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Short communication

Customisation of the decision support system MOIRA-PLUS for applications to the marine environment

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ABSTRACT

The present short communication describes a technique to customise the decision system MOIRA-PLUS for applications to the marine environment. MOIRA-PLUS was originally designed to predict the behaviour of ^{137}Cs and ^{90}Sr in fresh water ecosystems and to evaluate the environmental, social and economic impacts of selected countermeasures aimed at restoring the polluted environment and at reducing the doses to man. An example of application for predicting the concentration of radiocaesium of Chernobyl origin in the Mediterranean Sea is described and discussed. The technique allows the user to easily integrate existing state-of-the-art box models of sea water circulation into the MOIRA-PLUS decision system.

1. Introduction

The development and application of predictive models for the assessment of the behaviour of radioactive substances in the marine environment were the subject of a great many of studies in past decades (Harms and Karcher, 2003; Povinec et al., 2005). The models show different degrees of sophistication – ranging from box models to models based on 3-D dispersion-transport equations – and account for the complexity of processes occurring in the aquatic environment (Agüero, 2005; Håkanson, 2004; Iosjpe et al., 2002; Koziy et al., 1998; Lepicard et al., 2004; Osvath et al., 1999; Periáñez, 2008; Smith et al., 2003).

MOIRA-PLUS is a PC-based user friendly, Decision Support System (DSS) aimed at helping decision makers to chose optimal remedial strategies for fresh water environments contaminated with ^{137}Cs and ^{90}Sr (Monte et al., 2009). The present work describes a technique to extend to the marine environment the application domain of the decision system MOIRA-PLUS originally designed for fresh water ecosystems.

The DSS is based on validated models for predicting the behaviour of the above mentioned radionuclides in catchment, lakes, rivers and reservoirs, the doses to the population and the effectiveness of selected countermeasures to reduce the levels of contamination of the environment and the doses to man. The effectiveness of the countermeasure strategies is evaluated by a multi-attribute analysis module that accounts for the social, ecological and economic detriments as well as the costs and benefits of the countermeasures (Ríos-Insua et al., 2006).

An operative system working on Windows based PC computers links the different modules with a friendly output–input user interface allowing the user to run the models, to define different countermeasure options, to rank the options in view of their predicted outcomes and of the ecological, economic and social impacts, to produce a report of the results and to profit from the functionality of a Geographic Information System (Map-Info software) (Hofman, 2004, 2005; Hofman and Nordlinder, 2003).

The new version of the DSS (release 4.1.2, https://sites.google.com/site/moirasoftware) allows the user to customise the migration models of MOIRA-PLUS to assess the behaviour of radionuclides in complex networks of water systems including, for instance, a main watercourse and several tributaries of different order, provided that the size of the system does not exceed 20 reaches. However the domain of application of this version is limited to managing aquatic networks with movement of water masses occurring along the direction from springs to the water body mouth as typically occurs in fresh water systems.

The aim of the present communication is to describe a new functionality of the MOIRA-PLUS migration models that allows the

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user to apply the decision system to water bodies characterised by two-way water fluxes between different portions of the aquatic system and by current circulations typical of the marine environment.

A great many box models describing the circulation of water in seas are available (Archer et al., 2003; Ikeda et al., 1999). The models are used for many different kinds of evaluations of the complex processes occurring in seas. This work will show that these box-type models, like those suggested for the Mediterranean Sea and for the seas in northern Europe by CCE (1979), can be easily integrated into MOIRA-PLUS to predict the behaviour of radiocaesium and radiostrontium in the marine environment.

An example of application of the DSS to the Mediterranean and the Black Seas contaminated following the Chernobyl accident is presented and discussed.

2. Principles of MOIRA-PLUS migration models

MOIRA-PLUS predicts the behaviour of contaminants transported by the water flowing through an aquatic system. The water body is subdivided into "sectors" (reaches). The contaminant behaviour is modelled accounting for the basic processes depicted in Fig. 1. Such processes are common to marine and fresh water environments. The model structure shown in Fig. 1 has obtained a wide consensus among modellers. Indeed, it is simple and based on a limited number of parameters for predicting the behaviour of contaminants in the water column. The migration of radionuclides through complex aquatic ecosystems can be simulated by a "chain of sectors" representing different portions, such as river reaches, of water systems comprised of lakes, reservoirs, main rivers and theirs tributaries (Monte, 2011).

The standard version of MOIRA DSS assumes that water can flow between different sectors according to a unidirectional flux from the spring towards the mouth. Consequently, the recirculation of water among different sectors is not allowed.

For applications to the marine environment as well as to deep water bodies, MOIRA was improved by introducing the possibility of managing two-way water movements and recirculation in order to simulate the migration of contaminant through seas, large lakes and stratified water bodies. Moreover, site specific values can be assigned to the migration parameters (sedimentation velocity, migration rates to and from bottom sediment, bioaccumulation factors, etc.) in order to simulate more appropriately the dynamics of the processes occurring in the marine environment.

The MOIRA models for assessing the contamination of aquatic biota account for two fish species, namely prey and predator. The behaviour of radionuclides in each species is modelled by a single compartment and by assuming that a first order process controls the uptake-excretion dynamics. Moreover, the model evaluates the contaminant concentrations in predators performing random movements through the water body in order to account for the effects of the spatial heterogeneity of the pollution levels on the biota contamination (Monte, 2002). The prey and predator compartments can be used to simulate the radionuclide behaviour in two different biota species: stationary and migrating organisms in the marine environment. Therefore, it is possible to carry out calculations for shellfish and fish as suggested by basic safety standards (IAEA, 2001) provided that appropriate values are assigned to the bioaccumulation factors and to the biological loss rates of radionuclide in the selected living species.

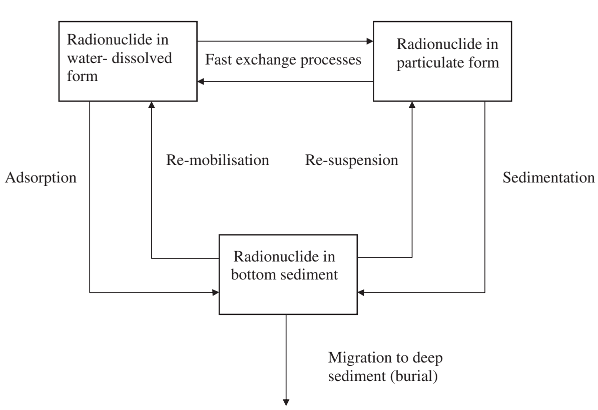

Fig. 1. Basic processes of radionuclide interaction with suspended matter and bottom sediment.

The customisation of MOIRA-PLUS to simulate the movement of masses of water through different segments is as simple as to input the values of the entries of a matrix.

Let us assume that the modelled sea is subdivided in N different sectors. If we denote by B_i the balance, in the generic sector i, between the evaporation, the precipitation and the water discharged by rivers (or from other external water sources such as the Atlantic Ocean in the case of the application to the Mediterranean Sea that will be described in the following section), we can write:

$$B_i + \sum_{1;j\neq i}^{N} k_{ij}\varphi_j - \varphi_i = 0 \quad (1)$$

where $\varphi_j(\varphi_i)$ is the total flux of water that flows out of the sector j (i) and k_{ij} is the proportion of this total flux that flows from sector j to $i \neq j$ (φ_{ij}):

$$\varphi_{ij} = k_{ij}\varphi_j \quad (2)$$

The model calculates the balances of radionuclide in each sector assuming that the radionuclide fluxes (ϕ_{ij}) from sector j to i is equal to the radionuclide concentration in water of sector j (C_j) multiplied by the water flux from j to i: $\phi_{ij} = C_j k_{ij}\varphi_j$.

If ratios k_{ij} are known, the fluxes φ_i can be obtained from the following equation:

$$K\varphi = B \quad (3)$$

where

$$K = \begin{bmatrix} 1 & \cdots & -k_{1N} \\ \vdots & \ddots & \vdots \\ -k_{N1} & \cdots & 1 \end{bmatrix} \quad (4)$$

and φ and B denote the vectors with components φ_i an B_i, respectively. The entries of matrix K are the parameters required by MOIRA-PLUS to determine the fluxes of water and radionuclide among the different sectors of the water body.

When estimates of the fluxes φ_{ij} are available, the values to assign to entries k_{ij} can be easily obtained by formula (2) accounting for $\varphi_j = \sum_{1;i\neq j}^{N}\varphi_{ij} + \varphi_{out}$, where $\varphi_{out} = k_{out}\varphi_j$ is the flux of water that flows into the ocean.

Matrix K and the relevant mathematical algorithms previously described were integrated in the following sub-models of MOIRA-PLUS: HYDRO (Hydrologic module), MIGRA (module simulating the migration of radionuclides through the abiotic components of the water body) and BIOT (module simulating the migration of radionuclides from the abiotic components of the water body to the fish species) (Monte et al., 2009). The integration did not require any modification of the input–output structure of the data files of the DSS. Consequently, MOIRA-PLUS can maintain its whole functionality (running models, defining different countermeasure options, ranking these options in view of their outcomes and of the