

METHOD OF PROGNOSTICATION OF DISTRIBUTION OF RADIO-ACTIVE CONTAMINATIONS IN SURFACE WATER

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ABSTRACT

Model UNDBE takes account that the transposition flows past in two stages. In the first steps each portion of the water and pollution only moves through box till the outflow. In the second step only at the end of transportation each portion of water and pollution mixes up in a certain part of compartment and interacts there with sediments and bottom depositions as in ordinary box model. Such approach allows taking into account time of transporting of water masses and intermixing of contamination in some part of volume of the compartment at the moment of a termination of transporting. The assumptions reduce in a model which is described by a system of the usual differential equations with retardation parameter. The new model is simple, less requiring for full-scale measurements, short time of computation. It contributes to increase the accuracy of the model and provides the possibility of its adjustment to a particular water object. Results of calibration of the model on a dataset of field measurements through critical 1991, 1994, 1999 and comparison with the box model of complete mixing and validation on data (^{90}Sr) through critical situations are given. The post-Chernobyl measurements were used. The research of passing of ejections ^3H in 350 kilometres channel Loire River (France) was made in the framework of the IAEA program EMRAS. Comparison of results demonstrates good coincidence of outcomes of modeling and measurements and shows that box model UNDBE gives coincidence with measurements not worse of the more complicated 1-D models.

1 INTRODUCTION

A set of models of different complexity (from three-dimensional to box model) was developed to simulate radionuclide transport in surface water as shown by IAEA (1985), Rauch et al. (1998), Whicker et al. (1999). The simplest of these is a box (complete mixing) model, for which variables are averaged over the volume of the compartment representing either the whole water object or its major sections. Such models are less sensitive to the quality of initial data than more complex 1-, 2-, or 3-dimensional models. The use of latter models imposes fundamental constraints on the possibility of obtaining accurate predictions because of the need for a large body of accurate initial and boundary data, as well as considerable computer time. The paper presents a new box model – UNDBE with the same simplicity and with same requirements for initial data as ordinary box model, but with improved predictability, as well as calibration on a dataset of field measurements.

2 THE MODEL UNDBE

In a vector form as shown by Rauch et al. (1998) one-dimensional transport equation can be written as:

$$\frac{\partial(A\vec{C})}{\partial t} + \frac{\partial(Q\vec{C})}{\partial x} = \frac{\partial}{\partial x} \left(AD_L \frac{\partial \vec{C}}{\partial x} \right) + A\vec{R}(\vec{C}, \vec{P}) \quad (1)$$

where A – cross-sectional area; Q – streamflow rate; D_L – longitudinal dispersion coefficient; $\vec{C}$ – vector of cross-section averaged concentrations of various constituents; $\vec{R}(\vec{C}, \vec{P})$ – vector of rates of change of cross-section averaged concentrations due to conversion processes; x – distance along the watercourse. If (1) is integrated for subsequent flow stretches which complete mixing is assumed we can obtain box model for which the mass balance is expected by the vector equation

$$\frac{d(V\vec{C}^*)}{dt} = Q\vec{C}_i - Q\vec{C}^* + V\vec{R}^*(\vec{C}^*, \vec{P}^*) \quad (2)$$

where $\vec{C}^*$ – concentration vector; $\vec{C}_i$ – inflow concentration vector; V – box volume and $\vec{R}^*(\vec{C}^*, \vec{P}^*)$ – conversion rate vector (stars denote that the interpretation C , R and P is again different than in the one-dimensional case). The model assumes that contaminated water discharged into the compartment is instantaneously, completely and evenly mixed with the compartment water. Therefore, the concentration of contaminant in the outflow is the same as that is average and time of transport through compartment is not taken into account.

Model UNDBE takes account that in the first steps each portion of the water and pollution only moves ($D_L = 0$, $\vec{R}(\vec{C}, \vec{P}) = 0$) through reservoir till the outflow. It means that right side of the equation (1) equal zero and the solution for outflow of the box is:

$$\vec{C}(t, x) = \vec{C}_i \left(t - \frac{A}{Q} x \right) \quad (3)$$

where $Q/A = v$ – average velocity of flowing.

In the second step only at the end of transport each portion of the pollution mixes up in a certain part of compartment volume and interacts there with sediments and bottom depositions as in usual box model. Thus equation (2) looks like:

$$\frac{d(V\vec{C}^*)}{ndt} = Q\vec{C}_i \left(t - \frac{L}{v} \right) - Q\vec{C}^* + V\vec{R}^*(\vec{C}^*, \vec{P}^*) \quad (4)$$

where L – length of the compartment; $1/n$ – is the effective part of compartment in which water mixing occurs at the end of the transport time near the outflow of the box. Such modifications lead to a system of ordinary differential equations with time lag ($T_R = L/v$).

In the new equation, $\vec{C}$ are concentrations averaged, not over the total volume of the compartment, but only over the $1/n$ part found at the outlet. The model UNDBE has the same parameters as ordinary box model and – n . The time lag T_R can be calculated through the mean flow v and length L of the compartment or through the V and Q

($T_R = L/v = V/Q$). This parameter typically varies.

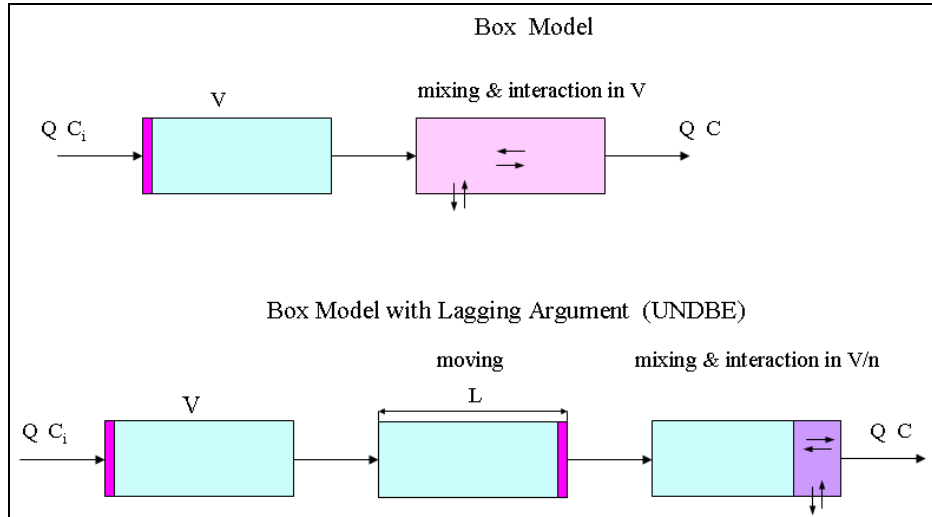


Figure 1. Assumptions of ordinary box model and box model with lagging argument.

The difference between ordinary box model and UNDBE box model is the impulse response to contamination at the inflow of the box. Figures 2 illustrates the impulse of the inflow at the first camera and the outflow response of the joint boxes. The ordinary box model gives an immediate response on outflow of the box where it is stipulated that intermixing is instantaneous at the inflow. Whereas, the UNDBE box model with lagging argument accounts for the time of contamination transposition.

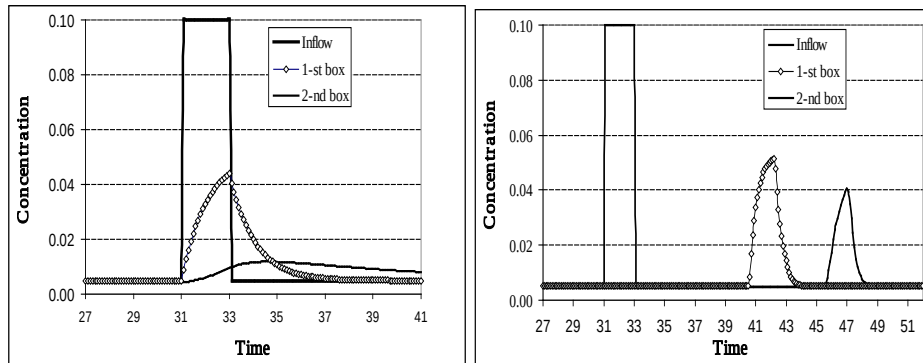


Figure 2. Response of the ordinary box model and the box model with lagging argument.

Simplicity of the new box model and the use of effective procedure for solving equations with time lag as shown by Hairer et al. (1987) made it possible to rapidly calculate the transport of contamination through the reservoir and give the possibility to undertake calibration.

3 COMPARISON RESULTS OF MODELLING

The floodplain areas near the Chernobyl Nuclear Power Plant and surrounding catchments are heavily contaminated with radionuclides, especially ^{90}Sr . The major fraction of the radionuclides wash-off comes from the watershed of the Pripjat River, the right-hand tributary of the River Dnepr. The ^{90}Sr run-off from these watersheds is transported to the Black Sea through a system of six reservoirs located along the Dnepr River. The largest part of the annual runoff goes through the reservoirs from March until June during flood season. The upper reservoir is Kiev reservoir which has a capacity of 3.7 km^3 , the length is 70 km, the maximum depth is 14.5 m, the average depth is 4 m, and there are four main tributaries including Pripjat River.

The calibration of the model was executed on the data set of field measurements 1994 on the Pripjat River and Kiev reservoir. An ice jam took place in the Pripjat River in 1994 and water covered heavily contaminated area and inflow concentration of ^{90}Sr increased rapidly up to 5920 Bq/m^3 during the period 10–14 February 1994. At that time water discharge in the Pripjat was low – $520 \text{ m}^3/\text{sec}$. The spring flood occurred from 27 March to 22 April and concentrations of ^{90}Sr had increased up to 2553 Bq/m^3 . Water discharge in the latter period reached $1700 \text{ m}^3/\text{sec}$ (see Figure 3). The radiological and hydrological data for calculations was prepared by Ukrainian Hydro meteorological Institute and the Ukrainian Hydrological Forecasting Department of the Hydro Met Center. Daily data were used for water discharges and values of concentrations as shown by Voitsekhovitch et al. (1997).

The inflow stream of pollution (1994)

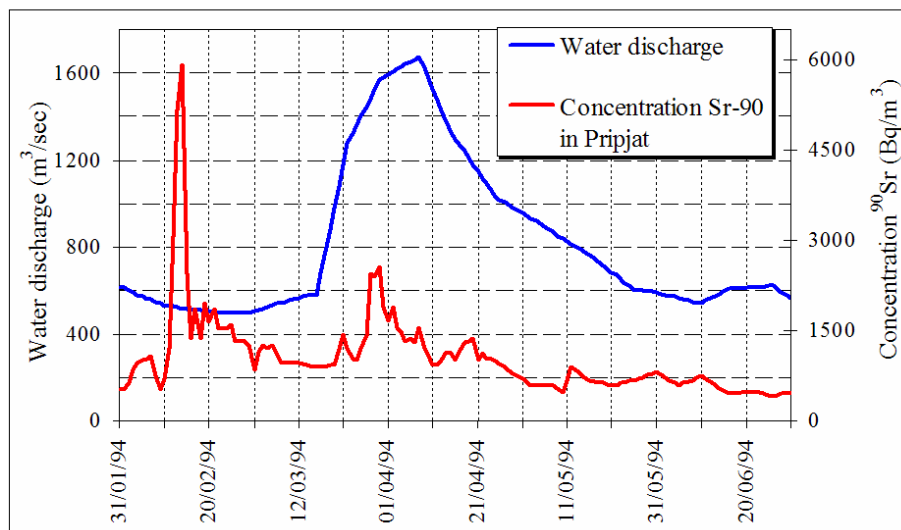


Figure 3. Dynamics of water discharge and ^{90}Sr concentrations in the Pripjat River.

Hereafter “ ^{90}Sr concentration” means – concentration ^{90}Sr in solution since this radionuclide is scarcely adsorbed by suspended material, and the dissolved fraction

typically exceeds 97% of the total.

Concentrations of ^{90}Sr in the Pripjat and the outlet of the Kiev reservoir displayed the same peaks but with some lag due to the water retention time. The delay in the first period was 28 days, in the second 10 days. In the first period, the inflow, outflow, stream velocity in the reservoir was low and the transport time for water was long, in the second case vice versa (Figure 4).

Contaminated water appeared at the outlet of the reservoir at a time interval proportional to the transport time. Because the first peak of concentration in the inflow of the reservoir was more than the second but in the outflow vice versa we can imply mixing in some part of the reservoir during the transportation. The quantity of contamination per unit time was less in the first case as the contaminated water discharge was very low and mixing up in the same volume made outflow concentration less than that during the flood. Measurements also showed that monthly averages (and even decade averages) data do not predict concentrations that can vary 2 – 4 times during the course of a day.

Concentration of ^{90}Sr inflow and outflow (1994)

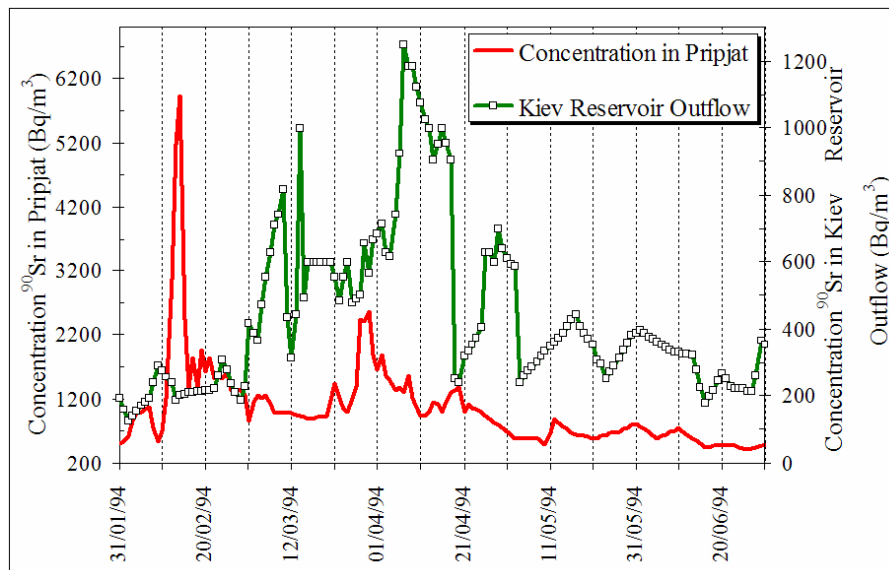


Figure 4. Inflow and outflow concentration ^{90}Sr .

Figure 5 presents ordinary box model WATOX as shown by Zheleznyak et al., (1992) results in a comparison with daily data for ^{90}Sr concentrations in the outflow of the Kiev reservoir.

The results usage of the new model with lagging argument for the same situation is in Figure 6. One box was used for modeling only in both cases. Time of modelling is a few seconds.

An ice jam took place in the Pripjat River 1991 year the same way as in 1994, but the spring flood was absent. Inflow concentrations of ^{90}Sr increased rapidly up to 9546

Comparison of measurements and results of ordinary box model for outflow

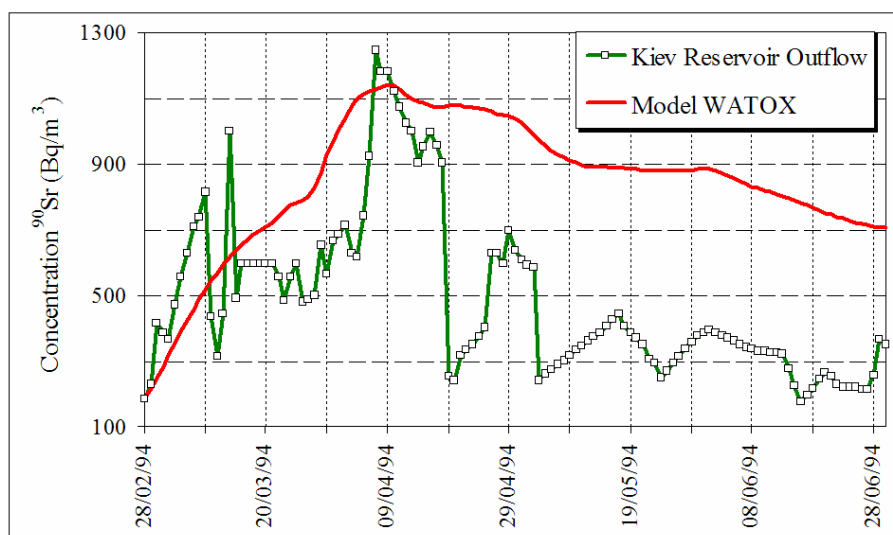


Figure 5. Dynamics of ^{90}Sr concentrations in the outflow of the Kiev reservoir and ordinary box model WATOX predictions.

Comparison of measurements and results of the new box model for outflow

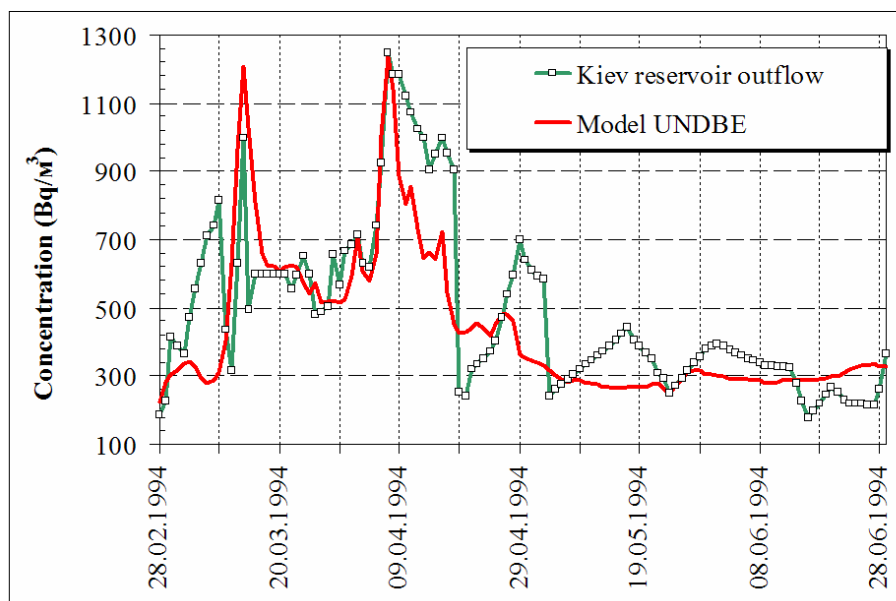


Figure 6. Dynamics of ^{90}Sr concentration in outflow of the Kiev reservoir in 1994 and UNDBE model predictions.

Bq/m³ in the period 22–26 January. There are representative radiological data for this period for concentrations of ⁹⁰Sr in the Pripyat River, but less representative radiological data set for the Kiev reservoir outflow. The latter was measured by different organizations and show considerable spread. The model predictions, concentration of ⁹⁰Sr in the Pripyat River and the Kiev reservoir outflow concentration (measurements with 25% error) are given in Figure 7. The modeling was made at same significances level for parameters, as for case with reduced bed sediment concentration. There was concurrence of peaks of simulated and measured concentrations, although the inclusion of uncertain empirical data allows us to consider the results satisfactory.

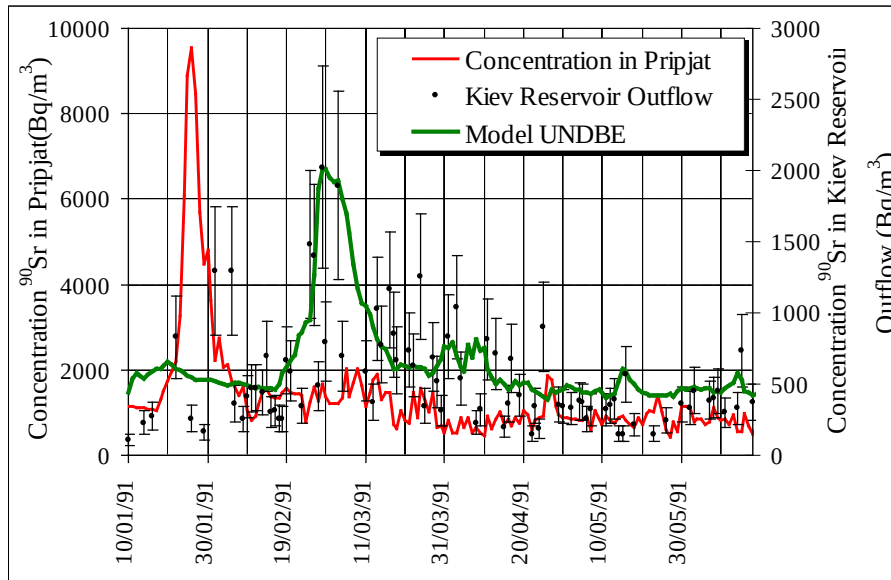


Figure 7. Dynamics of ⁹⁰Sr concentration in the Pripyat River, in the Kiev reservoir outflow and UNDBE model predictions (1991).

The situation of February – June 1999 when high spring flood in the Pripyat River took place is the next example of validation. The model predictions, concentration of ⁹⁰Sr in the Pripyat River and the Kiev reservoir outflow concentration are given in Figure 8. The error of measuring of ⁹⁰Sr was appraised by the size of order $\pm(30-40)\%$ for this case as shown by Voitsekhovitch et al. (1997). As practically all UNDBE model values of concentrations (Figure 8) are in an interval $\pm 35\%$, the results of design can be considered consistent with measuring with sufficient exactness.

Concentration of ^{90}Sr inflow, outflow and results of the new box model for outflow (1999)

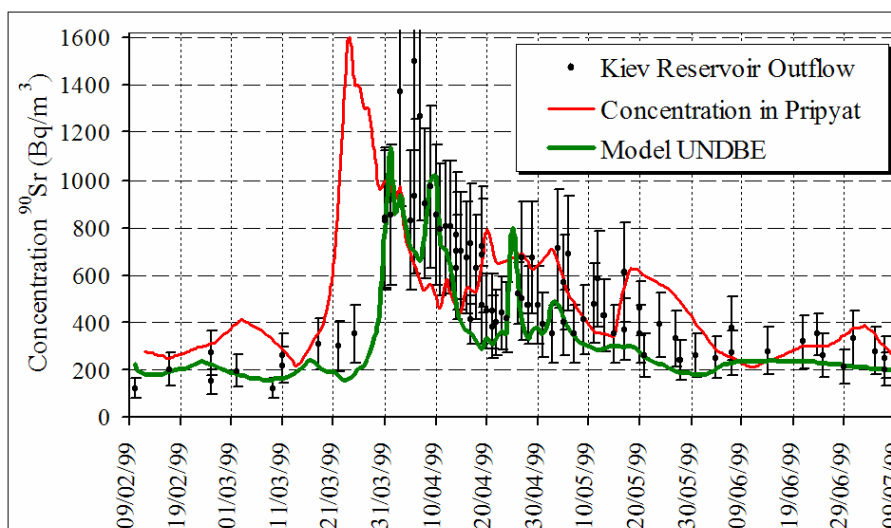


Figure 8. Dynamics of ^{90}Sr concentration in the Pripyat River, in the Kiev reservoir outflow and UNDBE model predictions (1999).

4 MODELING EJECTIONS ^3H IN THE LOIRE RIVER

The research of passing of ejections ^3H in 350 kilometers channel Loire River (France) was made in the framework of the IAEA program EMRAS (**E**nvironmental **M**odelling for **R**adiation **S**afety) as shown by EMRAS (2007). The data for calculations was prepared by EDF-LNHE (France).

A calculations of tritium dispersion for 11 points along the river (Figure 9) on stretch a half-year taking into account water discharges from tributaries and using real hydraulic conditions of the year 1999 with 1 hour time step was conducted with help of the model. The ejections of ^3H take place in an outcome of normal work of five NPP. The outcomes obtained with the help of the model UNDBE in Angers and compared to measurements, are represented on Figure 10. Comparison of results is executed by employees EDF. Figure 10 demonstrates good coincidence of outcomes of modeling and measurements. Computing time for modeling is only 2 minutes.

Sharp growths of concentration of tritium are investigation of interference of the ejections ^3H from different stations. Thus there is of principle possibility to decrease the maximal concentrations ^3H by the change of time of the ejections of the separate stations. The amplitude and duration of separate ejections remains without modifications. The search of favorable combinations of moments of the ejections can be certain with the help by the modeling.

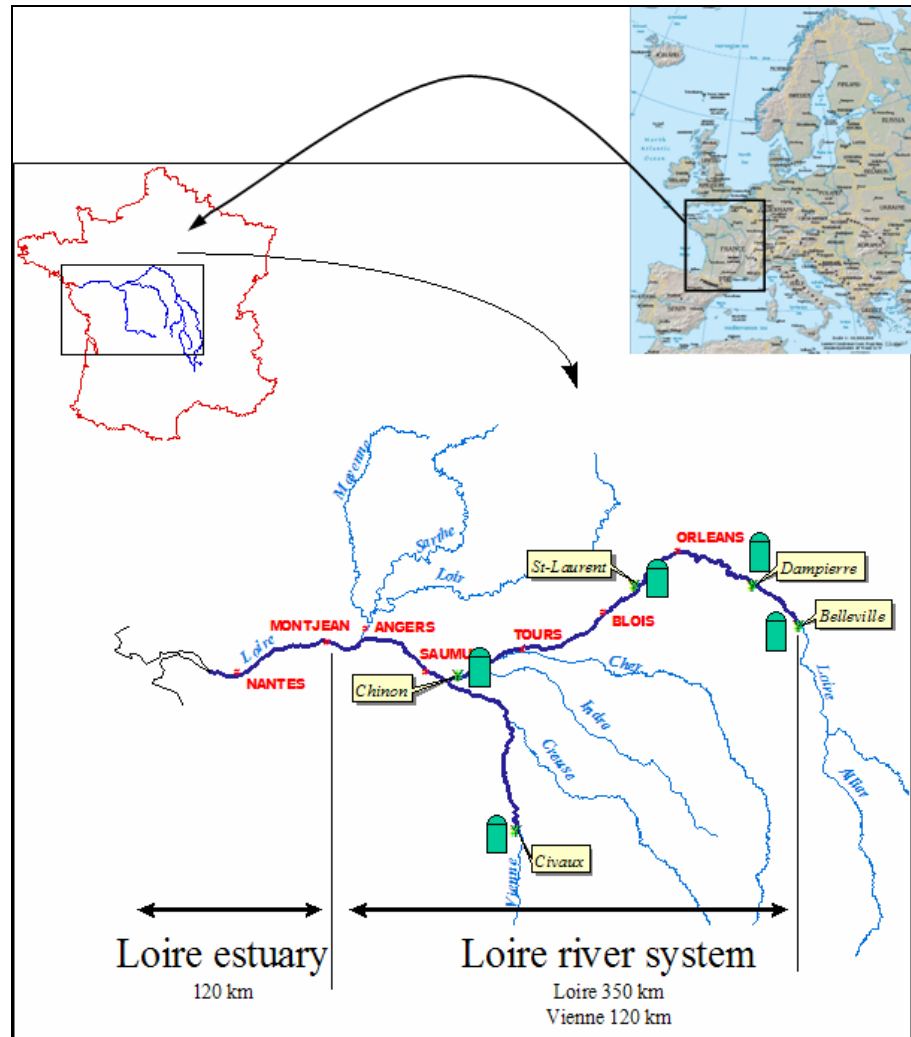


Figure 9. Loire River basin.

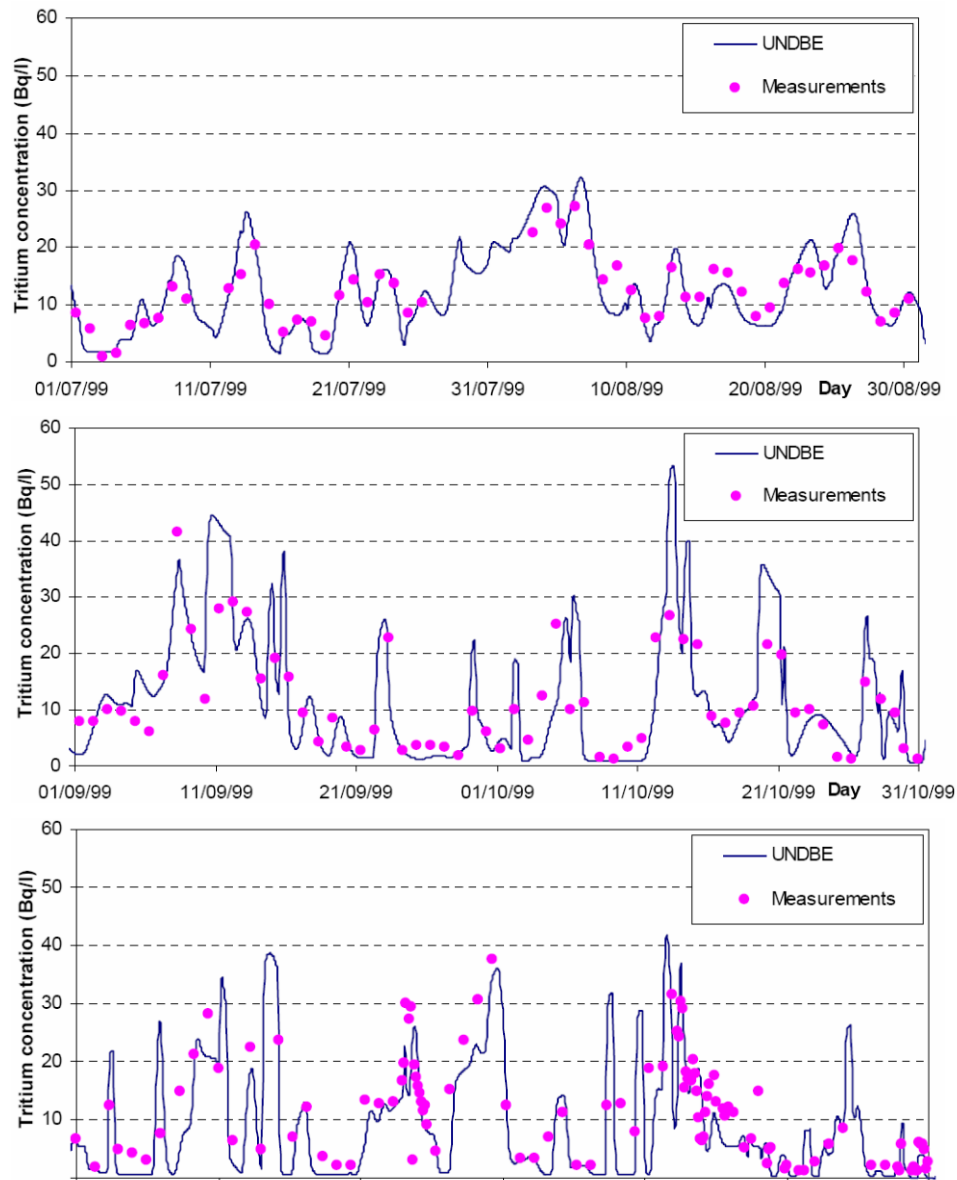


Figure 10. Comparison between calculated and measured tritium concentration at Angers for Undbe.

Within the framework of the EMRAS project, comparison of results of got by different models was foreseen. The 1-D model MASKARET is specially developed in EDF France and adapted for prognostication of situation in Loire showed very near results as shown by EMRAS (2007).

The results got by other 1-D and box models of taking part in this comparison, in

opinion of author, considerably worse coincide with measurements.

5 CONCLUSIONS

A box model with a lagging argument is shown intended to simulate radionuclide transport in surface water.

Application of the offered box model unlike an ordinary box model allowed to take into account time of transporting of contamination and diffusion in part of volume of box.

Comparison of results of the offered model with the results got by an ordinary box model for the identical situation of passing of contamination shows the increase of accuracy of modeling.

The offered model shows results not worse than the 1-D models.

Acknowledgments. The author kindly thanks to the researchers of Ukrainian Hydrometeorological Institute, the Hydrological Forecasting Department of the HydroMet Center in Kiev, Derzhvodgosp of Ukrain, the DIREN Centre and EDF (France) for radiological and hydrological data.

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