figure 1). The main ideas of the proposed architecture are:

1. It is necessary to establish data exchange between MOIRA and HDM by introducing in these systems functionality necessary to support one of the data exchange standards (such as for example Web Services or OpenMI).

2. Other models and DSS could be integrated either with MOIRA or HDM (depending whether model was developed in Windows and Unix environment respectively) using methods of integration already used in MOIRA or HDM. MOIRA and HDM in this case will function like a “bridges” between different models and data sources on the Windows and Unix system respective.

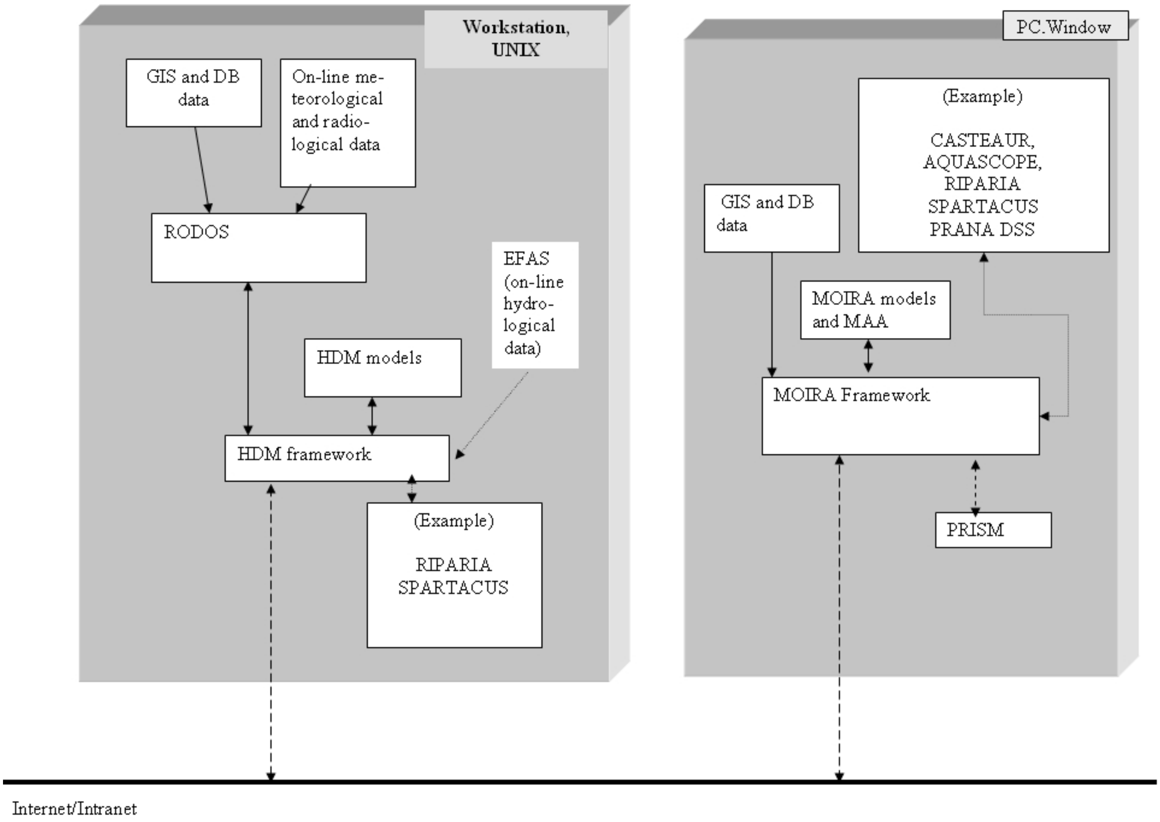


Figure 1 Software architecture for communication between DSSs.

References:

Argent R.M. An overview of model integration for environmental applications—components, frameworks and semantics, Environmental Modelling & Software, Volume 19, Issue 3, March 2004, pp. 219-234

Blind M., Gregersen J. Towards an Open Modelling Interface (OpenMI) – The HarmonIT project.In Pahl-Wostl, C., Schmidt, S. and Jakeman, T. (eds) iEMSs 2004 International Congress: "Complexity and Integrated Resources Management". International Environmental Modelling and Software Societey, Osnabrueck, Germany, June 2004.

CONCLUSIONS

1. Evaluations of the decision support systems performed in the framework of the EVANET-HYDRA have shown that current releases of the MOIRA, RODOS-HDM, AQUASCOPE, AQUASTAR, RIPARIA and SPARTACUS are ready-to-use and available tools for solving of end-users' practical tasks related to the predicting of the migration of radionuclides in the aquatic environment. CASTEAUR is available for the end-user as the prototype tool.

2. EVANET-HYDRA evaluations and exercises allowed specification (implementation already undertaken in some cases) of the short-term improvements necessary in each DSS, as well as correctly identifying directions for long-term improvements.

3. As result of the evaluation made in the frame of EVANET-HYDRA, a new issue, integration, has appeared. It was recognised that support of the automated run-time data exchange between MOIRA and RODOS-HDM would be simplified using these two systems as the complimentary tools. Taking into account the high flexibility of model integration already present in MOIRA and RODOS-HDM, such a connection would allow easy "binding" of all the DSSs evaluated in the frame of EVANET-HYDRA and would help to establish networks of integrated DSS for the management of radionuclide contaminated aquatic areas.

Annex 1 Criteria for the assessment of software in the field of decision support for radionuclide contaminated aquatic ecosystems.

Type of software

1. Model (code)
    a. Predictive environmental model
    b. Dose assessment model
    c. Economic model
    d. Cost/benefit analyses (e.g. CBA, MAA)

2. Data (experimental data, experience (including reports), maps)

3."User Interface + system" - Tools for entering data, pre-processing, visualisation and execution of the model. These tools could be "home-made" or commercial programmes (for example ArcInfo, Powersim, MS Access, MS Excel) or "standard" tools supplied together with operating systems, such as text editors.

4. Modelling application or CBA/MAA application is the combination of software from categories one and three (1+3)

5. Data base/GIS application (2+3)

6. GIS-based model (1+2+3)

7. Computerised Decision Support System (Several models + 2-6 acting as unit system)

Users of the software:

1. Developer of the software (using software to answer requests of decision makers).

2. Expert in the field "covering" by application, but not developer.

3. Decision maker.

4. Advanced user – non-expert ("operator")

Requirements

1. Platform
    - PC
    - Unix workstation
    - Macintosh
    - Platform-independent Java application
    - Web application
2. OS
    - Windows 95/98/NT/2000
    - Unix , Linux
    - MacOS

3. Hardware requirements
    - Processor
    - Disk space
    - Memory
    - Special devices
    - Internet connection
    - Leased line connection

4. Additional software required:
    For example Internet Explorer,
    ArcInfo, MapInfo, Powersim.

Installation

1. Method of distribution (tape, diskette, CD, downloading from Internet)
2. Installation program

Documentation

1. End-user documentation
    - User's Guide
    - Installation Guide
    - On-line "Help" system
2. Data description
3. Guides for the separate models

Support

1. Updates of software and documentation
2. Web site, newsgroup, forum
3. User's group

User interface:

1. Real world metaphor
2. Style
    - Dialog-based
    - SDI (single document interface)
    - MDI (multiple documents interface)
    - Explorer-like
3. Look
    - Windows style
    - Motif style
4. Components:
    - Data input
    - Graphical data presentation
    - Presentation of the geographical information
    - On-line presentation of the modelling process
    - Presentation of the data alternatives (scenarios, countermeasure strategies)
    - Report creating

Data

1. Way to store data
    - Workspaces (projects, scenarios, solution boxes)
    - Data base, GIS

2. Data description
    - type ("non-spatial data" ,"spatial data", "time-series")
    - general content (name of table or layer);
    - attribute or field names;
    - units
    - the role or function in the model (e.g. model parameter, boundary or initial conditions, calibration or validation data, model results, additional "background" data)"

3. Data integrity (data consistency for each workspace)

Site-specific implementation

1. Data distributed together with software
2. Site.specific changes in data in the data base and

GIS - procedure, required tools and user skills

Integration with other applications locally or through network

1. Connection with other applications

    - Clipboard
    - Unix IPC (interprocess communication)
    - Windows IPC
    - COM/DCOM
    - CORBA
    - Files

2. Automation possibilities

    - Build-in language
    - OLE Automation

3. Running programme/accessing data with Internet/local network/Intranet

Stability

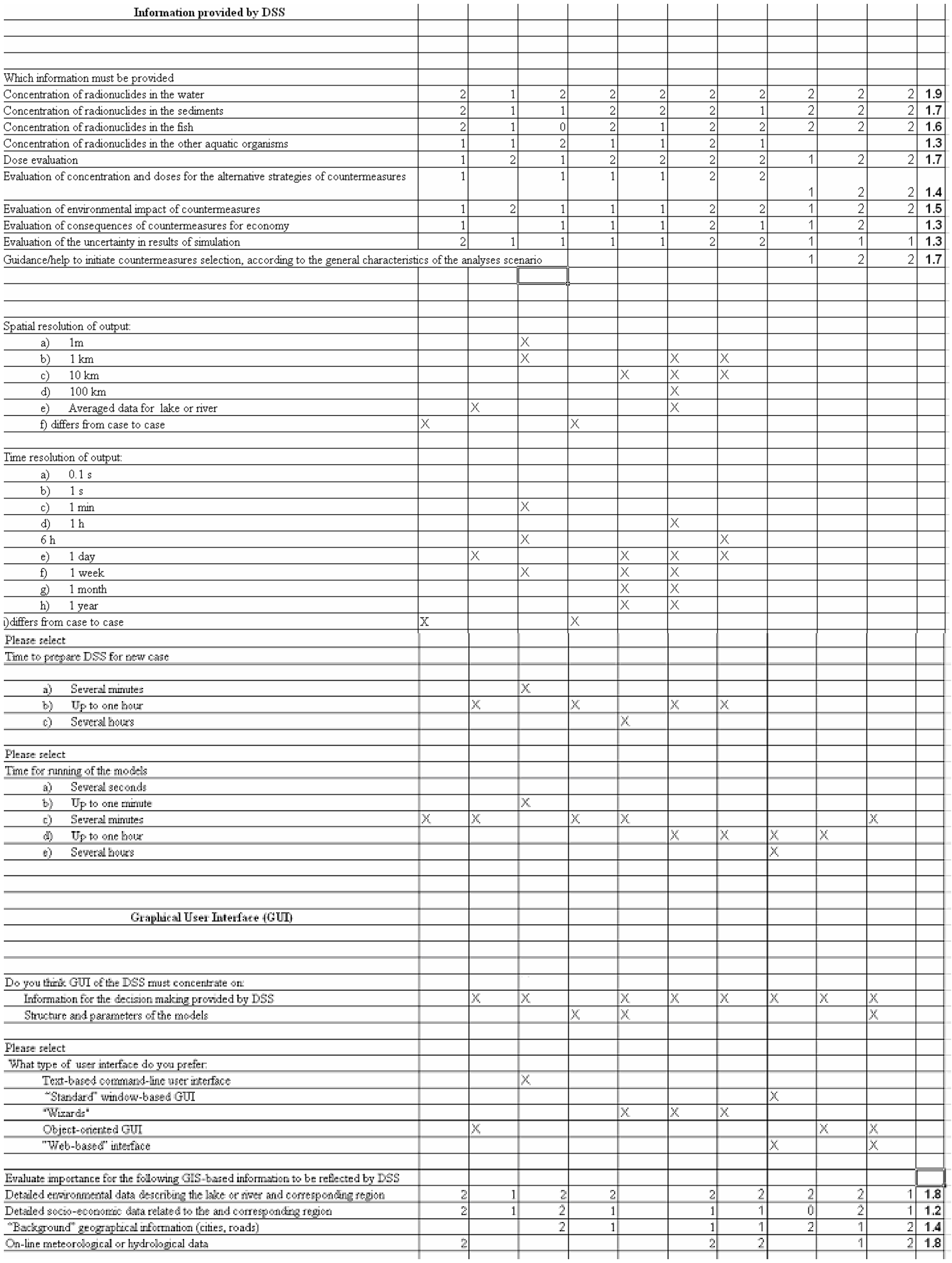
1. Routines implemented to avoid user errors (especially in input data)
2. Routines implemented to react to possible problems in calculated results
3. Routines implemented to react to resource-related problems (such as for example insufficient disk memory)
4. Routines implemented to react in the case that some components (e.g. GIS supporting software) are not installed

Software development quality

1. Flexibility (possibility to change data , components, functionality by end-user (without recompiling of the software))
2. Architecture
3. Methodology of development
4. Programming languages and tools
5. Software development process

Annex 2 End- user requirements for DSS software (answers to questionnaire “Criteria for the assessment of the software for management of contaminated fresh-water systems)

Proposed features of the EDSS had been evaluated by 10 users with the scale 0-unimportant , 1 –important, 2-very important



Information provided by DSS											
Which information must be provided											
Concentration of radionuclides in the water	2	1	2	2	2	2	2	2	2	2	**1.9**
Concentration of radionuclides in the sediments	2	1	1	2	2	2	1	2	2	2	**1.7**
Concentration of radionuclides in the fish	2	1	0	2	1	2	2	2	2	2	**1.6**
Concentration of radionuclides in the other aquatic organisms	1	1	2	1	1	2	1				**1.3**
Dose evaluation	1	2	1	2	2	2	2	1	2	2	**1.7**
Evaluation of concentration and doses for the alternative strategies of countermeasures	1		1	1	1	2	2	1	2	2	**1.4**
Evaluation of environmental impact of countermeasures	1	2	1	1	1	2	2	1	2	2	**1.5**
Evaluation of consequences of countermeasures for economy	1		1	1	1	2	1	1	2		**1.3**
Evaluation of the uncertainty in results of simulation	2	1	1	1	1	2	2	1	1	1	**1.3**
Guidance/help to initiate countermeasures selection, according to the general characteristics of the analyses scenario								1	2	2	**1.7**
Spatial resolution of output:											
a) 1m			X								
b) 1 km			X			X	X				
c) 10 km					X	X	X				
d) 100 km						X					
e) Averaged data for lake or river		X				X					
f) differs from case to case	X			X							
Time resolution of output:											
a) 0.1 s											
b) 1 s											
c) 1 min			X								
d) 1 h						X					
6 h			X				X				
e) 1 day		X			X	X	X				
f) 1 week			X		X	X					
g) 1 month					X	X					
h) 1 year					X	X					
i)differs from case to case	X			X							
Please select											
Time to prepare DSS for new case											
a) Several minutes			X								
b) Up to one hour		X		X		X	X				
c) Several hours					X						
Please select											
Time for running of the models											
a) Several seconds											
b) Up to one minute			X								
c) Several minutes	X	X		X	X					X	
d) Up to one hour						X	X	X	X		
e) Several hours								X			
Graphical User Interface (GUI)											
Do you think GUI of the DSS must concentrate on:											
Information for the decision making provided by DSS		X	X		X	X	X	X	X	X	
Structure and parameters of the models				X	X					X	
Please select											
What type of user interface do you prefer:											
Text-based command-line user interface			X								
"Standard" window-based GUI								X			
"Wizards"					X	X	X				
Object-oriented GUI		X							X	X	
"Web-based" interface								X		X	
Evaluate importance for the following GIS-based information to be reflected by DSS											
Detailed environmental data describing the lake or river and corresponding region	2	1	2	2		2	2	2	2	1	**1.8**
Detailed socio-economic data related to the and corresponding region	2	1	2	1		1	1	0	2	1	**1.2**
"Background" geographical information (cities, roads)			2	1		1	1	2	1	2	**1.4**
On-line meteorological or hydrological data	2					2	2		1	2	**1.8**

How important is the presentation of the following run-time information via GUI											
Please indicate 0-unimportant, 1- important, 2 – very important											
Model which is currently in run		1	1	1	1	1	1	2	2	2	**1.3**
"Modeling time" passed for the current model		1	2	1	0	1	1	1	1	1	**1**
Parts of the chain of models which are currently passed/left		2	1	1	1	1	1	0	2	2	**1.2**
Run-time changes in the results produced by the current model		1	1	1	1	1	1	0	1	1	**0.9**
Run-time changes in "internal" parameters of the current model		2		1		1	1	0	1	1	**1**
			2								**2**
Automation											
Evaluate importance of the following functionality to be supported:											
Please indicate 0-unimportant, 1- important, 2 - very important			1								**1**
Possibility to run DSS or separate tasks in interactive mode		1	2	1	2	2	2				**1.7**
Possibility to run DSS or separate tasks in automated (batch) mode		1	2	1	2	2	2	1	2	2	**1.7**
Possibility to define tasks to be run in batch mode by the end-user		1		1	1	2	2	1	2	1	**1.4**
Site- specific implementation of DSS											**2**
Input to DSS must be characterised by low number of environmental parameters			1	1	2	1	2				**1.4**
Input to DSS must be characterised by low number of socio-economic parameters			2	1	2	1	2				**1.6**
Possibility to access default values for the unknown environmental and socio-economic parameters			1	2	2	1	2	2	2	1	**1.6**
Possibility to access ranges (min and max values) for the parameters			2	1	2	1	1	2	2	2	**1.6**
Support of the DSS with tools for converting data from available GIS, CAD or data base formats to DSS formats				1	1	2	2				**1.5**
Support of the DSS with set of sub-models to estimate unknown environmental parameters			1	1	1	1	1	2	2	1	**1.3**
Support of the DSS with collections of GIS-based environmental and socio-economic information for the major European lakes and rivers				1	1	0	2	2	1	1	**1.1**
What time for the preparing of DSS with the new site-specific data is acceptable for the solving of your practical tasks:											
a) Up to one hour				X							
b) Several hours			X	X			X				
c) Up to one day			X			X					
d) Several days					X						
e) Up to one month											
Support and documentation											
Estimate importance of the following support-related aspects											
Documentation			2	2	2	2	2	2	2	2	**2**
Training courses			2	1	2	2	2				**1.8**
Example scenarios provided by software developers			1	1	1	2	1	2	2	2	**1.5**
Using local language for the software user interface and documentation				1	1	1	0	1	1	1	**0.9**
Direct e-mail connection with the software developers			2	1	1	1	1	0	2	2	**1.3**
Information about current updates in software with web-site			1	1	1	1	1	1	1	1	**1**
Information about current updates in software with mailing lists			1	1	0	1	2	2	2	2	**1.4**
Web-based tools to give possibility for the user to describe problems discovered				1	0	1	1	1	1	1	**0.9**
Newsgroup				1	0	1	1	1	1	0	**0.7**
Bulletin board			2	1	0	1	1	1	1	1	**1**
List of frequently asked questions			2	1	1	1	2	1	1	1	**1.3**
Availability of the full software installation via the Internet			2	1	1	1	2	1	1	1	**1.3**
Availability of the software demo version with Internet			2	1	0	1	1	1	1	1	**1**
Availability of the "service packs" with Internet				1	1	1	2	1	2	2	**1.4**
Compatibility of the DSS with IT system of your organisation											
What hardware platform and OS are preferable for you for the using as platform for the DSS?											
PC	X	X		X	X	X	X	X	X		
Workstation							X	X	X		
Apple											
Low requirements for hard disk space			1	1	0	1	1	0	0	0	**0.5**
Low requirements for memory			2	1	0	1	1	0	0	0	**0.6**
Low requirements for processor speed				1	0	1	2	0	0	0	**0.6**
Costs for the 3-rd party software											
Please select											
a) No cost			X				X		X	X	
b) low costs					X	X		X			
c) moderate costs				X							
d) high costs											

Annex 3. Software aspects of the MOIRA, RODOS-HDM, CASTEAUR, AQUASCOPE, SPARTACUS (answers to questionnaire “Assessment by the developer of the software for management of contaminated fresh-water systems[6]”)

Software features of the MOIRA DSS

General information

Specify what information is provided by your DSS to the decision maker:

Detailed information about concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Run-time information (during execution of the chain of the models) about changes in concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Evaluation of the uncertainty in results of simulation	X
Guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario	For “social” countermeasures only
Detailed description of the sequences of each strategy of the countermeasures in the terms of doses received by population , sequences for the environment and economic costs	X
Detailed information about process and results of multi-attribute analysis comparison of alternative strategies	X
Short summary of the data, strategies and results in the form of report	X
Detailed environmental data describing the lake/river or reservoir and corresponding region	X
Detailed socio-economic data related to the and corresponding region	X
"Background" geographical information (cities, roads)	X
Detailed description of each strategy of countermeasures	X

Specify which information is required for your DSS

Definition of the case (e.g. fallout data)	X
Definition of the alternative strategies of countermeasures	X
Environmental data describing lake/river or reservoir and corresponding region	X
Socio-economic data describing the region	X
Real-time hydrological and meteorological information	

Site- specific and scenario-specific implementation

Please select:
DSS will be used to manage several selected lake/rivers of the specific region (country)
DSS must be ready to deal with any lake/river or reservoir in the given region (country) **X**

Select the alternative, which is used in your DSS:
Detailed information for all possible lakes/rivers and reservoirs of the given region is permanently stored in data base before operational use of the DSS.. In normal mode user may only select the lake/river to deal with. Information in data base can be changed only by authorised advanced users

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[6] Questionnaire is based on the report “Assessment of the software in the field of decision support for radio nuclide contaminated aquatic ecosystems” available on the site of EVANET-HYDRA project (www.casaccia.enea.it/evanet-hydra).

System provides to the user copy of the data base information for the given lake/river or default values (if lake/river is absent in data base). User may change this information, but information in "main" data base can be changed only by authorised advanced users **X.**
Similar to b), but user have a possibility to transfer changes done in data into the "main" data base X (for "socioeconomic data base" and for default values and ranges)

What is implemented in your DSS?:

Support of the software with collections of GIS-based environmental and socio-economic information for wide range of the European lakes/rivers to avoid or significantly simplify procedure of site-specific implementation	X*
Possibility to access default values for the unknown lake/river-specific and socio-economic parameters	X
Possibility to access ranges (min and max values) for the parameters	X
Support of the software with set of sub models to estimate unknown lake/river-specific and economic parameters	X
Possibility to change "internal" parameters of the models, allowed for change by license (e.g. time-step of the simulation) during lake/river-specific implementation	Time-step only.
Possibility to access default values and ranges for the "internal" parameters	

Information for lakes and rivers is provided for 30 lakes in Sweden and river Tevere. Population , land use and fish species data are provided for almost all Western Europe. Large-scale data for bedrock and soil types and and precipitation data are provided for all Westerne Europe.

What alternative is implemented in your DSS for the construction of the chain of models to reflect lake/river specific (e.g. open or closed lake/river), case specification conditions (e.g. radionuclides present in fallout) and data availabilty (some data may need to be defined by sub-models if they are not provided by the user)?

Please indicate 0-unimportant, 1- important,2 - very important

User-friendly tools giving end-user possibility to define specific chain of models	
Ready-to-use tools giving developers possibility to define specific chain of models on user's request	
Automated definition of model chain by DSS kernel before simulation	X
No tools	

Is the following functionality implemented in your DSS? :

"Scenarios" ("solution boxes[7]") – possibility to save current values for all input data and corresponding to them output results without influence on the other data already present in DSS data base. Each "scenario" is saved with unique name allowing finding and opening it later.	X

Compatibility of the DSS with IT system and requirements of user's organisation

Please select
What hardware platform and OS is used for your DSS?

	Please select OS	Specify version of the OS (e.g. Windows 2000)
PC	Windows	Windows 95/98/2000/XP
Workstation (please specify producer HP, SUN, Digital)		
Macintosh		

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[7] "Solution box" is the term used in MOIRA. In many software products similar concept have also name "workspaces" or "projects". Except input and output "scenario" can keep also the layout of the GUI windows and setting of the system (e.g. setting of the printer) on the moment of the saving.

What are requirements of your DSS for the:

hard disk space	10 MB
memory	No specific requirements
processor speed	No specific requirements

Please select
What time of the execution of the chain of the models in your DSS:
Several seconds X
Up to one minute X
Several minutes X
Up to one hour
Several hours
<u>Graphical User Interface (GUI)</u>

Please select
Does GUI of the your DSS concentrate on:
Information for the decision making provided by DSS
Structure and parameters of the models

Note – Each model can have own GUI available for advanced users and dealing with (b)

Please select
What type of user interface is used in your DSS:
Text-based command-line user interface
"Standard" window-based GUI (example Microsoft Word)
Object-oriented GUI (example Windows Explorer, Windows desktop)
"Web-based" interface

What GUI tools are used in your DSS for the editing of the input data :

	Dialog - based forms	Tables	Definition of time-dependent or distributed data with graph-based tools	GIS- based techniques (clicking on the map following with the entering of the data for the given location)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed input data	X	X				
Time-dependent input data	X	X				
Spatially-distributed input data				X		

What GUI tools are used in your DSS for the presentation of the results:

	Tables	Linear or logarithmic graphs	GIS- based techniques (e.g. isolines, colour selection of areas on the maps)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed output data	X				
Time-dependent output data	X	X			
Spatially-distributed output data					

What run-time information about simulation is provided to user by your DSS:

Model which is currently in run	X
"Modelling time" passed for the current model	X
Parts of the chain of models which are currently passed/left	
Indication of data sets which are already prepared by the previous models of the chain	X
Run-time changes in the results produced by the current model	X
Run-time changes in “internal” parameters of the current model	X

What user interface tools are used in your DSS for the presentation of the run –time changes in data during simulation

	Changes in tables	Changes on graphs	GIS-based techniques (e.g. changes of isolines or colours on the map)	Changes on scales	Other (please specify)
Non-distributed data				X (PowerSim)	
Time-dependent data	X (PowerSim)	X (PowerSim)			
Spatially-distributed data					

Does your DSS support the following functionality?:

"Wizards" – dialog based GUI tools guiding user though the sequential steps of the task	X
Possibility to customise user interface according to the user’s preferences (fonts, colours, icons, view of the graphs, sets of the data represented and hidden, view of the data editing tools)	View of the tables and set of the data shown
Possibility to record and play macro for automation of repeated actions performed with GUI	

Data exchange and Internet support

Does your DSS support the following functionality?:

Support of the data exchange between DSS and other applications on the local computer	Clipboard copy of tables
Support of the data exchange between DSS and other applications via network	
Possibility to view results produced by DSS via Internet (without direct interaction with DSS)	
Possibility to run DSS via Internet with Web-based GUI	
Possibility to run DSS via Internet with telnet-based tools or with tools giving possibility to reflect of screen of remote computer on your local screen	

Automation

Does your DSS support the following functionality?:

Possibility to run DSS or separate tasks in automated mode	Chain of the models is formed and run
Possibility to use the build-in language to describe new tasks to be automated	

Support and documentation

Which of the following support-related aspects are provided for your DSS?

Documentation	X
Example scenarios provided by software developers	X (on requiest)
Using local language for the software user interface and documentation	
User's group	
Direct e-mail connection with the software developers	X
Information about current updates in software with web-site	X
Information about current updates in software with mailing lists	X
Web-based tools to give possibility for the user to describe problems discovered	X
Newsgroup	
Bulletin-board	X
List of frequently asked questions	
Availability of the full software installation via the Internet	X (password protected)
Availability of the software demo version with Internet	
Availability of the "service packs" with Internet	X

Software features of the RODOS-HDM

General information

Specify what information is provided by your DSS to the decision maker:

Detailed information about concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Run-time information (during execution of the chain of the models) about changes in concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Evaluation of the uncertainty in results of simulation	
Guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario	
Detailed description of the sequences of each strategy of the countermeasures in the terms of doses received by population , sequences for the environment and economic costs	
Detailed information about process and results of multi-attribute analysis comparison of alternative strategies	
Short summary of the data, strategies and results in the form of report	
Detailed environmental data describing the lake/river or reservoir and corresponding region	X
Detailed socio-economic data related to the and corresponding region	
"Background" geographical information (cities, roads)	R
Detailed description of each strategy of countermeasures	R

R = RODOS application, dealt by another part of the system

Specify which information is required for your DSS

Definition of the case (e.g. fallout data)	X
Definition of the alternative strategies of countermeasures	
Environmental data describing lake/river or reservoir and corresponding region	X
Socio-economic data describing the region	
Real-time hydrological and meteorological information	**

** = Depends on which model of RODOS-HDM. And in future use of real-time hydrology is envisaged

Site- specific and scenario-specific implementation

Please select:
DSS will be used to manage several selected lake/rivers of the specific region (country)
DSS must be ready to deal with any lake/river or reservoir in the given region (country)

Select the alternative, which is used in your DSS:

Detailed information for all possible lakes/rivers and reservoirs of the given region is permanently stored in data base before operational use of the DSS.. In normal mode user may only select the lake/river to deal with. Information in data base can be changed only by authorised advanced users
System provides to the user copy of the data base information for the given lake/river or default values (if lake/river is absent in data base). User may change this information, but information in "main" data base can be changed only by authorised advanced users.
Similar to b), but user have a possibility to transfer changes done in data into the "main" data base

What is implemented in your DSS?:

Support of the software with collections of GIS-based environmental and socio-economic information for wide range of the European lakes/rivers to avoid or significantly simplify procedure of site-specific implementation	
Possibility to access default values for the unknown lake/river-specific and socio-economic parameters	
Possibility to access ranges (min and max values) for the parameters	
Support of the software with set of sub models to estimate unknown lake/river-specific and economic parameters	X***
Possibility to change "internal" parameters of the models, allowed for change by license (e.g. time-step of the simulation) during lake/river-specific implementation	
Possibility to access default values and ranges for the "internal" parameters	

*** = in LAKECO many parameters are assessed by sub-model, and can't be overridden by user. In some case – KD – it is possible.

What alternative is implemented in your DSS for the construction of the chain of models to reflect lake/river specific (e.g. open or closed lake/river), case specification conditions (e.g. radionuclides present in fallout) and data availabilty (some data may need to be defined by sub-models if they are not provided by the user)?

Please indicate 0-unimportant, 1- important,2 - very important

User-friendly tools giving end-user possibility to define specific chain of models	
Ready-to-use tools giving developers possibility to define specific chain of models on user's request	
Automated definition of model chain by DSS kernel before simulation	
No tools	X***

X*** = Current version implements interactive starting of the model by user from HDM top-level interface

Is the following functionality implemented in your DSS? :

"Scenarios" ("solution boxes[8]") – possibility to save current values for all input data and corresponding to them output results without influence on the other data already present in DSS data base. Each "scenario" is saved with unique name allowing finding and opening it later.	X

Predefined scenarios used in the system, scenarios are customized during application of models chain to the region.

Compatibility of the DSS with IT system and requirements of user's organisation

Please select
What hardware platform and OS is used for your DSS?

	Please select OS	Specify version of the OS (e.g. Windows 2000)
PC	Windows	
Workstation (please specify producer HP, SUN, Digital)		X
Macintosh		

What are requirements of your DSS for the:

hard disk space	18 GB
memory	>512 MB
processor speed	>400 MHz

RODOS requirements: some more details:
Main requirement for binary installation of HDM is about 600Mb of hard disk space, mainly for default data scenarios, however hard disk requirements depends from tasks

Workstation:
Model: HP 9000 / C 3000, or similar (> 400 Mhz)
Memory: at least 512 MB ECC Memory
LAN-interfaces: Ethernet, extension to be specified by the Supplier
Graphics: HP VISUALIZE-EG (fxe)
Disk space: at least 18 GB
Mass storage: HP DAT Series Tape Device Driver (for backup)
HP CD-ROM Drive

Please select
What time of the execution of the chain of the models in your DSS:
Several seconds
Up to one minute
Several minutes
Up to one hour
Several hours

RODOS-HDM
LAKECO- minutes
RIVTOX – max one hour
COASTOX- up to one hour or more
THREETOX- up to one hour or more

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[8] "Solution box" is the term used in MOIRA. In many software products similar concept have also name "workspaces" or "projects". Except input and output "scenario" can keep also the layout of the GUI windows and setting of the system (e.g. setting of the printer) on the moment of the saving.

What additional software must be installed on user's computer together with your DSS? (Such as Excel, MapInfo)

for running RODOS alone:
HP-UX version 11.0
Allbase/SQL run time library
For development:
HP-UX version 11.0
C and C++-Development Bundles,
HP-Fortran 77 and 90
Allbase/SQL

Graphical User Interface (GUI)

Please select
Does GUI of the your DSS concentrate on:
A.Information for the decision making provided by DSS
B.Structure and parameters of the models

B

Please select
What type of user interface is used in your DSS:
Text-based command-line user interface (X)
"Standard" window-based GUI (example Microsoft Word) (X)
Object-oriented GUI (example Windows Explorer, Windows desktop) (X)
"Web-based" interface (X)

In current version of HDM a), b) and c) are used, depending from the model and system component, some new versions of integrated/replaced models (RETRACE, LAKECO, POSEIDON) work only in a) mode with data connections. Other models like RIVTOX, COASTOX/THREETOX use extended graphical user interfaces.

What GUI tools are used in your DSS for the editing of the input data :

	Dialog - based forms	Tables	Definition of time-dependent or distributed data with graph-based tools	GIS- based techniques (clicking on the map following with the entering of the data for the given location)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed input data		X				
Time-dependent input data		X	X	X	X	
Spatially-distributed input data		X	X	X	X	

What GUI tools are used in your DSS for the presentation of the results:

	Tables	Linear or logarithmic graphs	GIS- based techniques (e.g. isolines, colour selection of areas on the maps)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed output data					
Time-dependent output data	X	X	X	X	
Spatially-distributed output data	X	X	X	X	

What run-time information about simulation is provided to user by your DSS:

Model which is currently in run	X
"Modelling time" passed for the current model	
Parts of the chain of models which are currently passed/left	
Indication of data sets which are already prepared by the previous models of the chain	
Run-time changes in the results produced by the current model	
Run-time changes in “internal” parameters of the current model	

What user interface tools are used in your DSS for the presentation of the run –time changes in data during simulation

	Changes in tables	Changes on graphs	GIS-based techniques (e.g. changes of isolines or colours on the map)	Changes on scales	Other (please specify)
Non-distributed data					
Time-dependent data	X	X	X	X	
Spatially-distributed data	X	X	X	X	

Does your DSS support the following functionality?:

"Wizards" – dialog based GUI tools guiding user though the sequential steps of the task	
Possibility to customise user interface according to the user’s preferences (fonts, colours, icons, view of the graphs, sets of the data represented and hidden, view of the data editing tools)	
Possibility to record and play macro for automation of repeated actions performed with GUI	

<u>Data exchange and Internet support</u>

Does your DSS support the following functionality?:

Support of the data exchange between DSS and other applications on the local computer	
Support of the data exchange between DSS and other applications via network	
Possibility to view results produced by DSS via Internet (without direct interaction with DSS)	
Possibility to run DSS via Internet with Web-based GUI	
Possibility to run DSS via Internet with telnet-based tools or with tools giving possibility to reflect of screen of remote computer on your local screen	

Automation

Does your DSS support the following functionality?:

Possibility to run DSS or separate tasks in automated mode	X[9]
Possibility to use the build-in language to describe new tasks to be automated	

Support and documentation

Which of the following support-related aspects are provided for your DSS?

Documentation	X[10]
Example scenarios provided by software developers	X
Using local language for the software user interface and documentation	
User's group	
Direct e-mail connection with the software developers	
Information about current updates in software with web-site	
Information about current updates in software with mailing lists	
Web-based tools to give possibility for the user to describe problems discovered	
Newsgroup	
Bulletin-board	
List of frequently asked questions	
Availability of the full software installation via the Internet	
Availability of the software demo version with Internet	
Availability of the "service packs" with Internet	

Software features of the CASTEAUR

General information

Specify what information is provided by your DSS to the decision maker:

Detailed information about concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Run-time information (during execution of the chain of the models) about changes in concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Evaluation of the uncertainty in results of simulation	
Guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario	
Detailed description of the sequences of each strategy of the countermeasures in the terms of doses received by population , sequences for the environment and economic costs	
Detailed information about process and results of multi-attribute analysis comparison of alternative strategies	
Short summary of the data, strategies and results in the form of report	
Detailed environmental data describing the lake/river or reservoir and corresponding region	
Detailed socio-economic data related to the and corresponding region	
"Background" geographical information (cities, roads)	
Detailed description of each strategy of countermeasures	

Specify which information is required for your DSS

Definition of the case (e.g. fallout data)	X
Definition of the alternative strategies of countermeasures	
Environmental data describing lake/river or reservoir and corresponding region	X
Socio-economic data describing the region	
Real-time hydrological and meteorological information	X

---

[9] separate tasks only for some model

[10] needs to be updated

Site- specific and scenario-specific implementation

Please select:
DSS will be used to manage several selected lake/rivers of the specific region (country)
DSS must be ready to deal with any lake/river or reservoir in the given region (country) **X**

Select the alternative, which is used in your DSS:

Detailed information for all possible lakes/rivers and reservoirs of the given region is permanently stored in data base before operational use of the DSS.. In normal mode user may only select the lake/river to deal with. Information in data base can be changed only by authorised advanced users
System provides to the user copy of the data base information for the given lake/river or default values (if lake/river is absent in data base). User may change this information, but information in "main" data base can be changed only by authorised advanced users.
Similar to b), but user have a possibility to transfer changes done in data into the "main" data base

What is implemented in your DSS?:

Support of the software with collections of GIS-based environmental and socio-economic information for wide range of the European lakes/rivers to avoid or significantly simplify procedure of site-specific implementation	
Possibility to access default values for the unknown lake/river-specific and socio-economic parameters	X
Possibility to access ranges (min and max values) for the parameters	
Support of the software with set of sub models to estimate unknown lake/river-specific and economic parameters	X
Possibility to change "internal" parameters of the models, allowed for change by license (e.g. time-step of the simulation) during lake/river-specific implementation	X
Possibility to access default values and ranges for the "internal" parameters	X

What alternative is implemented in your DSS for the construction of the chain of models to reflect lake/river specific (e.g. open or closed lake/river), case specification conditions (e.g. radionuclides present in fallout) and data availabilty (some data may need to be defined by sub-models if they are not provided by the user)?

Please indicate 0-unimportant, 1- important,2 - very important

User-friendly tools giving end-user possibility to define specific chain of models	X
Ready-to-use tools giving developers possibility to define specific chain of models on user's request	
Automated definition of model chain by DSS kernel before simulation	
No tools	

Is the following functionality implemented in your DSS? :

"Scenarios" ("solution boxes[11]") – possibility to save current values for all input data and corresponding to them output results without influence on the other data already present in DSS data base. Each "scenario" is saved with unique name allowing finding and opening it later.	X

Compatibility of the DSS with IT system and requirements of user's organisation
Please select
What hardware platform and OS is used for your DSS?

	Please select OS	Specify version of the OS (e.g. Windows 2000)
PC	Windows	Windows 2000
Workstation (please specify		

---

[11] "Solution box" is the term used in MOIRA. In many software products similar concept have also name "workspaces" or "projects". Except input and output "scenario" can keep also the layout of the GUI windows and setting of the system (e.g. setting of the printer) on the moment of the saving.

producer HP, SUN, Digital)		
Macintosh		

What are requirements of your DSS for the:

hard disk space	STANDARD	MB
memory	STANDARD	MB
processor speed	STANDARD	MHz

Please select
What time of the execution of the chain of the models in your DSS:
Several seconds
Up to one minute
Several minutes
Up to one hour
Several hours

All the case are possible in function of the scenario

What additional software must be installed on user's computer together with your DSS? (Such as Excel, MapInfo) Excel

Graphical User Interface (GUI)

Please select
Does GUI of the your DSS concentrate on:
Information for the decision making provided by DSS
Structure and parameters of the models

Please select
What type of user interface is used in your DSS:
Text-based command-line user interface
"Standard" window-based GUI (example Microsoft Word)
Object-oriented GUI (example Windows Explorer, Windows desktop)
"Web-based" interface

What GUI tools are used in your DSS for the editing of the input data :

	Dialog - based forms	Tables	Definition of time-dependent or distributed data with graph-based tools	GIS- based techniques (clicking on the map following with the entering of the data for the given location)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed input data	x	x				
Time-dependent input data	x	x				
Spatially-distributed input data	x	x				

What GUI tools are used in your DSS for the presentation of the results:

	Tables	Linear or logarithmic graphs	GIS- based techniques (e.g. isolines, colour selection of areas on the maps)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed output data	x	x			
Time-dependent output data	x	x			
Spatially-distributed output data	x	x			

What run-time information about simulation is provided to user by your DSS:

Model which is currently in run	
"Modelling time" passed for the current model	x
Parts of the chain of models which are currently passed/left	
Indication of data sets which are already prepared by the previous models of the chain	
Run-time changes in the results produced by the current model	x
Run-time changes in “internal” parameters of the current model	

What user interface tools are used in your DSS for the presentation of the run –time changes in data during simulation

	Changes in tables	Changes on graphs	GIS-based techniques (e.g. changes of isolines or colours on the map)	Changes on scales	Other (please specify)
Non-distributed data	x	x			
Time-dependent data	x	x			
Spatially-distributed data	x	x			

Does your DSS support the following functionality?:

"Wizards" – dialog based GUI tools guiding user though the sequential steps of the task	
Possibility to customise user interface according to the user’s preferences (fonts, colours, icons, view of the graphs, sets of the data represented and hidden, view of the data editing tools)	
Possibility to record and play macro for automation of repeated actions performed with GUI	

Data exchange and Internet support

Does your DSS support the following functionality?: The same than EXCELL

Support of the data exchange between DSS and other applications on the local computer	
Support of the data exchange between DSS and other applications via network	
Possibility to view results produced by DSS via Internet (without direct interaction with DSS)	
Possibility to run DSS via Internet with Web-based GUI	

Possibility to run DSS via Internet with telnet-based tools or with tools giving possibility to reflect of screen of remote computer on your local screen	

Automation

Does your DSS support the following functionality?:

Possibility to run DSS or separate tasks in automated mode	
Possibility to use the build-in language to describe new tasks to be automated	

Support and documentation

Which of the following support-related aspects are provided for your DSS?

Documentation	x
Example scenarios provided by software developers	x
Using local language for the software user interface and documentation	
User's group	
Direct e-mail connection with the software developers	x
Information about current updates in software with web-site	
Information about current updates in software with mailing lists	
Web-based tools to give possibility for the user to describe problems discovered	
Newsgroup	
Bulletin-board	
List of frequently asked questions	
Availability of the full software installation via the Internet	
Availability of the software demo version with Internet	
Availability of the "service packs" with Internet	

Software aspects of the AQUASCOPE

General information

Specify what information is provided by your DSS to the decision maker:

Detailed information about concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Run-time information (during execution of the chain of the models) about changes in concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X
Evaluation of the uncertainty in results of simulation	X
Guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario	
Detailed description of the sequences of each strategy of the countermeasures in the terms of doses received by population , sequences for the environment and economic costs	
Detailed information about process and results of multi-attribute analysis comparison of alternative strategies	
Short summary of the data, strategies and results in the form of report	X
Detailed environmental data describing the lake/river or reservoir and corresponding region	
Detailed socio-economic data related to the and corresponding region	
"Background" geographical information (cities, roads)	
Detailed description of each strategy of countermeasures	

Specify which information is required for your DSS

Definition of the case (e.g. fallout data)	X
Definition of the alternative strategies of countermeasures	
Environmental data describing lake/river or reservoir and corresponding region	X
Socio-economic data describing the region	

Real-time hydrological and meteorological information	

Site- specific and scenario-specific implementation

Please select:
DSS will be used to manage several selected lake/rivers of the specific region (country)
DSS must be ready to deal with any lake/river or reservoir in the given region (country) **X**

Select the alternative, which is used in your DSS: **None of these answers applies.**

Detailed information for all possible lakes/rivers and reservoirs of the given region is permanently stored in data base before operational use of the DSS.. In normal mode user may only select the lake/river to deal with. Information in data base can be changed only by authorised advanced users
System provides to the user copy of the data base information for the given lake/river or default values (if lake/river is absent in data base). User may change this information, but information in "main" data base can be changed only by authorised advanced users.
Similar to b), but user have a possibility to transfer changes done in data into the "main" data base

What is implemented in your DSS?:

Support of the software with collections of GIS-based environmental and socio-economic information for wide range of the European lakes/rivers to avoid or significantly simplify procedure of site-specific implementation	
Possibility to access default values for the unknown lake/river-specific and socio-economic parameters	
Possibility to access ranges (min and max values) for the parameters	
Support of the software with set of sub models to estimate unknown lake/river-specific and economic parameters	
Possibility to change "internal" parameters of the models, allowed for change by license (e.g. time-step of the simulation) during lake/river-specific implementation	X
Possibility to access default values and ranges for the "internal" parameters	

What alternative is implemented in your DSS for the construction of the chain of models to reflect lake/river specific (e.g. open or closed lake/river), case specification conditions (e.g. radionuclides present in fallout) and data availabilty (some data may need to be defined by sub-models if they are not provided by the user)?

Please indicate 0-unimportant, 1- important,2 - very important

User-friendly tools giving end-user possibility to define specific chain of models	
Ready-to-use tools giving developers possibility to define specific chain of models on user's request	
Automated definition of model chain by DSS kernel before simulation	
No tools	X

Is the following functionality implemented in your DSS? :

"Scenarios" ("solution boxes[12]") – possibility to save current values for all input data and corresponding to them output results without influence on the other data already present in DSS data base. Each "scenario" is saved with unique name allowing finding and opening it later.	X

---

[12] "Solution box" is the term used in MOIRA. In many software products similar concept have also name "workspaces" or "projects". Except input and output "scenario" can keep also the layout of the GUI windows and setting of the system (e.g. setting of the printer) on the moment of the saving.

<u>Compatibility of the DSS with IT system and requirements of user's organisation</u>

Please select
What hardware platform and OS is used for your DSS?

	Please select OS	Specify version of the OS (e.g. Windows 2000)
PC	Windows	Windows 2000, could be used on any Windows
Workstation (please specify producer HP, SUN, Digital)		
Macintosh		

What are requirements of your DSS for the:

hard disk space Anything that can run EXCEL	MB
memory Anything that can run EXCEL	MB
processor speed Anything that can run EXCEL	MHz

Please select
What time of the execution of the chain of the models in your DSS:
Several seconds **X**
Up to one minute
Several minutes
Up to one hour
Several hours

What additional software must be installed on user's computer together with your DSS? (Such as Excel, MapInfo) **EXCEL**

<u>Graphical User Interface (GUI)</u>

Please select
Does GUI of the your DSS concentrate on:
Information for the decision making provided by DSS
Structure and parameters of the models

Please select
What type of user interface is used in your DSS:
Text-based command-line user interface
"Standard" window-based GUI (example Microsoft Word)
Object-oriented GUI (example Windows Explorer, Windows desktop)
"Web-based" interface
None of the above – interface is EXCEL spreadsheet.

What GUI tools are used in your DSS for the editing of the input data :

	Dialog - based forms	Tables	Definition of time-dependent or distributed data with graph-based tools	GIS- based techniques (clicking on the map following with the entering of the data for the given location)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed input data		x				

Time-dependent input data			x			
Spatially-distributed input data		N/A	N/A			

What GUI tools are used in your DSS for the presentation of the results:

	Tables	Linear or logarithmic graphs	GIS- based techniques (e.g. isolines, colour selection of areas on the maps)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed output data	X	X			
Time-dependent output data	X	X			
Spatially-distributed output data	N/A	N/A			

What run-time information about simulation is provided to user by your DSS:

Model which is currently in run	x
"Modelling time" passed for the current model	
Parts of the chain of models which are currently passed/left	
Indication of data sets which are already prepared by the previous models of the chain	
Run-time changes in the results produced by the current model	
Run-time changes in “internal” parameters of the current model	

What user interface tools are used in your DSS for the presentation of the run –time changes in data during simulation

	Changes in tables	Changes on graphs	GIS-based techniques (e.g. changes of isolines or colours on the map)	Changes on scales	Other (please specify)
Non-distributed data	X	x			
Time-dependent data	X	X			
Spatially-distributed data					

Does your DSS support the following functionality?:

"Wizards" – dialog based GUI tools guiding user though the sequential steps of the task	
Possibility to customise user interface according to the user’s preferences (fonts, colours, icons, view of the graphs, sets of the data represented and hidden, view of the data editing tools)	
Possibility to record and play macro for automation of repeated actions performed with GUI	

<u>Data exchange and Internet support</u>

Does your DSS support the following functionality?:

Support of the data exchange between DSS and other applications on the local computer	X
Support of the data exchange between DSS and other applications via network	

Possibility to view results produced by DSS via Internet (without direct interaction with DSS)	
Possibility to run DSS via Internet with Web-based GUI	
Possibility to run DSS via Internet with telnet-based tools or with tools giving possibility to reflect of screen of remote computer on your local screen	

Automation

Does your DSS support the following functionality?:

Possibility to run DSS or separate tasks in automated mode	
Possibility to use the build-in language to describe new tasks to be automated	

Support and documentation

Which of the following support-related aspects are provided for your DSS?

Documentation	X
Example scenarios provided by software developers	X
Using local language for the software user interface and documentation	
User’s group	
Direct e-mail connection with the software developers	
Information about current updates in software with web-site	
Information about current updates in software with mailing lists	
Web-based tools to give possibility for the user to describe problems discovered	
Newsgroup	
Bulletin-board	
List of frequently asked questions	
Availability of the full software installation via the Internet	
Availability of the software demo version with Internet	
Availability of the “service packs” with Internet	

Features of the software developed in the frame of SPARTACUS project

General information

Specify what information is provided by your DSS to the decision maker:

Detailed information about concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	X (no fish)
Run-time information (during execution of the chain of the models) about changes in concentration of radionuclides in the water, sediments and fish in given lake/river or reservoir	
Evaluation of the uncertainty in results of simulation	
Guidance / help to initiate countermeasures selection, according to the general characteristics of the analysed scenario	
Detailed description of the sequences of each strategy of the countermeasures in the terms of doses received by population , sequences for the environment and economic costs	
Detailed information about process and results of multi-attribute analysis comparison of alternative strategies	
Short summary of the data, strategies and results in the form of report	
Detailed environmental data describing the lake/river or reservoir and corresponding region	x
Detailed socio-economic data related to the and corresponding region	
"Background" geographical information (cities, roads)	
Detailed description of each strategy of countermeasures	

Specify which information is required for your DSS

Definition of the case (e.g. fallout data)	X
Definition of the alternative strategies of countermeasures	X
Environmental data describing lake/river or reservoir and corresponding region	X
Socio-economic data describing the region	
Real-time hydrological and meteorological information	

Site- specific and scenario-specific implementation

Please select:
~~DSS will be used to manage several selected lake/rivers of the specific region (country)~~
DSS must be ready to deal with any lake/river or reservoir in the given region (country)

Select the alternative, which is used in your DSS:

~~Detailed information for all possible lakes/rivers and reservoirs of the given region is permanently stored in data base before operational use of the DSS.. In normal mode user may only select the lake/river to deal with. Information in data base can be changed only by authorised advanced users~~
~~System provides to the user copy of the data base information for the given lake/river or default values (if lake/river is absent in data base). User may change this information, but information in "main" data base can be changed only by authorised advanced users.~~
~~Similar to b), but user have a possibility to transfer changes done in data into the "main" data base~~
Detailed information of the catchment should be implemented by the user

What is implemented in your DSS?:

Support of the software with collections of GIS-based environmental and socio-economic information for wide range of the European lakes/rivers to avoid or significantly simplify procedure of site-specific implementation	
Possibility to access default values for the unknown lake/river-specific and socio-economic parameters	x
Possibility to access ranges (min and max values) for the parameters	
Support of the software with set of sub models to estimate unknown lake/river-specific and economic parameters	
Possibility to change "internal" parameters of the models, allowed for change by license (e.g. time-step of the simulation) during lake/river-specific implementation	
Possibility to access default values and ranges for the "internal" parameters	x

What alternative is implemented in your DSS for the construction of the chain of models to reflect lake/river specific (e.g. open or closed lake/river), case specification conditions (e.g. radionuclides present in fallout) and data availabilty (some data may need to be defined by sub-models if they are not provided by the user)?
Please indicate 0-unimportant, 1- important,2 - very important

User-friendly tools giving end-user possibility to define specific chain of models	
Ready-to-use tools giving developers possibility to define specific chain of models on user's request	
Automated definition of model chain by DSS kernel before simulation	
No tools	X

Is the following functionality implemented in your DSS? :

"Scenarios" ("solution boxes13") – possibility to save current values for all input data and corresponding to them output results without influence on the other data already present in DSS data base. Each "scenario" is saved with unique name allowing finding and opening it later.	No

Compatibility of the DSS with IT system and requirements of user's organisation

---

13"Solution box" is the term used in MOIRA. In many software products similar concept have also name "workspaces" or "projects". Except input and output "scenario" can keep also the layout of the GUI windows and setting of the system (e.g. setting of the printer) on the moment of the saving.

Please select
What hardware platform and OS is used for your DSS?

	Please select OS	Specify version of the OS (e.g. Windows 2000)
PC	Windows	
Workstation (please specify producer HP, SUN, Digital)		
Macintosh		

What are requirements of your DSS for the:

hard disk space	500 MB
memory	128 MB
processor speed	500 MHz

Please select
What time of the execution of the chain of the models in your DSS:
Several seconds
Up to one minute
Several minutes
Up to one hour X
Several hours X

What additional software must be installed on user's computer together with your DSS? (Such as Excel, MapInfo)
PCRaster GIS for execution of the models
ArcGIS for preparation of the GIS database

Graphical User Interface (GUI)

Please select
Does GUI of the your DSS concentrate on:
~~Information for the decision making provided by DSS~~
Structure and parameters of the models X

Please select
What type of user interface is used in your DSS:
Text-based command-line user interface
~~"Standard" window-based GUI (example Microsoft Word)~~
~~Object-oriented GUI (example Windows Explorer, Windows desktop)~~
~~"Web-based" interface~~

What GUI tools are used in your DSS for the editing of the input data :

	Dialog - based forms	Tables	Definition of time-dependent or distributed data with graph-based tools	GIS- based techniques (clicking on the map following with the entering of the data for the given location)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed input data						Model script
Time-dependent input data		X				

Spatially-distributed input data				X		

What GUI tools are used in your DSS for the presentation of the results:

	Tables	Linear or logarithmic graphs	GIS- based techniques (e.g. isolines, colour selection of areas on the maps)	Scales (thermometer or speedometer-like)	Other (please specify)
Non-distributed output data	X	X	X		
Time-dependent output data	X	X			
Spatially-distributed output data			X		

What run-time information about simulation is provided to user by your DSS:

Model which is currently in run	X
"Modelling time" passed for the current model	X
Parts of the chain of models which are currently passed/left	
Indication of data sets which are already prepared by the previous models of the chain	
Run-time changes in the results produced by the current model	
Run-time changes in “internal” parameters of the current model	

What user interface tools are used in your DSS for the presentation of the run –time changes in data during simulation

	Changes in tables	Changes on graphs	GIS-based techniques (e.g. changes of isolines or colours on the map)	Changes on scales	Other (please specify)
Non-distributed data	X	x	X		
Time-dependent data	X	X	X		
Spatially-distributed data			X		

Does your DSS support the following functionality?:

"Wizards" – dialog based GUI tools guiding user though the sequential steps of the task	No
Possibility to customise user interface according to the user’s preferences (fonts, colours, icons, view of the graphs, sets of the data represented and hidden, view of the data editing tools)	No
Possibility to record and play macro for automation of repeated actions performed with GUI	No

<u>Data exchange and Internet support</u>

Does your DSS support the following functionality?:

Support of the data exchange between DSS and other applications on the local computer	Yes
Support of the data exchange between DSS and other applications via network	No
Possibility to view results produced by DSS via Internet (without direct interaction with DSS)	No
Possibility to run DSS via Internet with Web-based GUI	No
Possibility to run DSS via Internet with telnet-based tools or with tools giving possibility to reflect of screen of remote computer on your local screen	No

Automation

Does your DSS support the following functionality?:

Possibility to run DSS or separate tasks in automated mode	No
Possibility to use the build-in language to describe new tasks to be automated	Yes

Support and documentation

Which of the following support-related aspects are provided for your DSS?

Documentation	X
Example scenarios provided by software developers	X
Using local language for the software user interface and documentation	
User's group	
Direct e-mail connection with the software developers	
Information about current updates in software with web-site	
Information about current updates in software with mailing lists	
Web-based tools to give possibility for the user to describe problems discovered	
Newsgroup	
Bulletin-board	
List of frequently asked questions	
Availability of the full software installation via the Internet	X
Availability of the software demo version with Internet	
Availability of the "service packs" with Internet	

Annex 4 MOIRA data guide

Site-specific environmental data

Lake – specific (L)/ Complex. Catch. Spec (R)	**Table**	Parameters
L	Lake char.	Lake area (m2) Catchment area (m2) Mean depth(m) Max depth(m) Altitude (m.a.s.l) Latitude (deg.) Longitude (deg.)
L	Init. Values (can be provided by users or estimated by mode)	Initial K conc. (mg/l) Initial TP conc. (mg/m3) Initial PH Initial Ca (mg/l)
L,R	Ice cover	Ice cover (m)
L	Fish species	Present fish species
L,R	Soil type	One of the: clay, mountain area, organic, sand, loam
L	Bedrock type	One of the: Acid Basic Precambr Sedimentary Sedimentary metamorphosed
L	Selection/Region-environmental/Precipitation	Min. precipitation (mm/year) Max. precipitation (mm/year) Precipitation (mm/year)
L,R	Ground use	Forest (%) Oil plants (%) Cereal areas (%) Pasturages (%) Root veg. areas (%)
L	Continentality	Order of distance from ocean in km
R	River database	Runoff from right sub-catchments: box ith (i=1..20) , month=1..12 m^3 m^{-2} month^{-1} Runoff from left sub-catchments: box ith (i=1..20) , month=1..12 m^3 m^{-2} month^{-1} Average depth of box ith (i=1..20) m Average width of box ith (i=1..20) km Length of box ith (i=1..20) km Area of box ith left sub-catchment (i=1..20) km^2 Area of box ith right sub-catchment (i=1..20) km^2 Precipitation on box ith (i=1..20) mm year^{-1} Identification of the type of box(i) 1 to 3 lake (=2), river (=1), reservoir (=3) Water flux (averaged over the year) to first box due to spring m^3 month^{-1} Sedimentation velocity m day^{-1} (if option =1 radionuclide sedimentation velocity default values are used)

Deposition

L	Fallout Cs-137 Fallout Sr-90	Time (month) Depos. catchment (Bq/m2) Depos. lake (Bq/m2)	Time-serie
R	Fallout Cs-137 Fallout Sr-90	Time (month) On right catchment (Bq/m2) On left catchment (Bq/m2) On box (Bq/m2) Input rate to box (Bq/month)	Time-serie (could be provided for each of 20 boxes)

Socioeconomic data

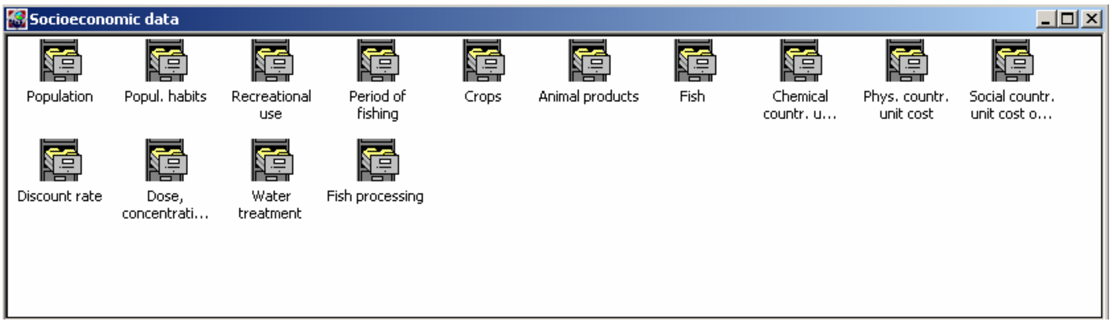


Figure 1

Date and time

L,R	Simulation time	From 1 Jan of ... year Period (months)	

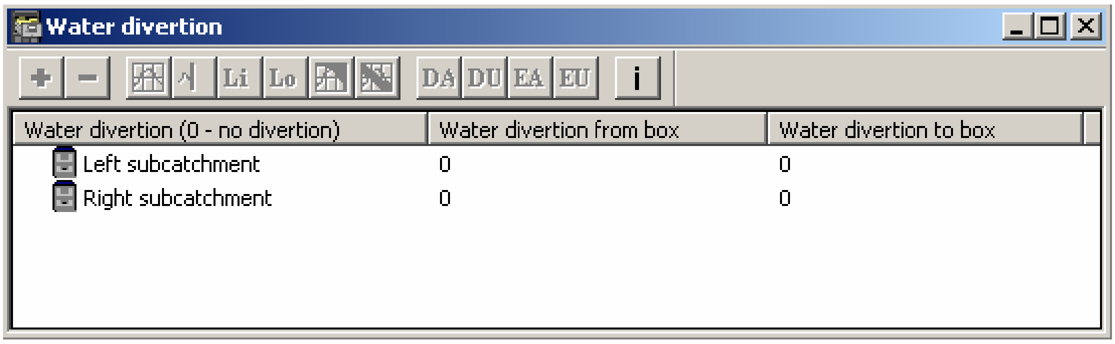
Strategy-related input data (countermeasures)

Each strategy is the combination of one or more countermeasures. “No action” strategy does not contain any countermeasures.

Physical and chemical countermeasures

Lake –specific (L)/ Complex. Catch. Spec (R)	**Table**	Parameters	**Time-serie**	**For river scenarios could be provided :**
L	Chemical treatment	Lake lime (tons) Wetalnd lime (tons) Potash (tons) Fertilizer (kg)	Time-serie	
L	Removal of contaminated snow and ice	Volume of snow and ice removed (m3)	Time-serie	For each of 20 boxes

L	Removal of contaminated sediments	Sed. Area removed (m2) Sediment depth removed (m)	Time-serie	For each of 20 boxes
R	Removal of contaminated snow and ice from left catchment	Start time (month) Area of snow and ice removed (m2)		For each of 20 boxes
R	Removal of contaminated snow and ice from right catchment	Start time (month) Area of snow and ice removed (m2)		For each of 20 boxes
R	Removal of contaminated sediments	Start time (month)		For each of 20 boxes
R	Control of water flow : Isolation time Water divertion	Beginning of water divertion (month) End water divertion (month) See Fig. 2		



Water divertion

Water divertion (0 - no divertion)	Water divertion from box	Water divertion to box
Left subcatchment	0	0
Right subcatchment	0	0

Figure 2

Social countermeasures

Lake –specific (L)/ Complex. Catch. Spec (R)	**Table**	**Parameters**	**Time-serie**	**For river scenarios could be provided :**
L	Bans on fish consumption	Beginning of restriction End of restriction		
L,R	Bans on water consumption (Alternative sources for drinking water)	Beginning of restriction End of restriction		For one box
L,R	Bans on irrigation	Beginning of restriction End of restriction		For one box
L,R	Restricted access to contaminated areas	Beginning of restriction End of restriction		For one box
L,R	Automatic advice	Ban on water consumpt. Ban on fish consumpt. Ban on irrigation Restricted acess to area	Time-serie	

		Treatment of water Processing of fish		

Strategy-specific results

Lake –specific (L)/ Complex. Catch. Spec (R)	**Table**	Fields	**Time-serie**
L	Lake Cs-137 concentration	Water (Bq/m3) Phytoplankton dw (Bq/kg) Prey - whole body ww (Bq/kg) Predator - flesh ww (Bq/kg) Sediments (Bq/g dw)	Time-serie
L	Lake Sr-90 concentration	Water (Bq/m3) Phytoplankton dw (Bq/kg) Prey - whole body ww (Bq/kg) Predator - flesh ww (Bq/kg) Sediments (Bq/g dw)	Time-serie
L	Lake chem..	Lake pH Actual K conc.(meq/l) Actual TP conc. (mg/m3)	Time-serie
L	LEI	Lake Ecosystem Index (1-norm. cond,5 –destruct)	
R	Cs-137 conc.	Conc. water (Bq/m3) Conc. in sediments (Bq/kg dw)	Time-serie
R	Sr-90 conc.	Conc. in water (Bq/m3) Conc. in sediments (Bq/kg dw)	Time-serie
L,R	Collective doses	External dose (manSv) Dose fr. intake water (man.Sv) Dose fr. intake fish (man.Sv) Dose fr. intake crops (man.Sv) Dose fr. intake animal pr. (man.Sv) Dose fr. ingestion (man.Sv) Total dose rad. Cs (man.Sv) Total dose rad. Sr (man.Sv) Total dose (man.mSv)	
L,R	Dynamics of collective doses	Same	Time-serie
L,R	Indiv. Doses Age 0-1., 1-2,3-7,8-12,12-17 18- y.	External dose (Sv) Water (Sv) Fish (Sv) Crops (Sv) Animal products (Sv) Ingestion (Sv) Total dose (Sv)	Time-serie
L,R	Total doses	Total collective dose(Sv*man) Total ing. dose 0-1y (Sv) Total ing. dose 1-2y (Sv) Total ing. dose 3-7y (Sv) Total ing. dose 8-12y (Sv) Total ing. dose 13-17y (Sv) Total ing. dose 18- y (Sv)	
L,R.	Econ. Cost	Cost of application (EUR) Costs to economy (EUR)	
L,R	Counterm. Costs	Costs related to each countermeasure	

MAA Ranking of strategies

L,R	Optimal strategy/rankN	Rank Overall value

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