Properties of deterministic models for prediction of radionuclide concentrations in river systems

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Abstract

A deterministic model was used for predicting the activity concentration of radionuclides in rivers. The model was validated in the framework of VAMP, aquatic working group, river subgroup, where scenarios as Clinch-Tennessee rivers as well as Dnjepr river were provided. This was a good chance to test the predictive power of the model. Some of the results of this exercise are presented.

Description of the model

The model was developed by /Sc 76/ and modified to predict the activity concentration the river Danube/Pr 82/. It is a simple deterministic model, taking into account interaction with suspended material, radioactive decay and sedimentation. The model seems promising, because of the small numbers of parameters needed for evaluation.

The basic equation is :

$$C_{i,j}=C_{(i-1),j}\cdot W_{(i-1)}\frac{1}{W_i}\cdot e^{-(k'+\frac{\lambda}{v})x}(1-E_{i,j})\cdot\frac{1}{1+k_d S}$$

C_{ij}	activity concentration of radionuclide i at site j [Bq/m^3]
Q_i	annual release of radionuclide [Bq/a]
K	conversion factor s→a = $3.17\cdot 10^{-8}$ [a/s]
W_j	mean annual flow at a point j (m^3/s)
k′	depletion factor for sedimentation (m-1)
λ	decay constant (s^{-1})
x	distance (m)
v	flow velocity (m/s)
K_d	K_d-factor (l/kg)
S	amount of suspended material (kg/l)

The scenarios are sufficiently described in the final report of VAMP (in press).

To apply this model to the scenarios some assumptions had to be made:

The discharge of radioactive effluents is continuous and instantaneous mixing with the river or reservoir water takes place.

The activity removed by biological materials can be neglected.

The river system is divided into several parts, representing the boxes of the model

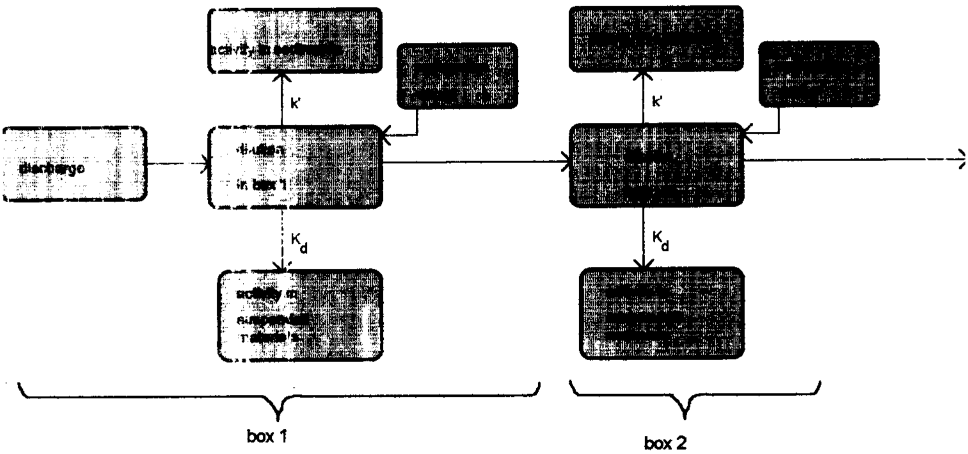
Some parameters as flow velocity, amount of suspended materials of the water body are constant in a box.

There is no resuspension of radioactive material absorbed by the sediments.

Reduction of radioactive materials due to chemical processes are not considered.

The cross section area of the river can be described by mean values of width and depth.

The processes simulated by the model and the mechanism are shown in figure 1:



Large river systems like the Clinch Tennessee rivers or the Dnjepr cascade have to be divided into several segments. The choice of the number of boxes is arbitrary, but the modelist must find segments in which the properties are well known and of interest. As a consequence of using a deterministic box model results, are not time dependent and also the transport of the activity concentration downstream will not be simulated correctly. The model was initially developed to provide yearly averaged values of the activity concentration. Modelling the Clinch Tennessee rivers the experience was made that the model led to reasonable results, when using adequate parameters When monthly averaged values had to be calculated, the model still led to satisfying results, as there are high flow velocities. Modelling the Dnjepr cascade monthly averaged values of the activity concentration were not in a good agreement with the experimental data. The were two reasons: the first was that the same parametrisation as for the Clinch Tennessee rivers could not be used, and the second reason was that the correlation between the calculated and the experimental data was not satisfying. The second one sets up on the big range of the reservoirs of the Dnjepr cascade (each reservoir is longer than 100 km) and on the very slow flow velocities. To improve the time dependence a new term for the dilution was used, which was based on a differential equation. The new term, describing dilution, considers how the activity concentration changes, when the inflow has a different activity concentration as the flowing off. As there was not enough hydrological data (e.g. reservoir depth in each month) the assumption was made , that the capacity of each reservoir was constant.

Choice of parameters

As mentioned above, choice of parameters is very important. The first approach for the Clinch Tennessee rivers was don by using "default parameters". K_d was taken from /IA82/, and the k' as suggested by /ME 79/. Using the same parameters for the Dnjepr cascade and comparing the results with the experimental data, the experience was made that especially for longer distances the calculated values underpredicted the measured values. A calibration with the monthly averaged data of the Dnjepr cascade was carried out and a new set of values was obtained. With this new set of parameters all values were recalculated, what led to an improvement in the quality of the results.

Sensitivity analysis

To identify the most important parameter and variables of the model, a sensitivity analysis was carried out. For each parameter and variable, a range of its value was determined. Regarding variables, the maximum and the minimum of the observed data were taken. For the parameters the maximum and the minimum found in the literature were taken. A sensitivity index SI /Ho 83/ was calculated. The model is sensitive for the parameter when SI is close to 1. The calculations show that the flow rate is a very important parameter for all radionuclides. In addition, for radionuclides as Cs-137, which strongly interact with suspended material and bottom sediments, the depletion factor for sedimentation and the amount of suspended materials are of even more importance.

Table 1: table of sensitivity indexes for Cs-137 and Sr-90, Kiev reservoir

	sensitivity index	
	Cs-137	Sr-90
flow velocity	0.0032	0.0040
flow rate	0.5055	0.6278
suspended material	0.9356	0.4990
Kd-factor	0.3764	0.0151
k'-factor	0.9047	0.5938

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