European ALARA Network 17th Workshop
ALARA in Emergency Exposure Situations
15 – 17 May 2017, Lisbon, Portugal

# Modelling of Nuclear Accident Consequences on Freshwater Bodies

## (With emphasis on the long-term radiological impact)

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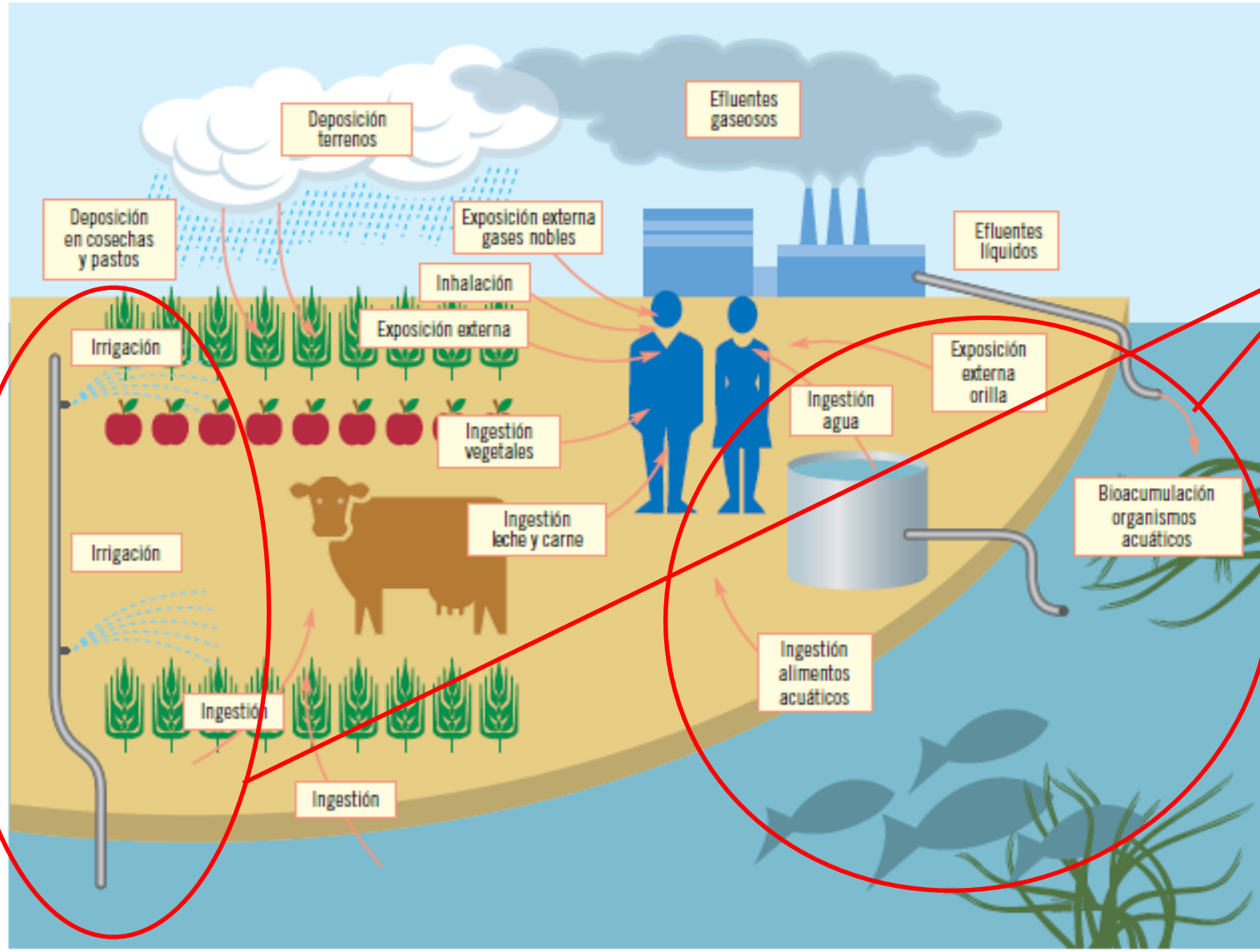
- Introduction
- Integration of models for radionuclide transport and aquatic pathways in Decision Support Systems – JRodos - HDM
- Models for long-term radionuclide transport in freshwater bodies and catchments: MOIRA
- Dose assessment from aquatic pathways. FDMA
- Final considerations

# With special thanks to:

- All the colleagues in MOIRA and PREPARE WP5 projects:
  - Luigi Monte
  - Lars Håkanson
  - Dmitry Hofman
  - John Brittain
  - Rudie Heling (in memoriam)
  - Liana Papush
  - Mark Zheleznyak
  - Yevgen Yevdin
  - … and many others

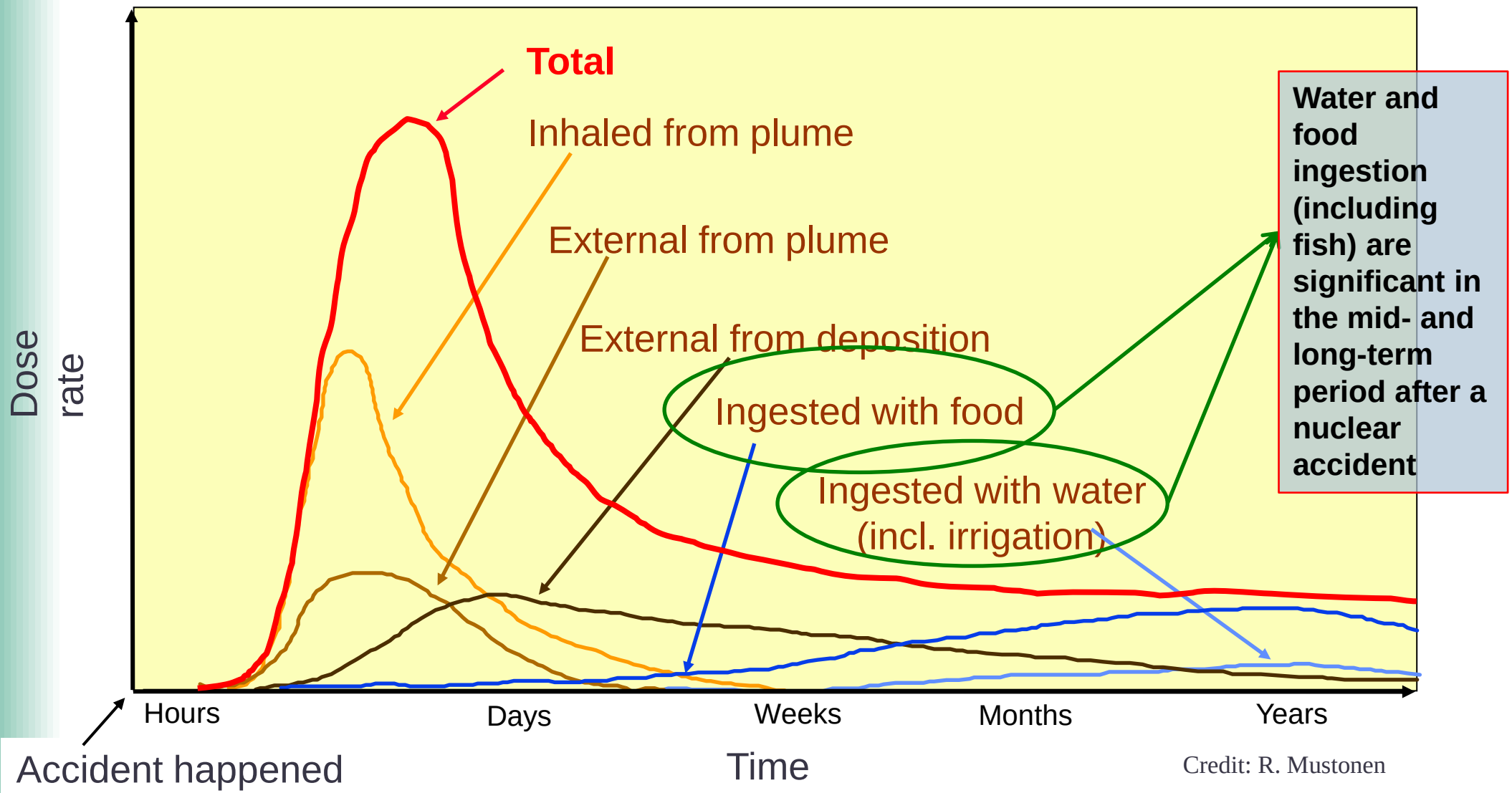
# Exposure pathways after a nuclear accident




**Exposure pathways linked to freshwater contamination, either by direct liquid releases or by atmospheric deposition onto the water bodies surface**

Figure: CSN

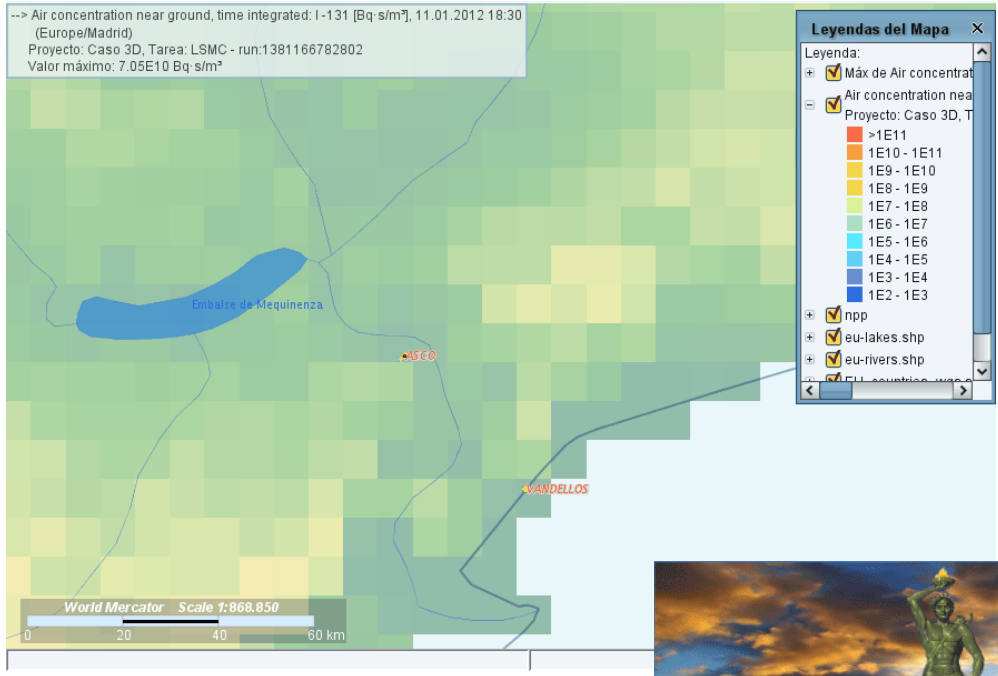
# Typical pattern of exposure during and after a nuclear accident

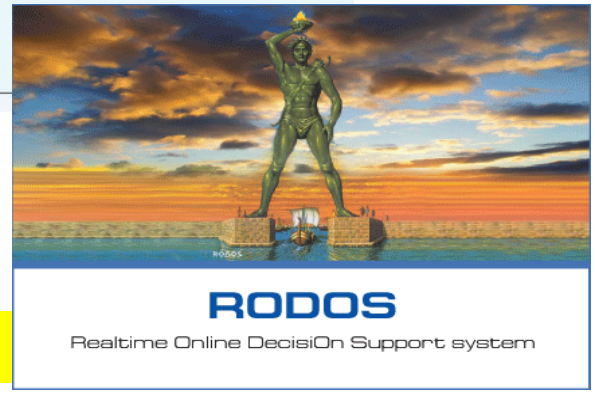



Credit: R. Mustonen

# **RODOS** – The **R**eal-time **O**n-line **D**ecisi**o**n **S**upport System.

Developed under auspices of 3rd - 7th Euratom Framework Programmes (1992-2016).




https://resy5.iket.kit.edu/JRODOS/

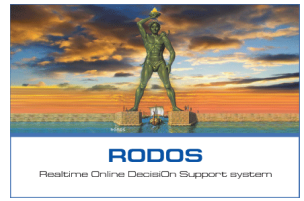
Re-engineered based on the JAVA technology and further named **JRodos**.

Included a Hydrological Dispersion Module (**HDM**).

Within **PREPARE** project (2013-2016) → additional developments to increase its capabilities with new functionalities

# Radio-ecological and dose models in JRodos

[adapted from JRodos Team KIT, **2013**]




**Atmospheric Dispersion Model**

**Deposition Model**

**Deposition Monitoring Model**

**Food Monitoring Model**

**Hydrological Models**

**FDMT**

**Terrestrial food chain model**

**Terrestrial dose model**

**FDMF**

**Forest food chain and dose model**

**FDMA**

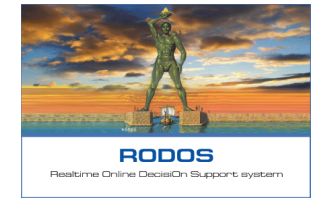
**Aquatic food chain and dose model**

**Gaps existing with regard to aquatic pathways in 2013:**

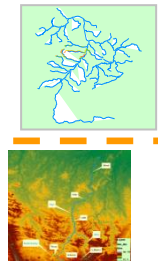
- **Long-term prognosis for freshwater bodies**
- **Coastal sea and ocean**

**EmerSim: Early Countermeasures Model**
**ERMIN: European model for inhabited areas**
**AgriCP: Agricultural Countermeasures Program**

# Hydrological Dispersion Models (HDM) in JRodos (2013)

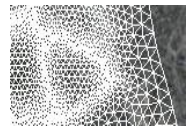



Models of radionuclide washoff from watersheds

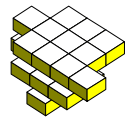


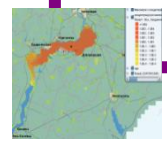
1-D river flow, sediments and radionuclide transport models

2-D reservoirs, floodplains and coastal areas model (unstructured grid)



3D model for deep river, reservoirs and lakes





HDM

RETRACE-RUNTOX

RIVTOX

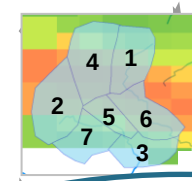
COASTOX

THREETOX

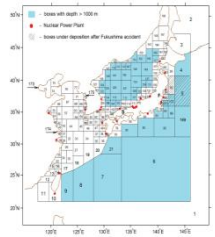
FDMA

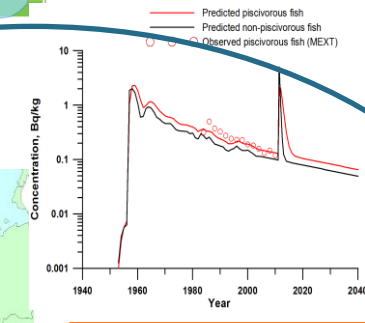
POSEIDON

Freshwater food chain and dose model




Marine food chain and dose model



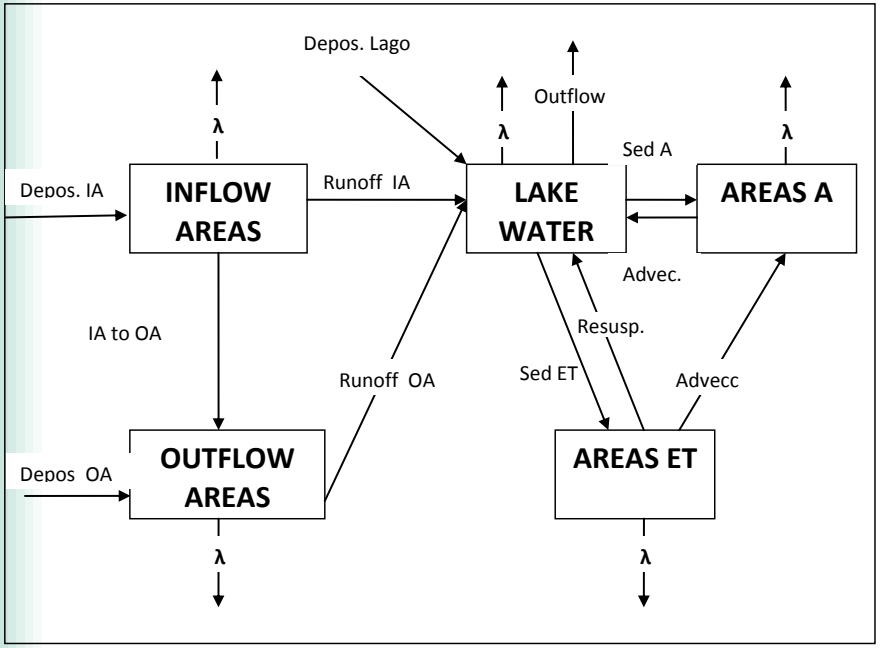


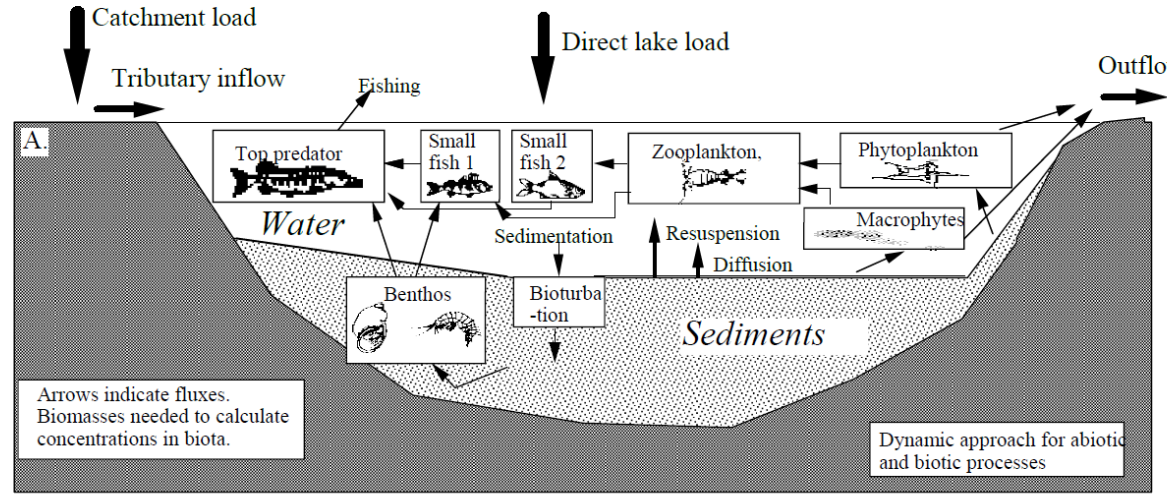

Credit: M. Zheleznyak

# MOIRA Decision Suport System

- MOIRA is a Decision Support System (DSS) developed in the 90's during Euratom FP4 (MOIRA, COMETES) and FP5 (EVANET-HYDRA). Implemented and applied to different scenarios in Spain, France, Italy, Chernobyl affected areas, etc. More than 20 users. Significant feedback from end-users during FP6 EURANOS project and NERIS-TP (PENTA).
- The purpose of MOIRA is to help characterizing the radiological situation and selecting adequate management strategies for different aquatic ecosystems contaminated by radionuclides.
- MOIRA is not aimed at the emergency, but rather at management strategies for the long-term. It complements JRODOS-HDM. Some users suggested integrating them.
- Based on validated models for predicting the dynamic behaviour of $^{137}Cs$ and $^{90}Sr$ in **lakes, rivers and drainage areas** and well as the effect of selected countermeasures to reduce the contamination levels.
  - To analyse complex rivers systems and catchments it is limited to the definition of 20 river branches and reaches.
  - The models have been validated against historical data from several lakes and rivers.

# MOIRA Lake model



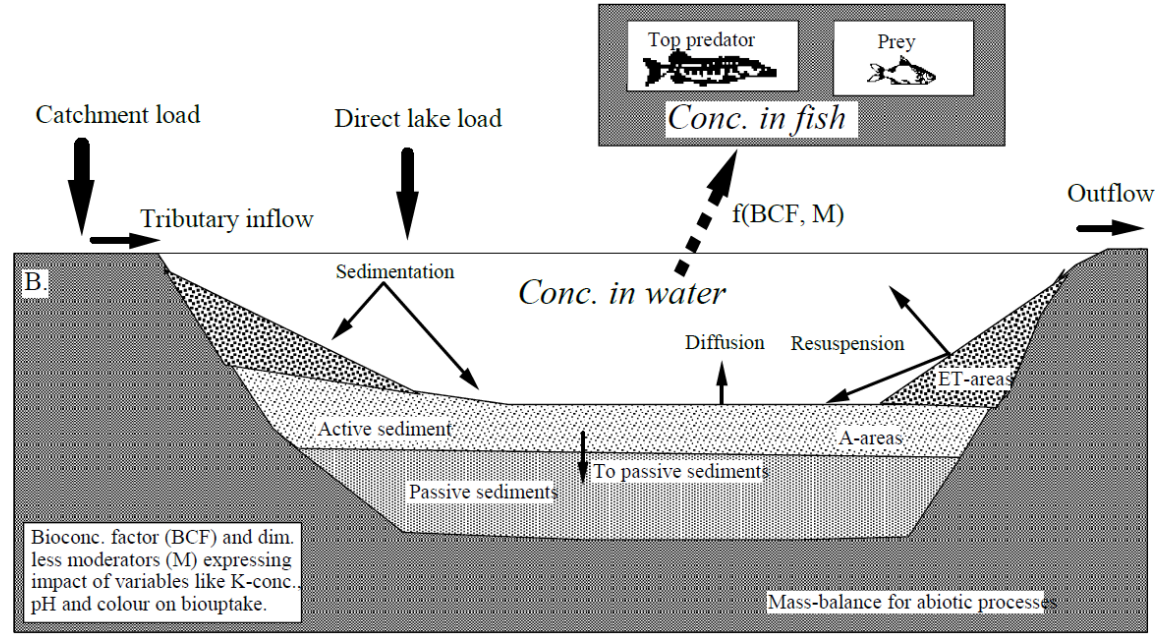
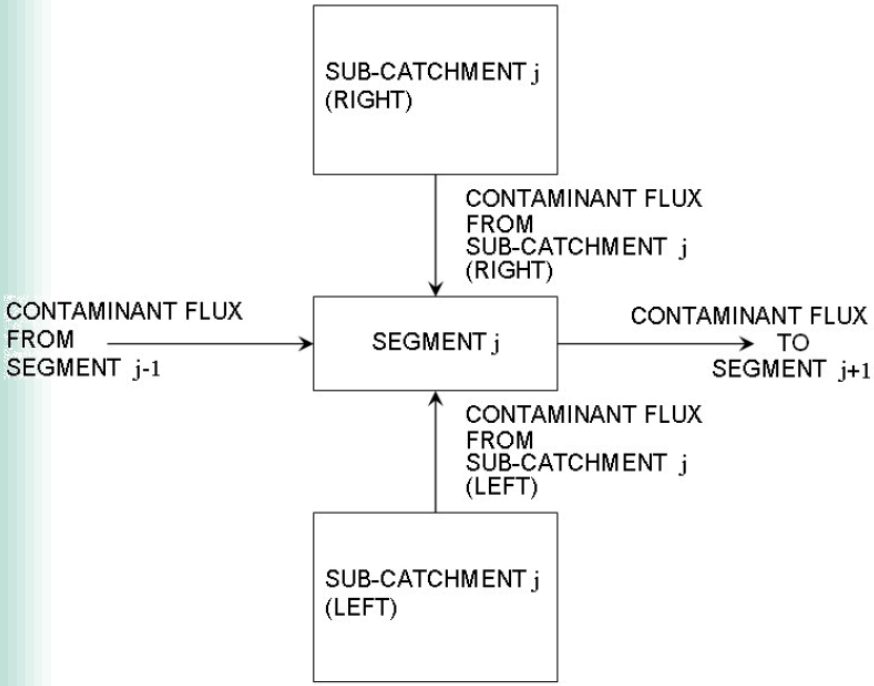




*Figure 1*: General view of the lake model (Håkanson, 1999).

# MOIRA River model




(Monte, 2001)

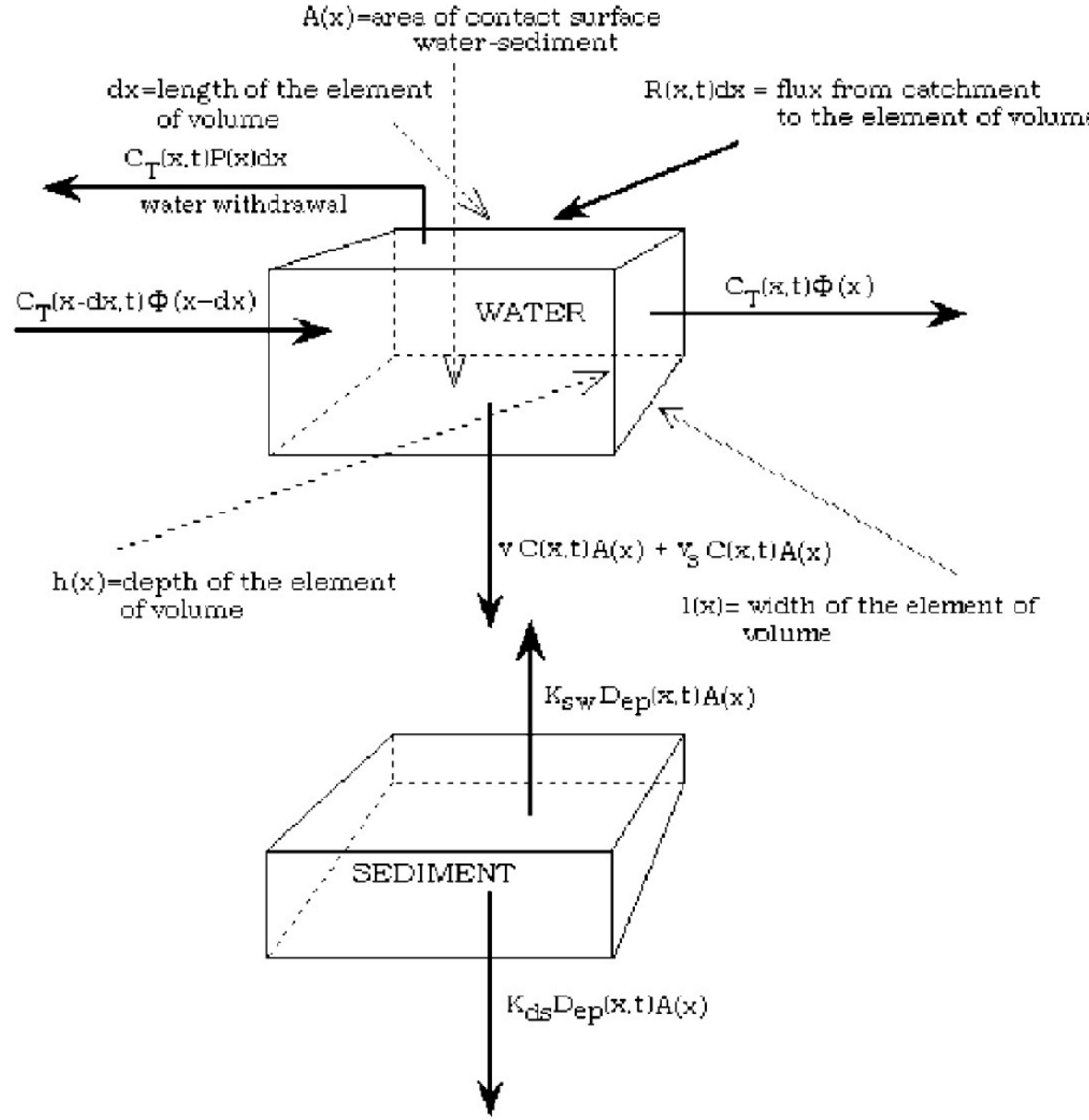
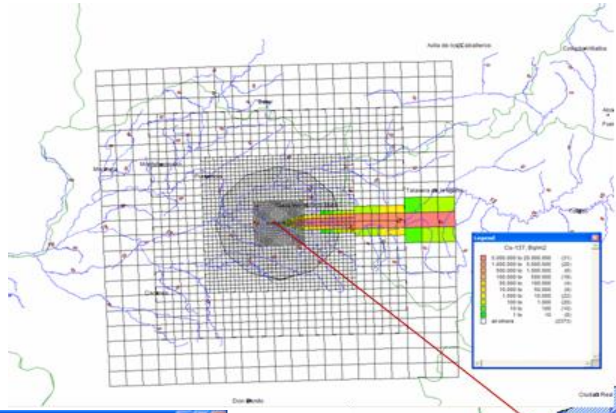
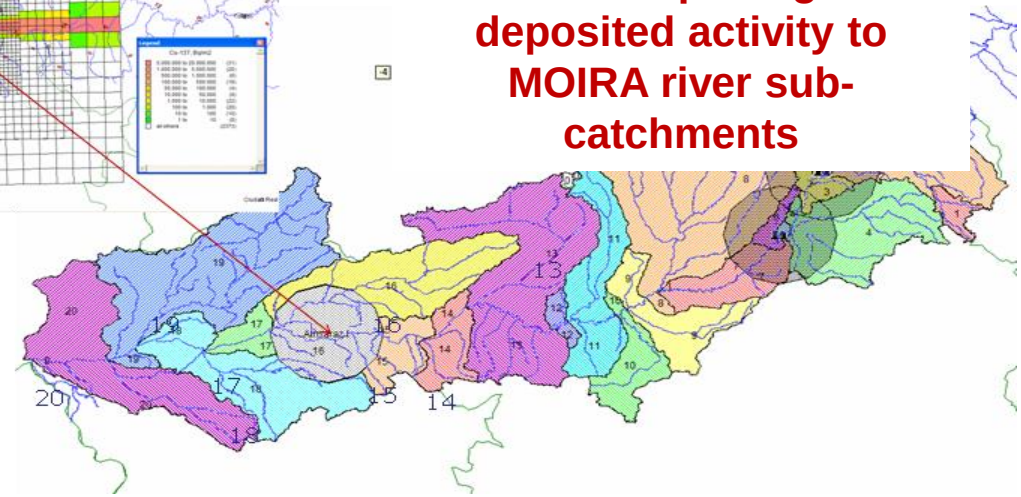


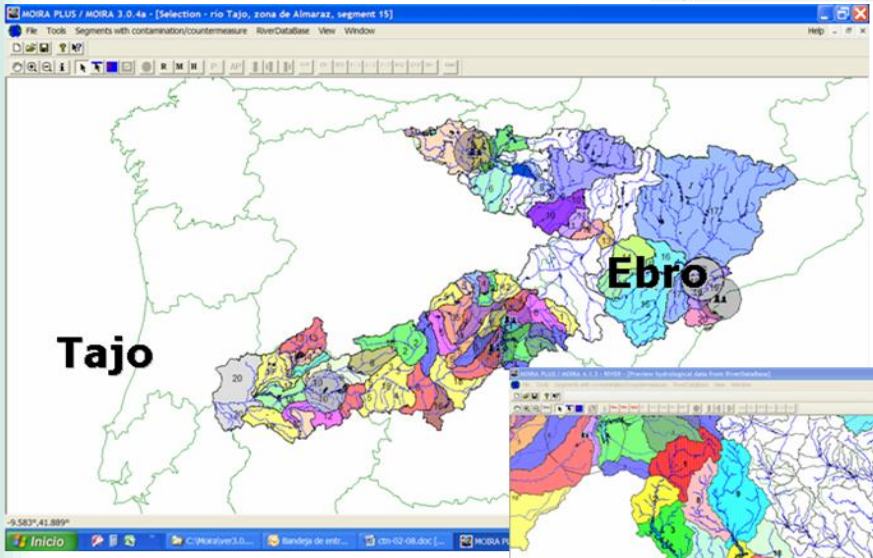

Figure 6. Radionuclide migration fluxes within an elementary segment.

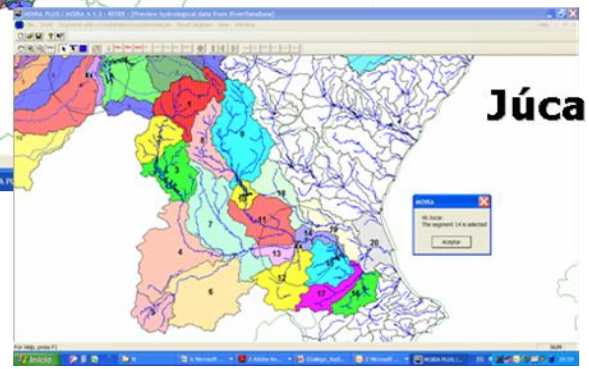
# Adaptation of MOIRA to Spanish Rivers



**For complex river scenarios: linking of JRODOS maps of ground deposited activity to MOIRA river sub-catchments**






**Characterization of Spanish rivers**

PREPARE

EC Euratom for Nuclear Research and Training Activities:
Project Acronym: **PREPARE** **2013-2015**

# Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe

## Work Package 5: Extension of aquatic dispersion and consequence modelling in Decision Support Systems, on the basis of recent experiences and technological advances

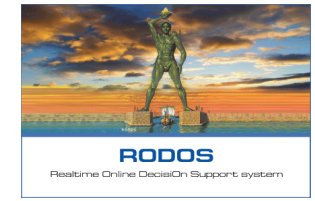
Work Package Coordinator: Mark Zheleznyak (UCEWP; IER)

Work Package participants: UCEWP; KIT; UPM; NRPA; CIEMAT; NRG; Liana Papush; IFIN; USEV; ENEA; IER

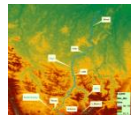
MOIRA

RODOS
Real-time Online Decision Support system

# Hydrological Dispersion Models (HDM) in JRodos (2017)




Models of radionuclide washoff from watersheds



HDM

RETRACE-RUNTOX

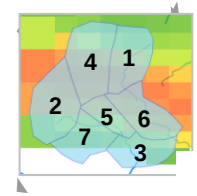
MOIRA

Long term prediction and management model: lakes and rivers

1-D river flow, sediments and radionuclide transport models

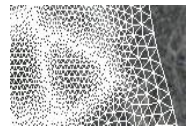
RIVTOX-SV

FDMA

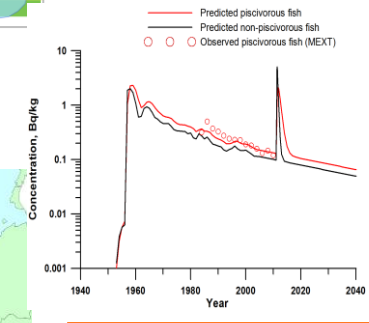



Freshwater food chain and dose model

2-D reservoirs, floodplains and coastal areas model (unstructured grid)

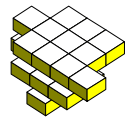


COASTOX-UN



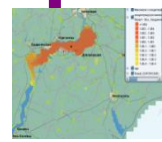

Marine food chain and dose model

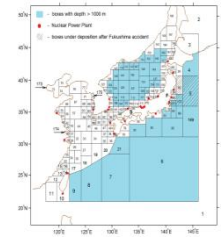
3D model for deep river reservoirs, lakes and marine environment



THREETOX

POSEIDON





Credit: M. Zhelezniak

## REFERENCES FROM PREPARE PROJECT:

PREPARE


**Hydrological dispersion module of JRODOS: renewed chain of the emergency response models of radionuclide dispersion through watersheds and rivers**
M. Zheleznyak, S. Kivva, I. Ievdin, O. Boyko, P. Kolomiets, M. Sorokin, O. Mikhalskyi and D. Gheorghiu
Radioprotection, 51 (2016) S129-S131 DOI: http://dx.doi.org/10.1051/radiopro/2016048

**Integration of 3D model THREETOX in JRODOS, implementation studies and modelling of Fukushima scenarios**
V. Maderich, I. Brovchenko, A. Dvorzhak, I. Ievdin, V. Koshebutsky and R. Periáñez
Radioprotection, 51 (2016) S133-S135 DOI: http://dx.doi.org/10.1051/radiopro/2016049

**Integration of marine food chain model POSEIDON in JRODOS and testing *versus* Fukushima data**
R. Bezhenar, R. Heling, I. Ievdin, M. Iosjpe, V. Maderich, S. Willemsen, G. de With and A. Dvorzhak
Radioprotection, 51 (2016) S137-S139 DOI: http://dx.doi.org/10.1051/radiopro/2016050

**Integration of long-term radionuclide transport models MOIRA-LAKE and MOIRA-RIVER into Hydrological Dispersion Module of JRODOS**
E. Gallego, L. Papush, I. Ievdin, A. García-Ramos, R. Pato-Martínez and L. Monte
Radioprotection, 51 (2016) S141-S143 DOI: http://dx.doi.org/10.1051/radiopro/2016051

**Implementation of Hydrological Dispersion Module of JRODOS for the assessment of Cs transport and fate in rivers, reservoirs and ponds of the Fukushima Prefecture**
K. Nanba, M. Zheleznyak, S. Kivva, A. Konoplev, V. Maderich, V. Koshebutsky, E. Gallego, L. Papush and O. Mikhalskyi
Radioprotection, 51 (2016) S145-S148 DOI: http://dx.doi.org/10.1051/radiopro/2016052

**A comparison of radionuclide dispersion model performances for the Baltic Sea and Fukushima releases in the Pacific Ocean**
R. Periáñez, R. Bezhenar, I. Brovchenko, C. Cuffa, M. Iosjpe, K.T. Jung, T. Kobayashi, F. Lamego, V. Maderich, B.I. Min, H. Nies, I. Osvath, I. Outola, M. Psaltaki, K.S. Suh and G. de With
Radioprotection, 51 (2016) S149-S151 DOI: http://dx.doi.org/10.1051/radiopro/2016053

# Additional development of JRodos-HDM in the frame of PREPARE project (WP5)

PREPARE

i. Modelling radionuclide transport in coastal waters driven by the atmospheric fallout from JRODOS ADM and/or by direct releases into marine environment.
   - for the post accidental real-time forecasting and for the analyses of long term contamination of the marine environment including marine biota;

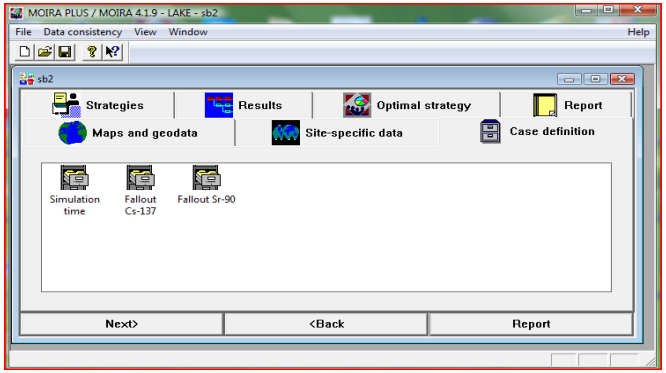
ii. Modelling of long-term fate of radionuclides in freshwater systems for predictions of the radiation doses via aquatic exposure pathways, by integrating the lake and river models from the MOIRA DSS;

iii. Analyses of the efficiency of countermeasures to diminish such doses after an accident, based on MOIRA and FDMA models

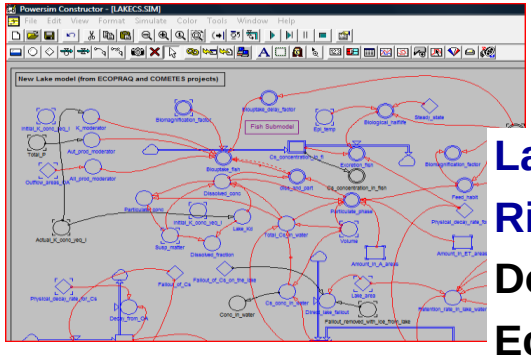
# Integration of MOIRA Lake and River models into JRODOS

PREPARE

## MOIRA DSS (standalone)




## Powersim®




**Lake Model**

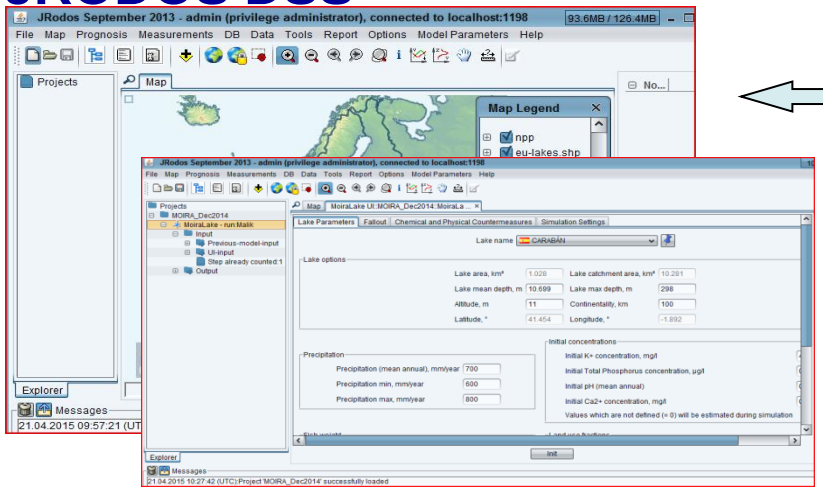
**River Model**

**Dose Model**

**Economic Model**

**Decision analysis MAA**

## JRODOS DSS




**MOIRA Lake and River Models** are developed as FORTRAN codes and compiled into .dll

Models are integrated as plug-ins

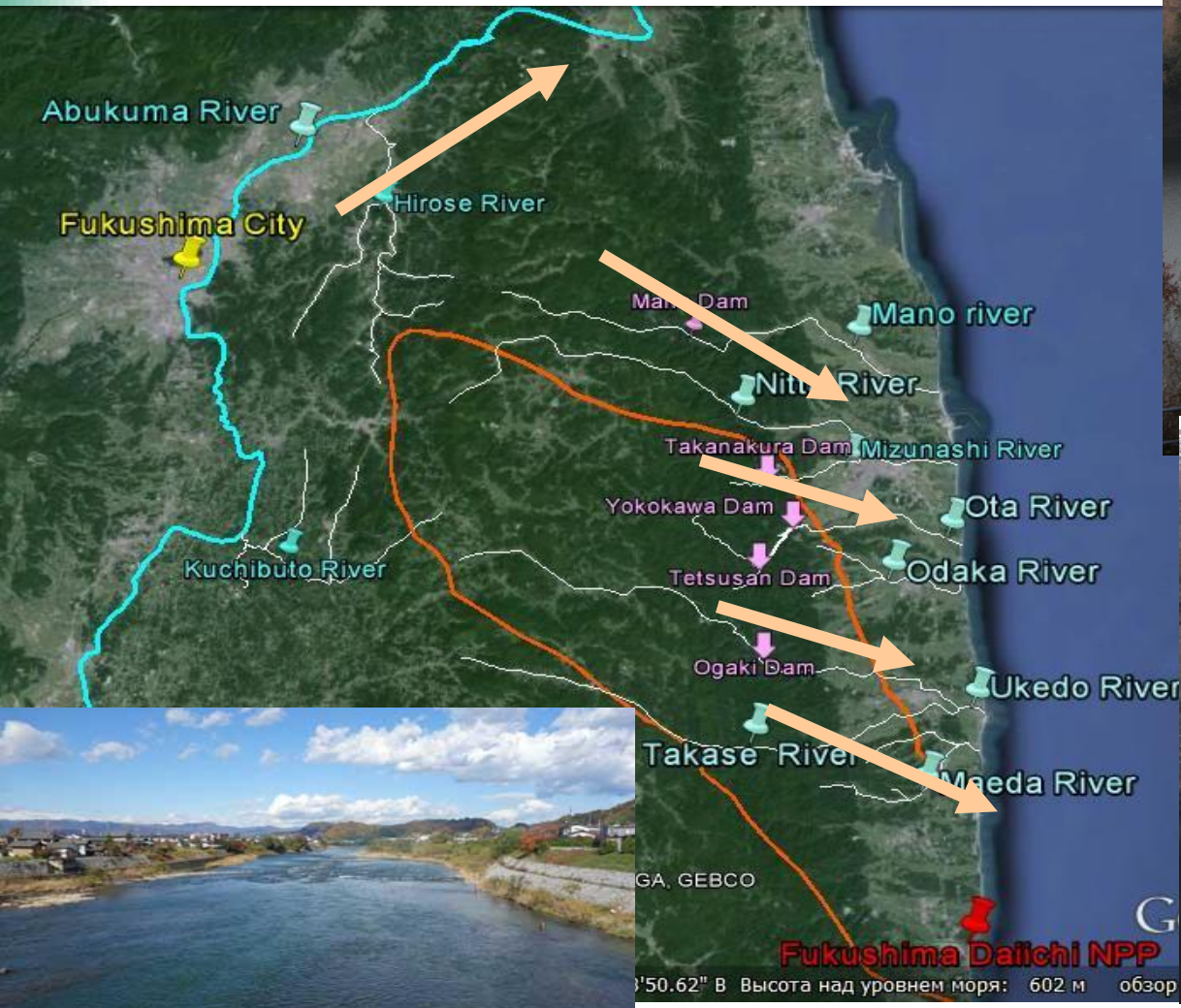
# Integration of MOIRA Lake and River models into JRODOS

PREPARE

## Main elements

- Development of the MOIRA Models (Lake, River, LEI) as Fortran modules (based on their Powersim® implementations in the MOIRA DSS)
- Development of the model-specific JRODOS User Interface Java modules
- Establishment of the data exchange between models and user interface
- Transfer of the GIS data available in the MOIRA DSS into the JRODOS GIS (instead of the actual MapInfo based systems in MOIRA).
- Integration into the overall JRODOS structure:
  - Getting environment contamination input data from ADM module.
  - Connecting MOIRA models results to FDMA to assess radiation doses and affected population.
  - Select information and manage reporting in JRODOS.

# JRodos-HDM models implementation for simulation of $^{137}Cs$ transport in the reservoirs of Fukushima fallout Zone






Credit: M. Zheleznyak

# JRodos-HDM models implementation for simulation of $^{137}Cs$ transport in the reservoirs of Fukushima fallout Zone

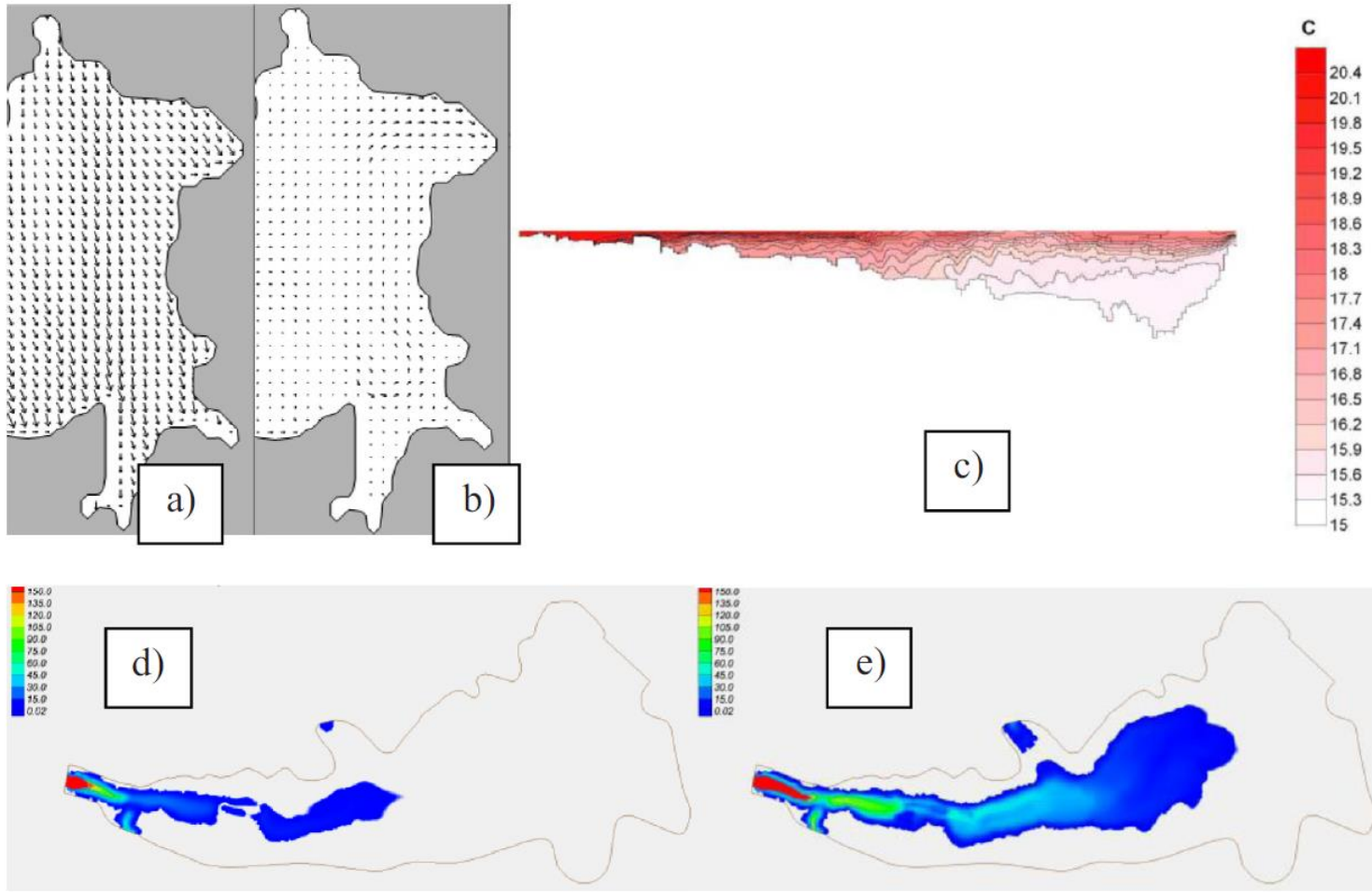



**Figure 2.** Hydrothermodynamics of Takanokura Reservoir simulated by 3D model THREETOX: (a) velocity at near dam area at water surface, (b) velocity near bottom, (c) the vertical profile of the water temperature along the reservoir). Dynamics and $^{137}Cs$ density in the bottom calculated by 2D COASTOX model for the 4th day (d) and 6th day (e) of the high flood of November 2011.

Namba et al., 2016

# JRodos-HDM models implementation for simulation of $^{137}$Cs transport in the reservoirs of Fukushima fallout Zone

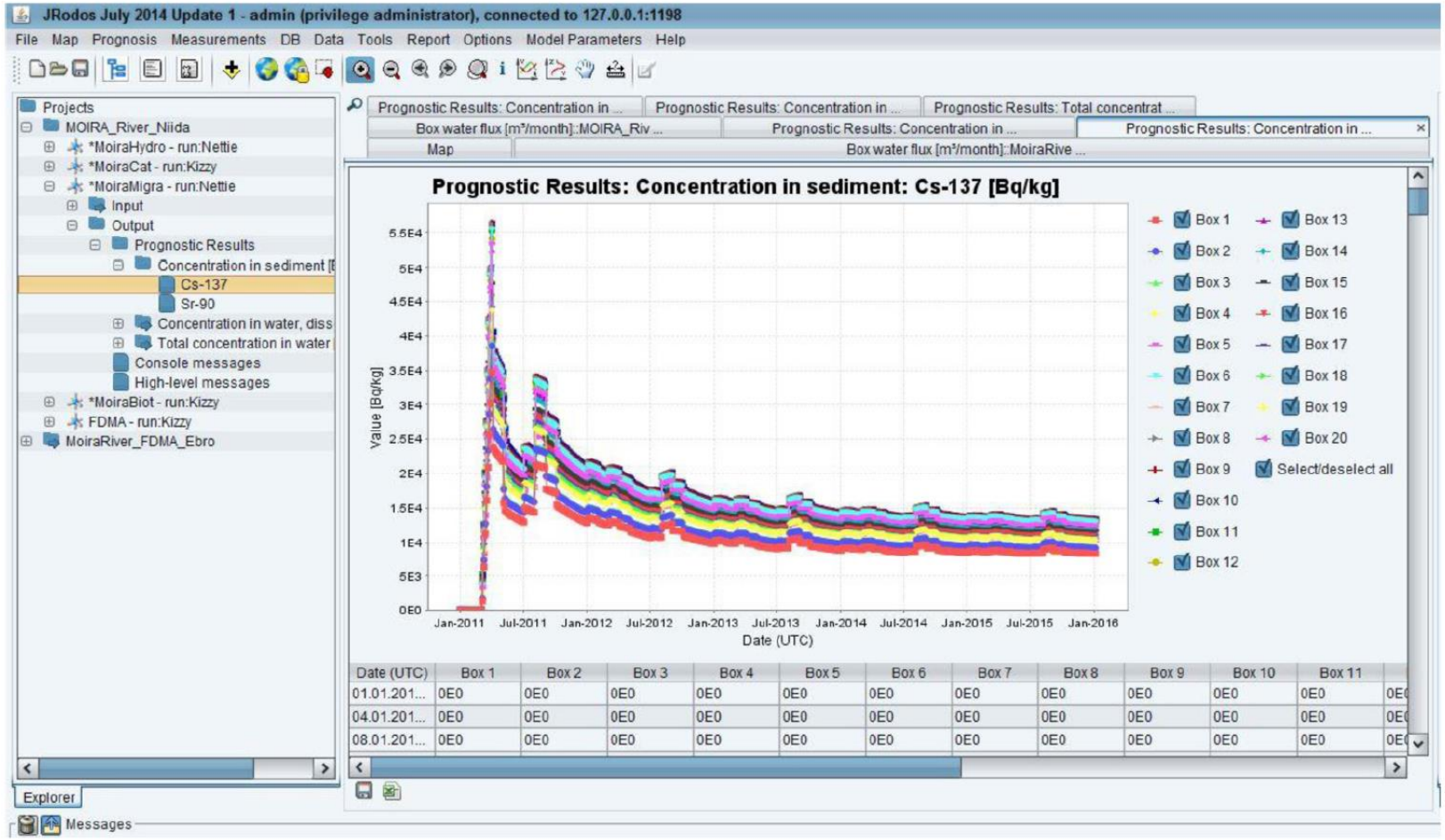
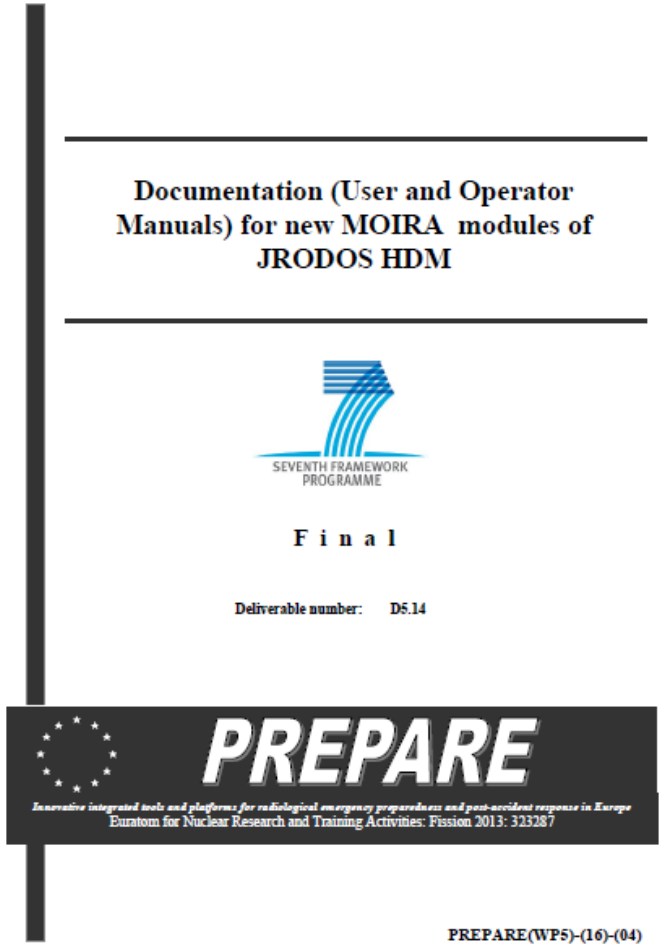



**Figure 3.** JRODOS MOIRA_RIVER interface demonstrating the computed temporal dynamics of $^{137}$Cs on suspended sediments in 20 Niida river strips in period 01.2011–01.2016.

Namba et al., 2016

# MOIRA in JRodos verification / application tasks

- Based on well-studied cases (by UPM). Previously run with MOIRA DSS.
- Lake scenarios:
  - Lake Palancoso (Spain)
  - Lake Kozhanovskoe (Russia)
  - Lake Svyatoye (Belarus)
- River scenarios:
  - Ebro – Ascó NPP (Spain)
  - Tagus – Almaraz NPP (Spain)
- Bug detection and QA
- User interface improvements


Documentation (User and Operator Manuals) for new MOIRA modules of JRODOS HDM

SEVENTH FRAMEWORK PROGRAMME

Final

Deliverable number: D5.14

PREPARE

Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe

Euratom for Nuclear Research and Training Activities: Fission 2013: 323287

PREPARE(WP5)-(16)-(04)

# Countermeasures available for simulation in the new MOIRA-JRODOS system

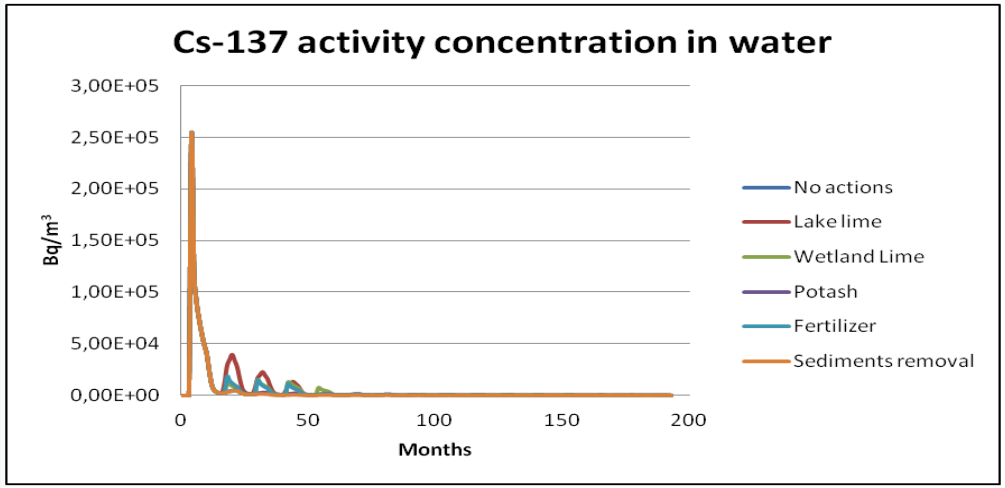
| Application of chemical agents (in Lakes) (Time dependent) | Application of physical measures (Time dependent) | Application of social restrictions (in FDMA) (in user defined periods) |
|---|---|---|
| • Potash treatment<br>• Direct liming<br>• Wetland liming<br>• Fertilisation | • Removal of sediments (Lakes and Rivers)<br>• Removal of snow and ice (Lakes)<br>• Water flow diversion between segments (Rivers) | • Bans on fish consumption<br>• Bans on water ingestion<br>• Bans on irrigation<br>   |

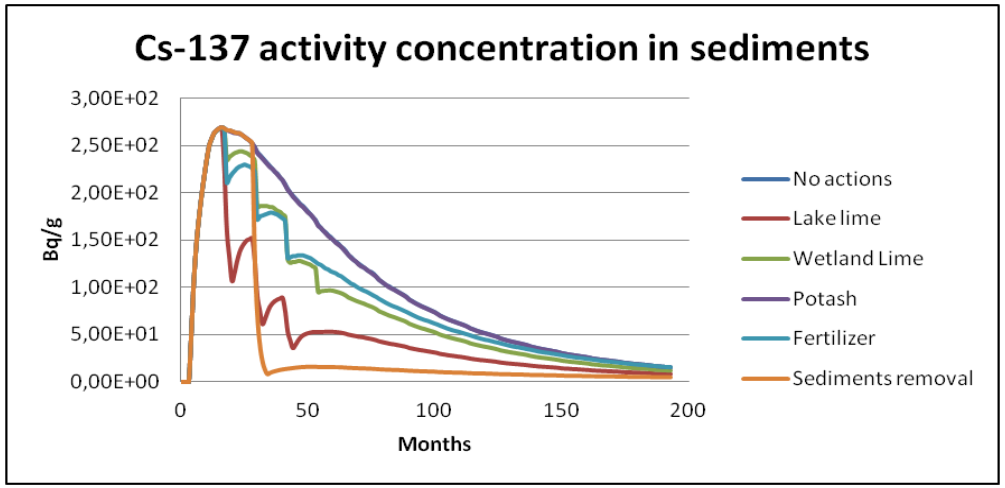
# Test case MOIRA-Lake: Kozhanovskoe, Russia

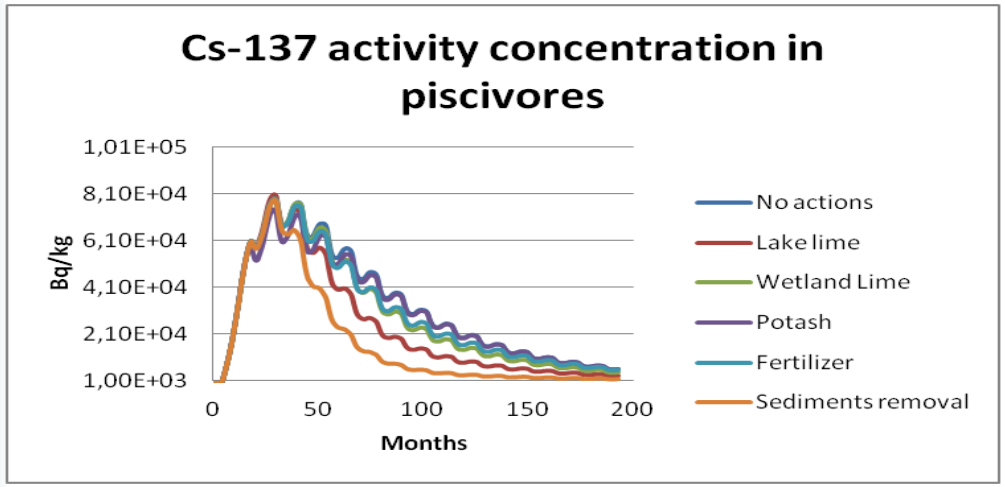
PREPARE

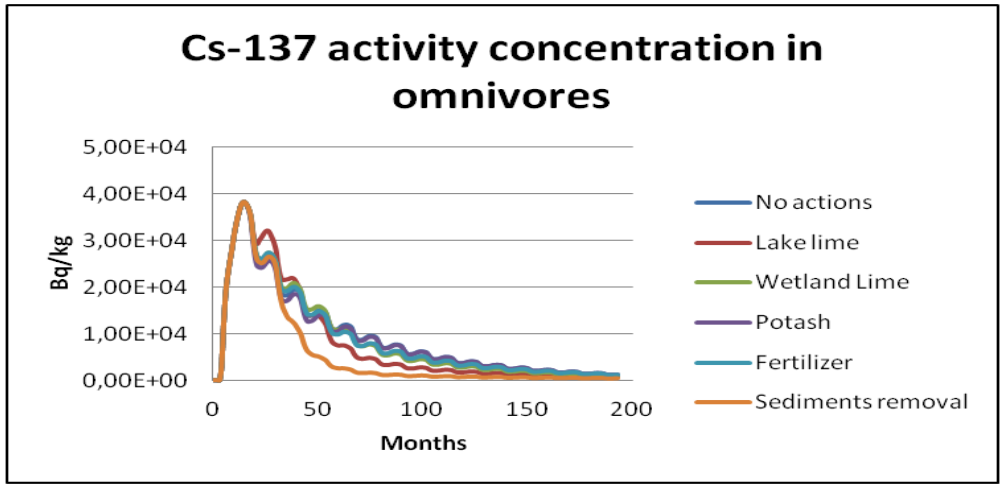
## Tests of the Countermeasures models

**The obtained results are identical to those in the original MOIRA DSS**

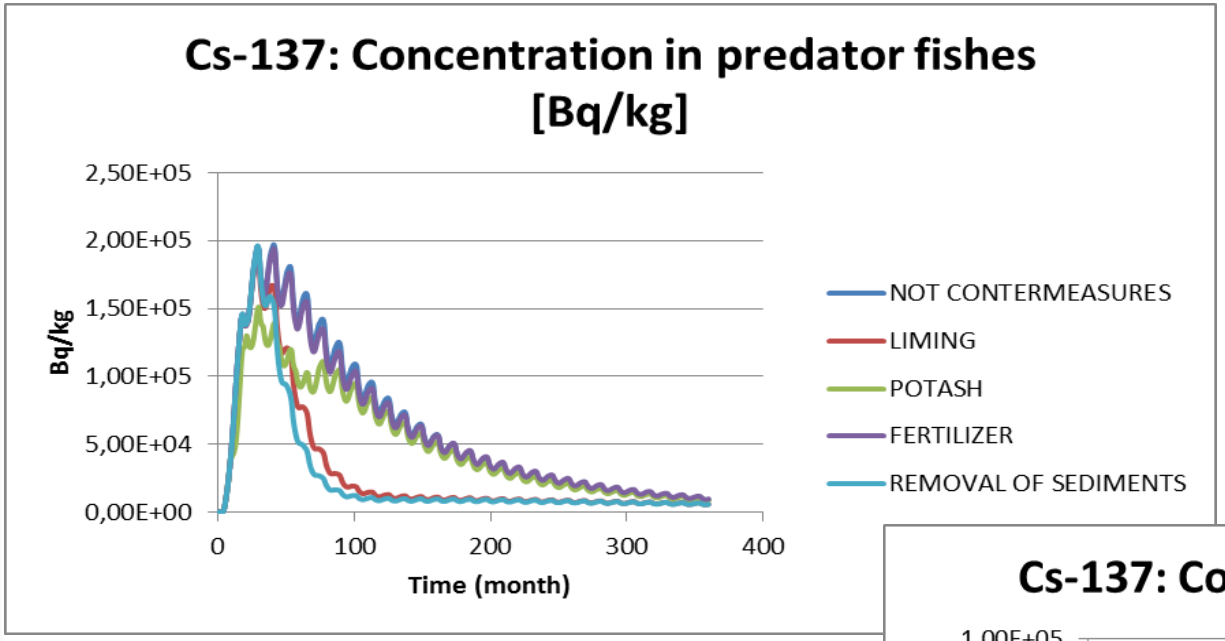


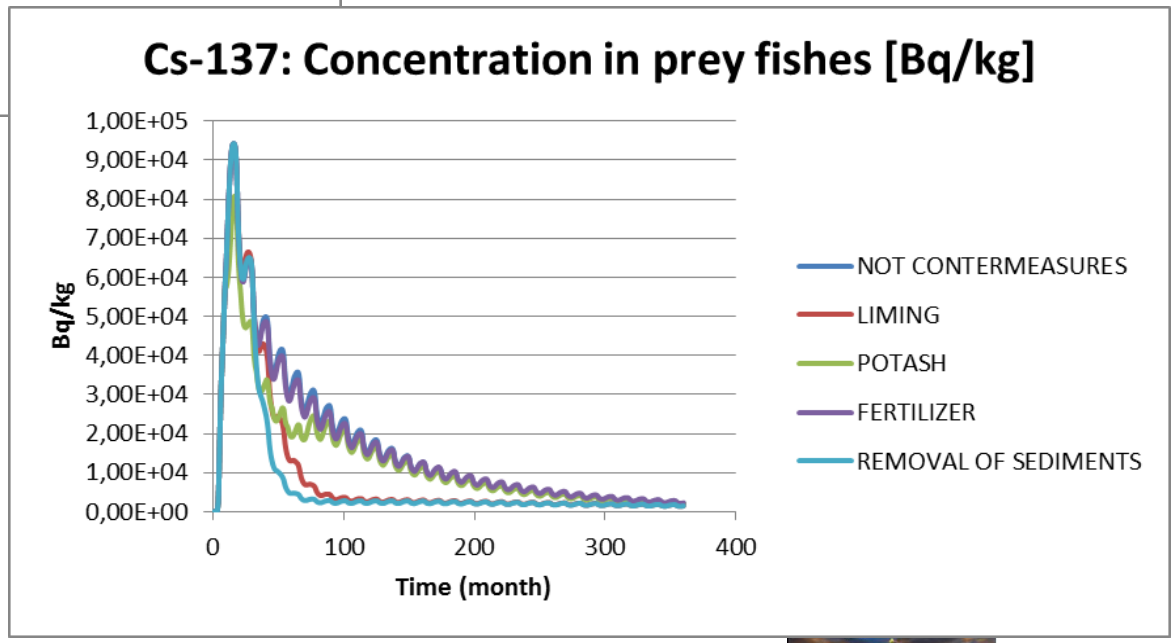



# Test case MOIRA-Lake: Svyatoye, Belarus




## Tests of the Countermeasures models

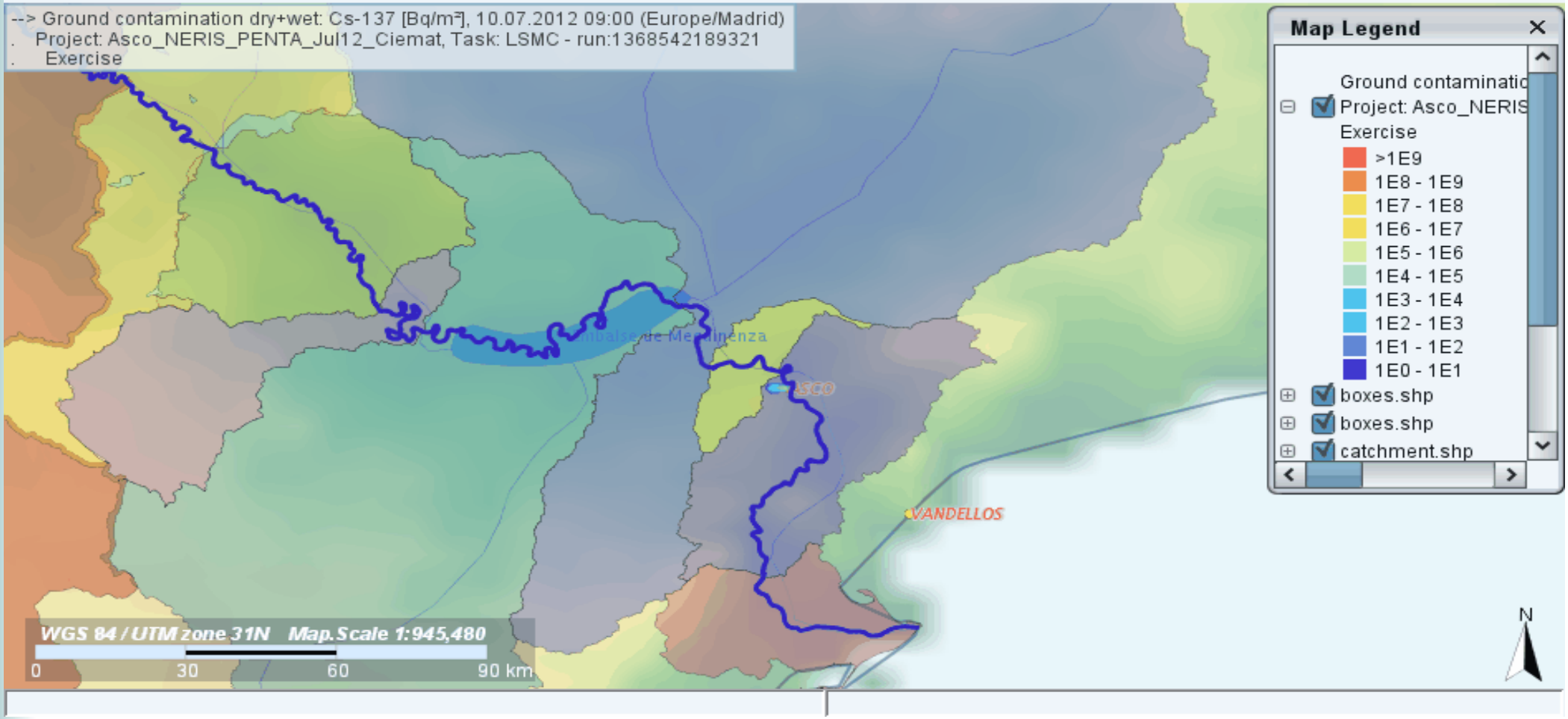
**The obtained results are identical to those in the original MOIRA DSS**



# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP

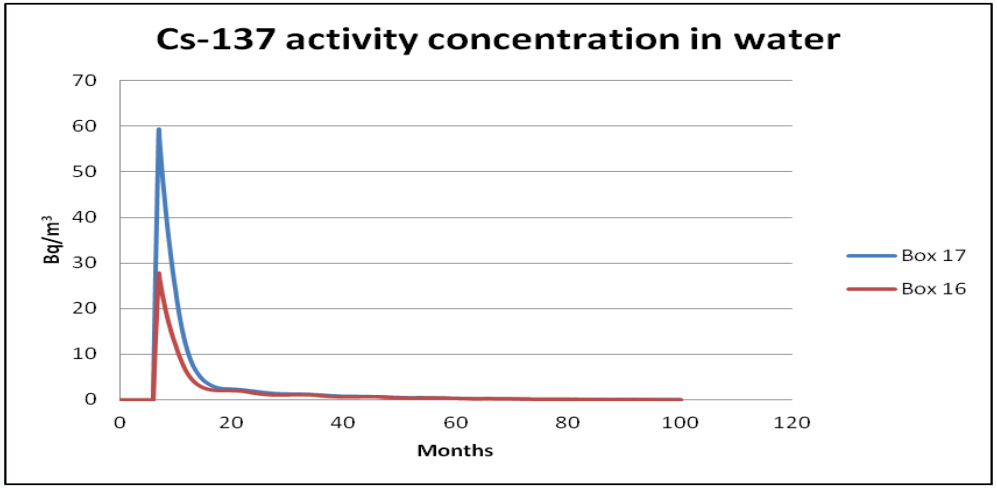
PREPARE

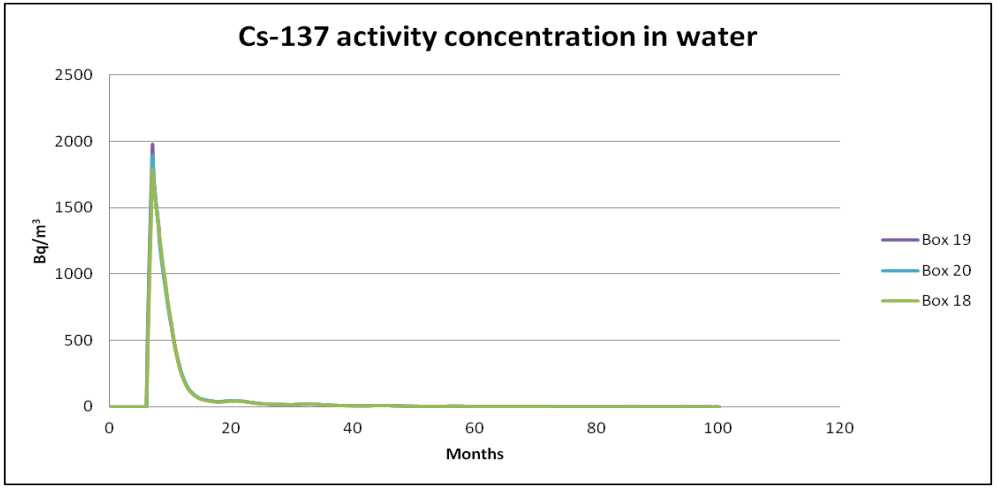
## Ground deposition of Cs-137 (dry+wet) simulated by LSMC JRODOS:

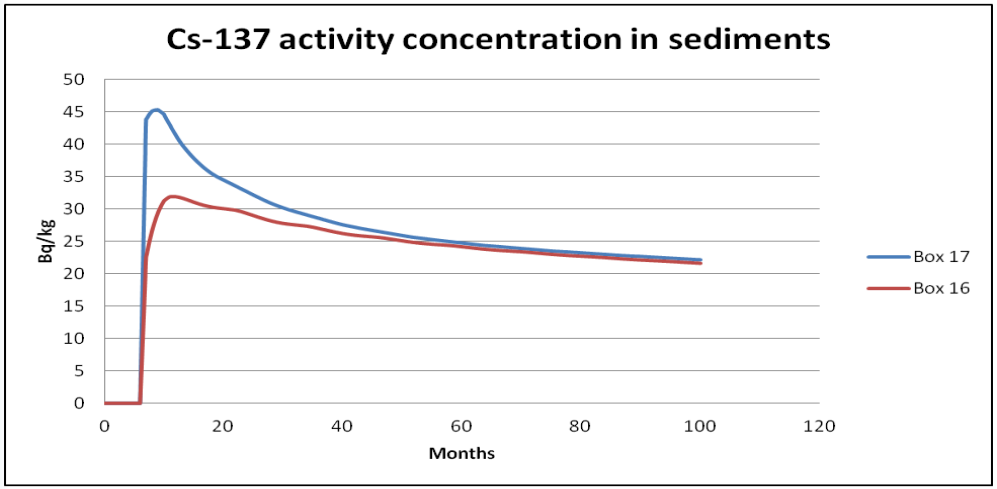


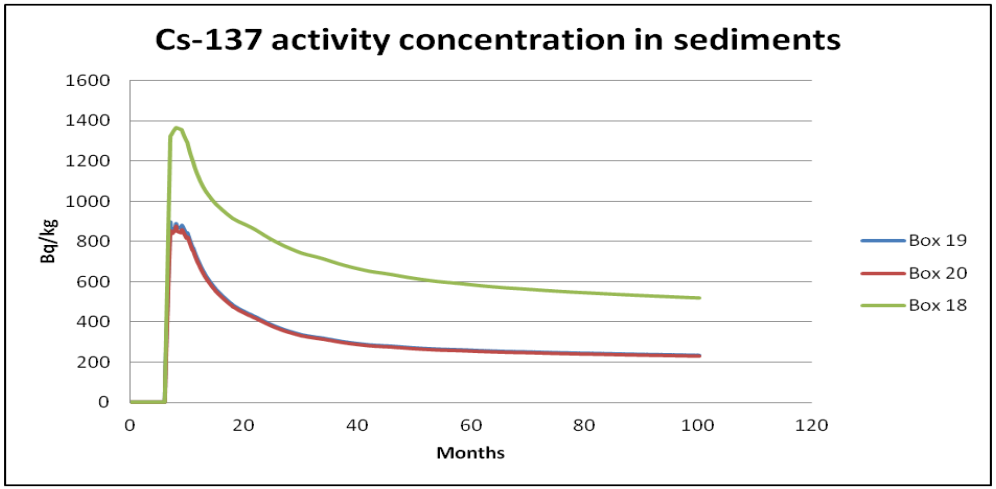
# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP

PREPARE



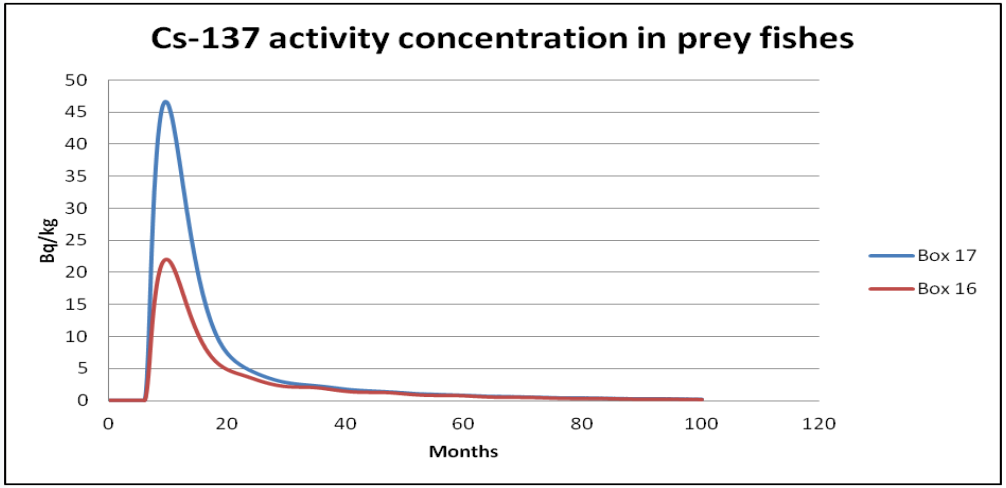



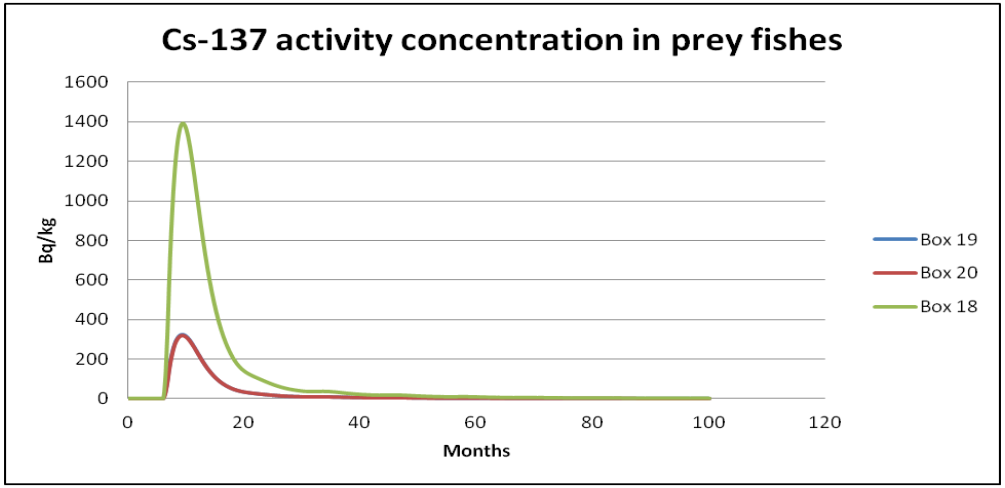



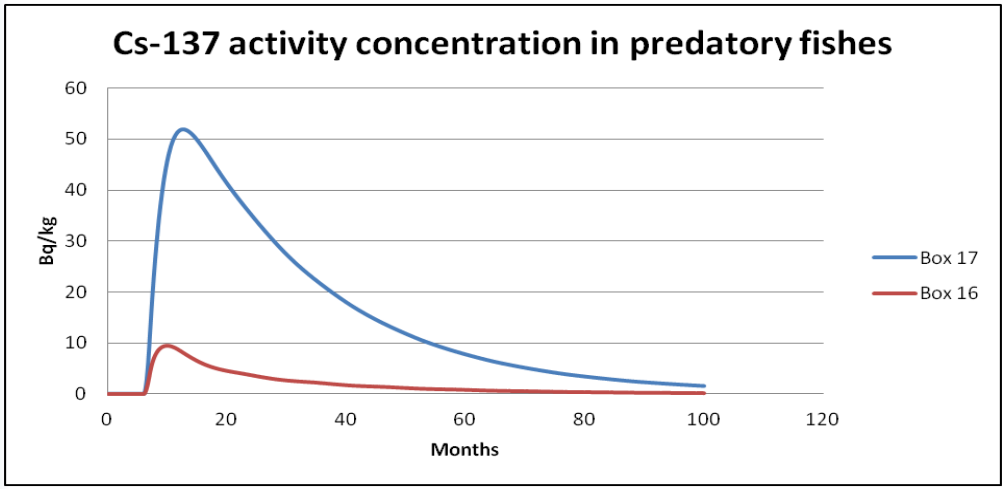



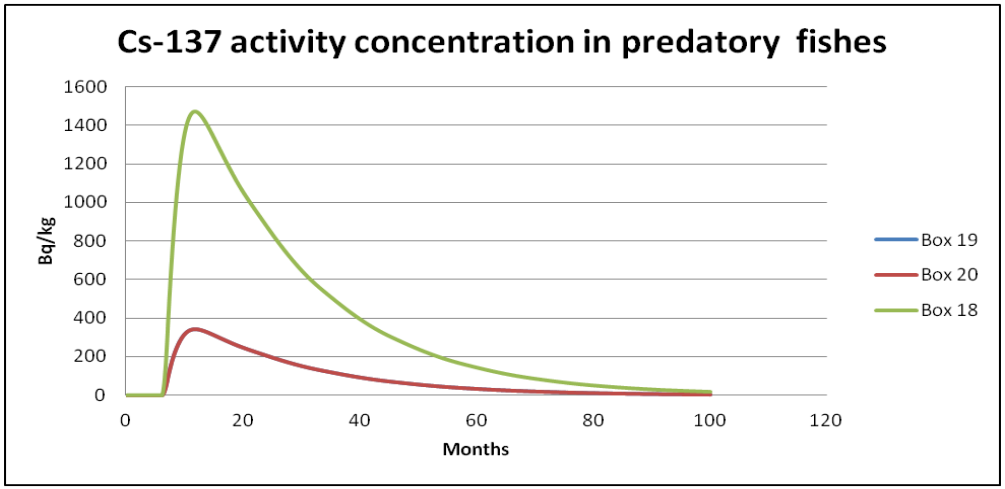

**Comparison of results between the original MOIRA River model (in Powersim®) and the JRODOS-MOIRA River**

# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP



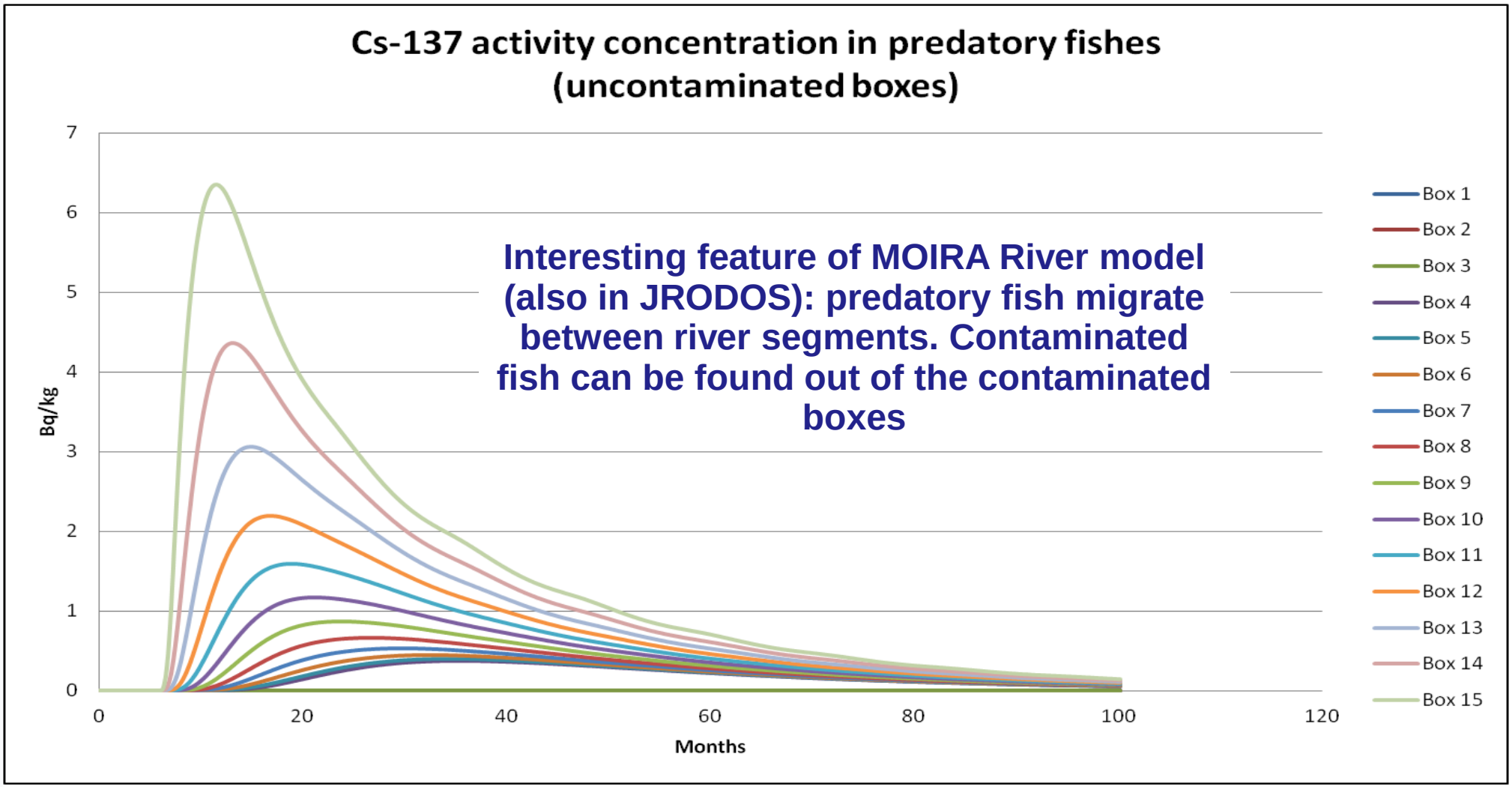



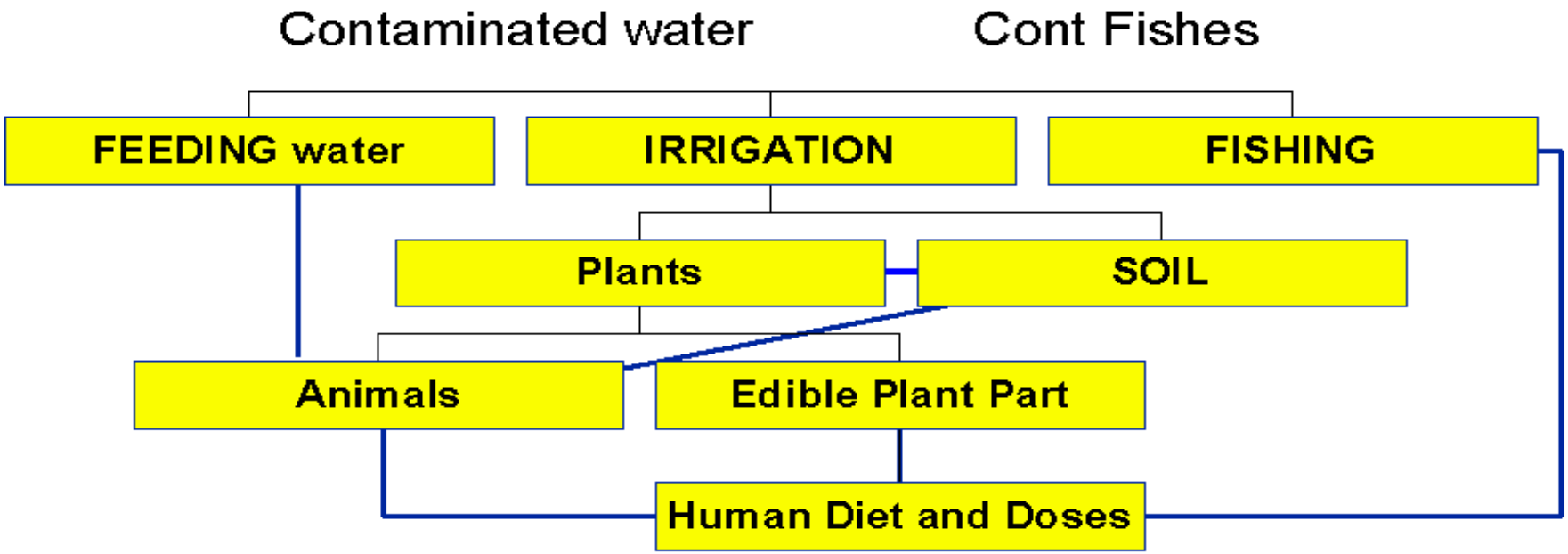

**Comparison of results between the original MOIRA River model (in Powersim®) and the JRODOS-MOIRA River**

# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP

PREPARE



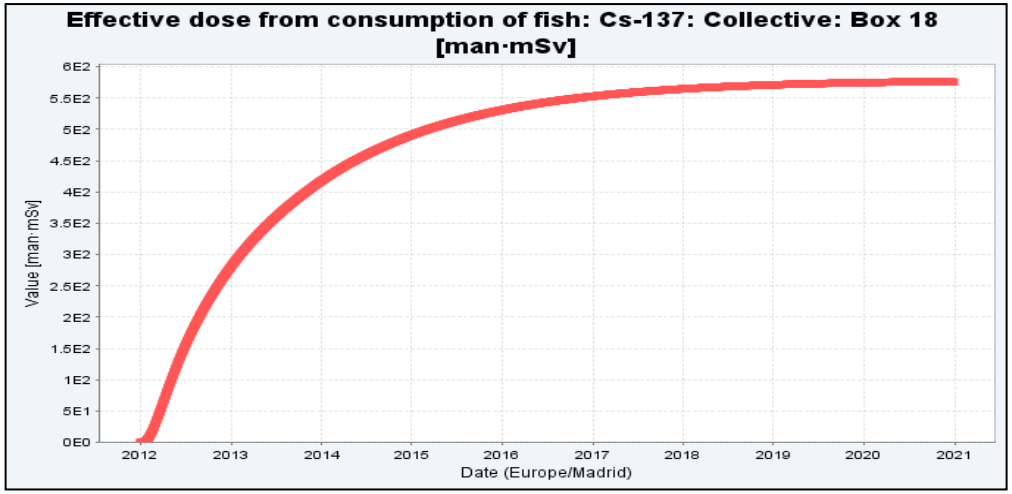
# FDMA Aquatic Exposure Pathway Scheme

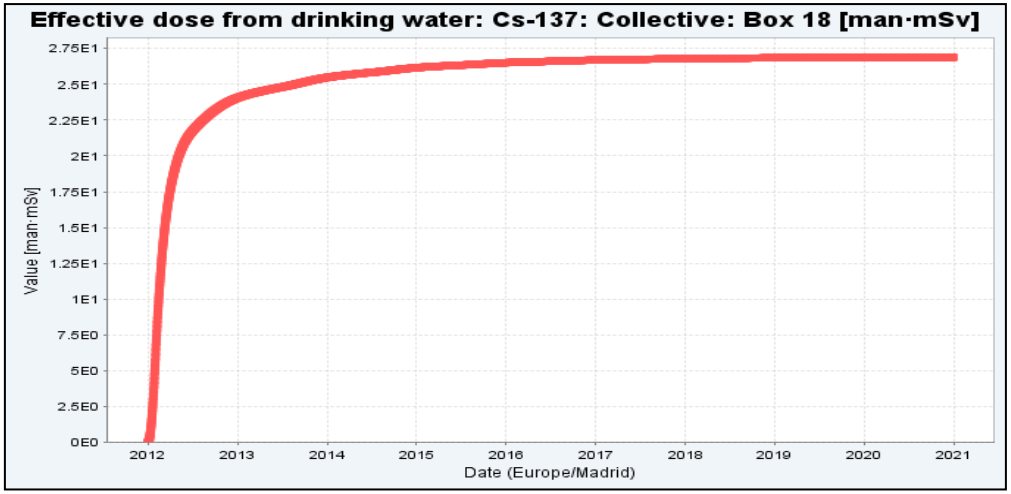


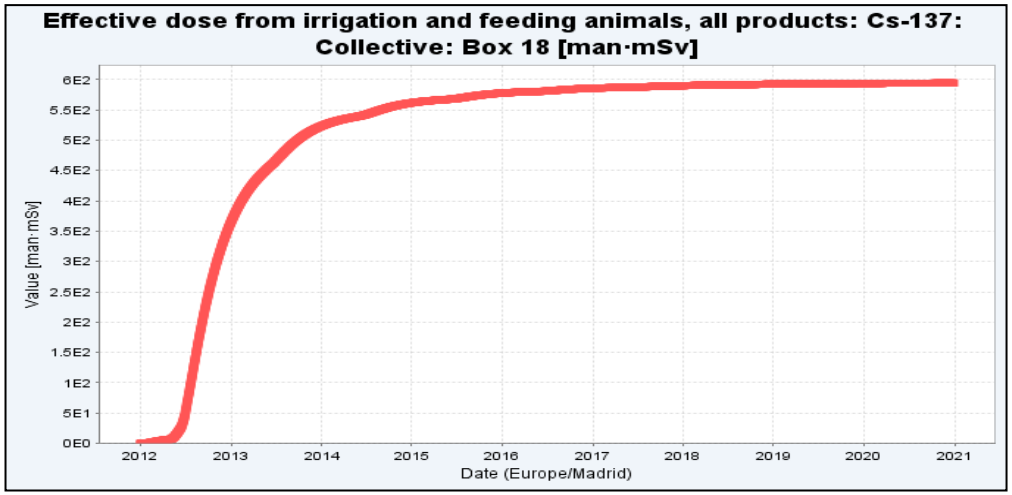
# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP

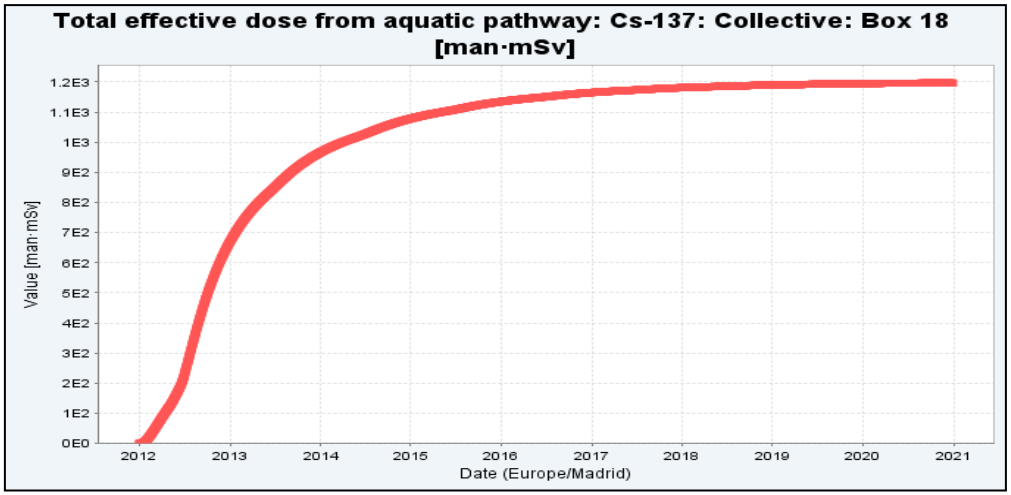
PREPARE

## Collective doses, Cs-137, Box 18



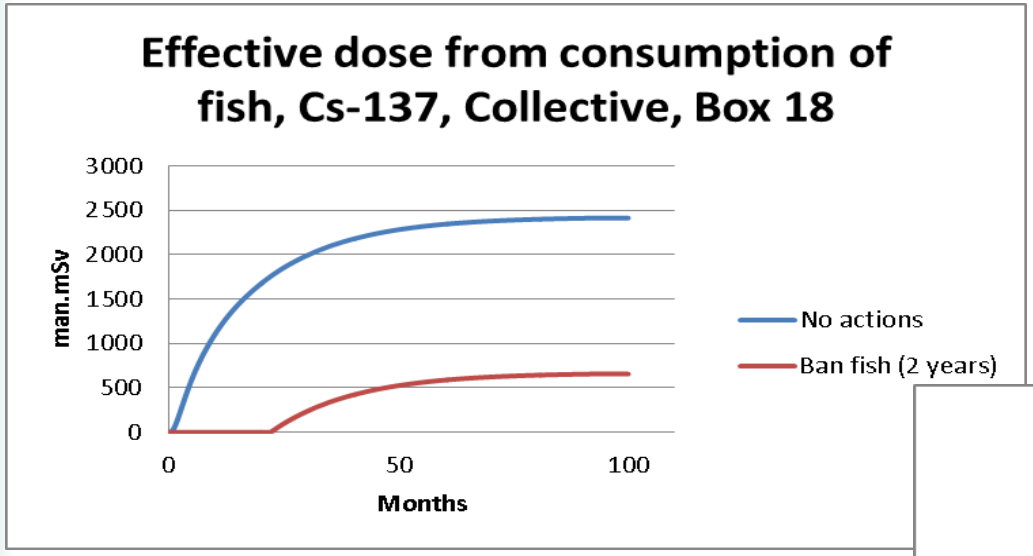



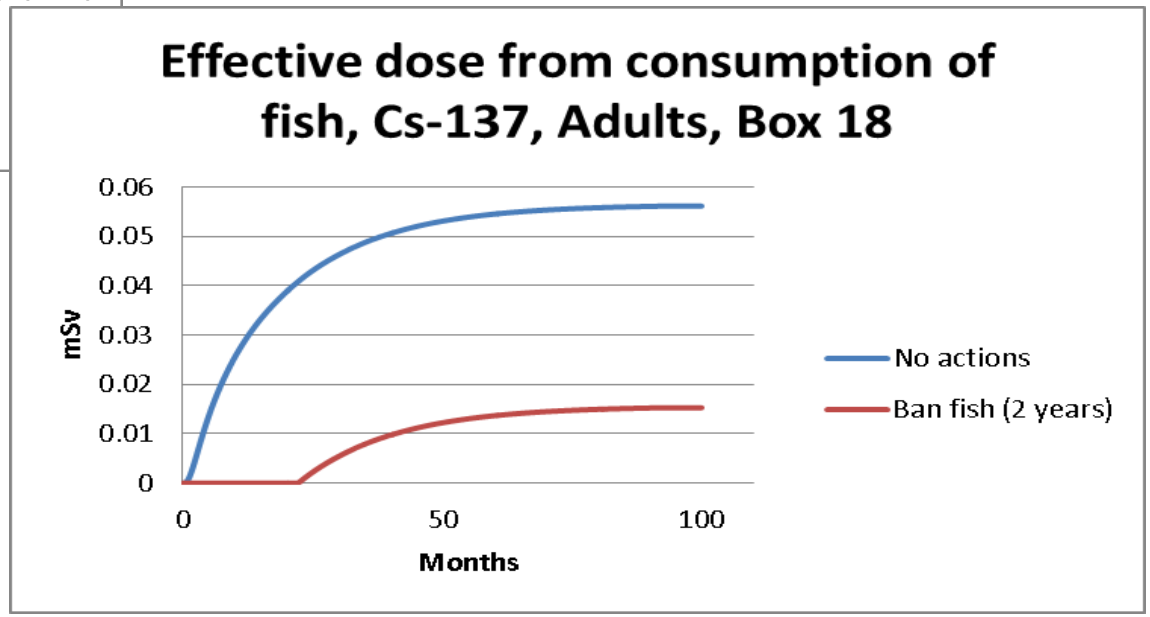
# Test MOIRA-River module in JRODOS. Ebro river near Ascó NPP

PREPARE

## Collective and individual dose from fish ingestion, Cs-137, Box 18

(with ban fish and without countermeasures)

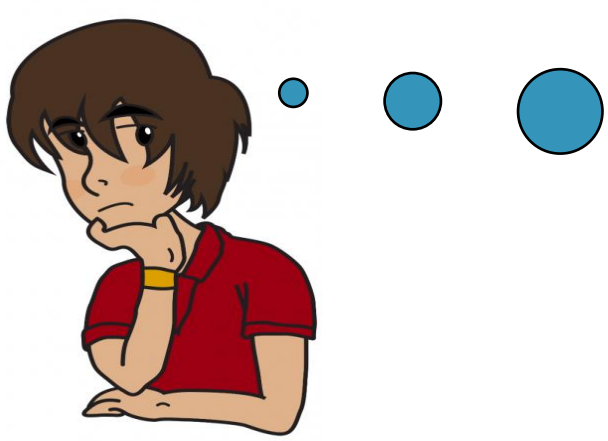


# Final considerations

- A significant effort is required to customise aquatic models by collecting and implementing all the necessary data (MOIRA Lake model is an exception).
- JRodos-HDM models are helpful tools for decision making in scenarios affecting water bodies. Using input from RODOS-ADM modules is great to have fallout from atmospheric releases + direct releases in the same system.
- Modelling aquatic exposure pathways is necessary to answer people's worries. It is important to explain why radioactivity concentration in water is usually not the most critical element compared to sediments and fish.

# Think about communication !



Fish with three eyes found in Embalse, Argentina