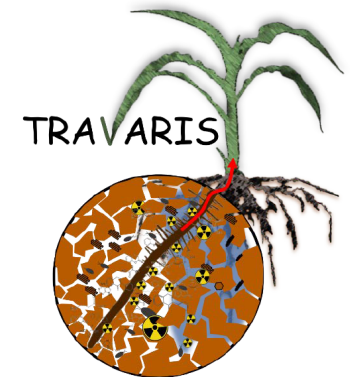


Long-Term Impact on Humans from a Repository for Radioactive Waste: Experimentally Verified Radioecological Biosphere Model

Joint Project TRAVARIS: **T**ransfer of long-lived radionuclides from the **v**adose zone to the **rhizo**sphere and their uptake by plants, taking microbiological processes into account

Veronika Ustohalova & Anna Kopp
safeND 2025
Berlin 17–19 September 2025



With funding from the:



Agenda

1 About the project TRAVARIS

2 Development of radioecological biosphere model

3 Model parts

4 Preliminary results

Overall concept



FRIEDRICH-SCHILLER-
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HZDR
HELMHOLTZ ZENTRUM
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Universität Bremen

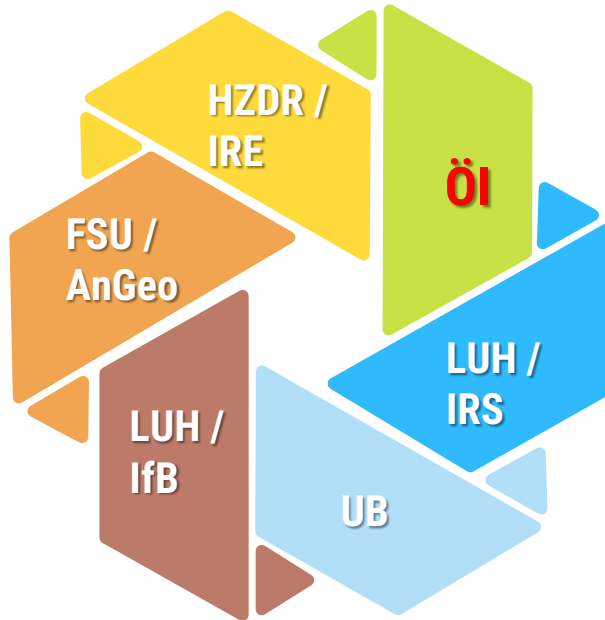


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Institute for Applied Ecology

Öko-Institut

11
102
1004

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Universität
Hannover



Radionuclides
I, Se, Tc, Am, Pu, U, Np, Eu

Experiments on water and radionuclide transport in the soil and uptake mechanisms of radionuclides in plants interlinked with the model development.

- Subproject A (FSU-AnGeo): Water level fluctuations, influence of variable hydraulic conditions on the **distribution of radionuclides in soil**
- Subproject B1 (LUH-IRS): Water level fluctuations, microbial diversity, **interaction of radionuclides and root exudates, uptake in plants**
- Subproject B2 (LUH-IfB): **Plant transporters for the uptake of radionuclides** from the soil into plants
- Subproject C (HZDR-IRE): Soil microbiology in the presence of **root exudates** and radionuclides, **uptake mechanisms in plants**

Experiments

- **Subproject D (ÖI): Radioecological biosphere modelling with representation of uncertainties in dose estimation (AISM)**
- Subproject E (UB-IUP): **Geochemical modelling** of micro- and mesoscale systems (PHREEQC)

Modelling

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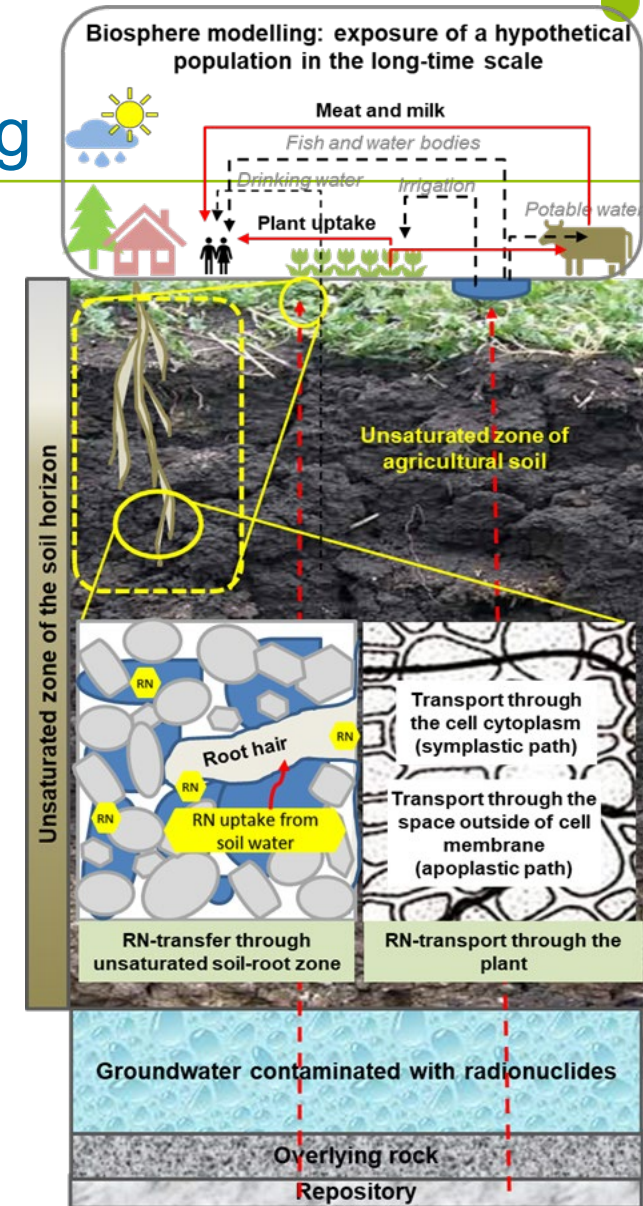
Radioecological biosphere model

Software AFRY Intelligent Scenario Modelling

Macroscale: Dose calculation, statistical analysis of uncertainties in exposure determination with Monte Carlo simulations.

Mesoscale: Radionuclide transport in soil due to water table fluctuations and evapotranspiration as f(e.g. C_{org} , clay/illite, pH).

Microscale: Radionuclide behaviour in the root zone and in plant compartments, implementing transfer factors, consideration of transporters and root exudates.



Radioecological biosphere model: model parts

- **Model part “soil transport”**: describes water level fluctuations in the pore space under the influence of evapotranspiration along several soil horizons and the associated interaction of the radionuclides in the pedosphere
- **Model part “plant”**: takes into account the microscale accumulation processes of radionuclides in the root area and the distribution in plant compartments
- **Model part “dose estimation”** over long periods of time due to water intake, plant consumption...
- Considering several scales from micro to macro



Experiments

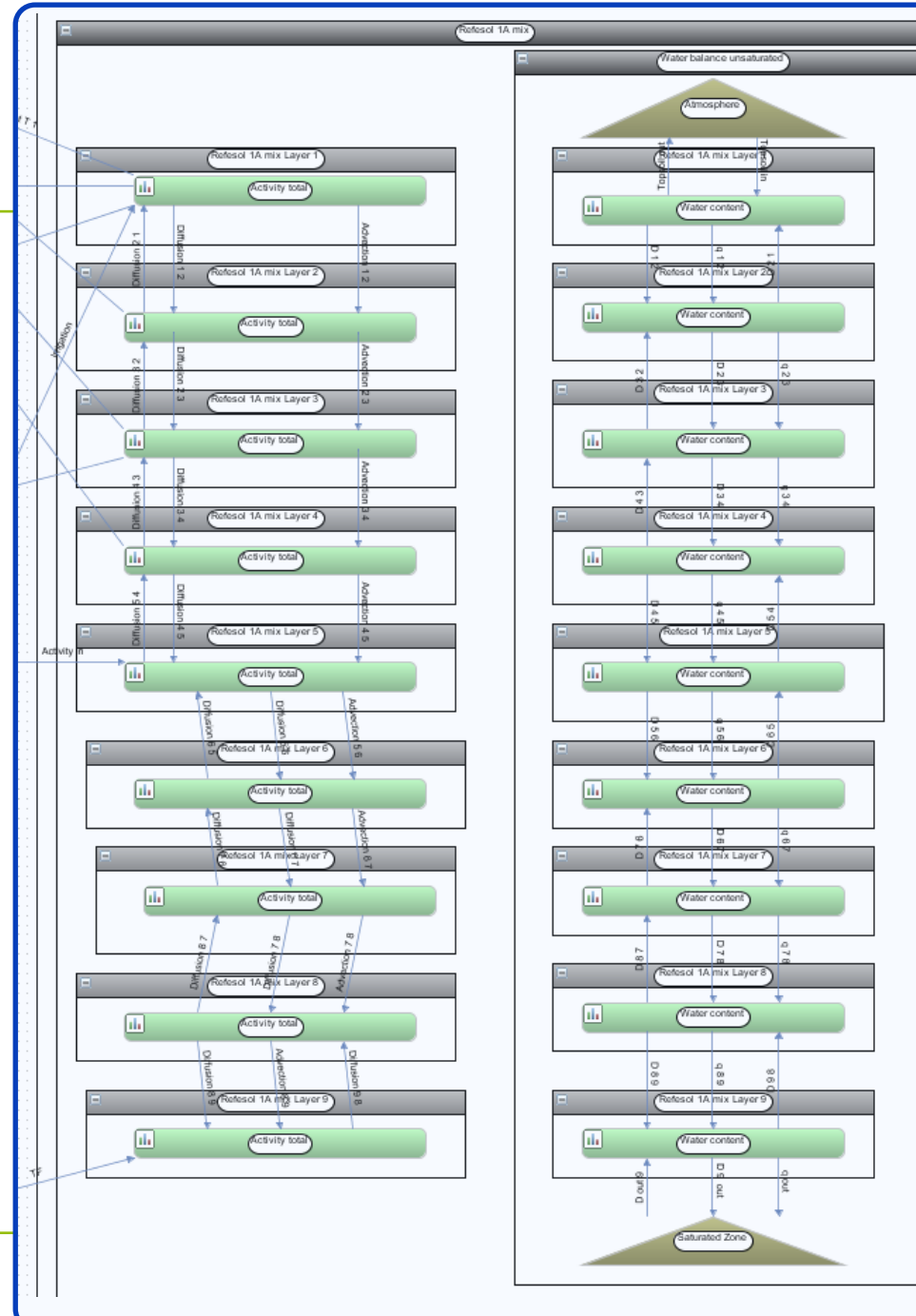
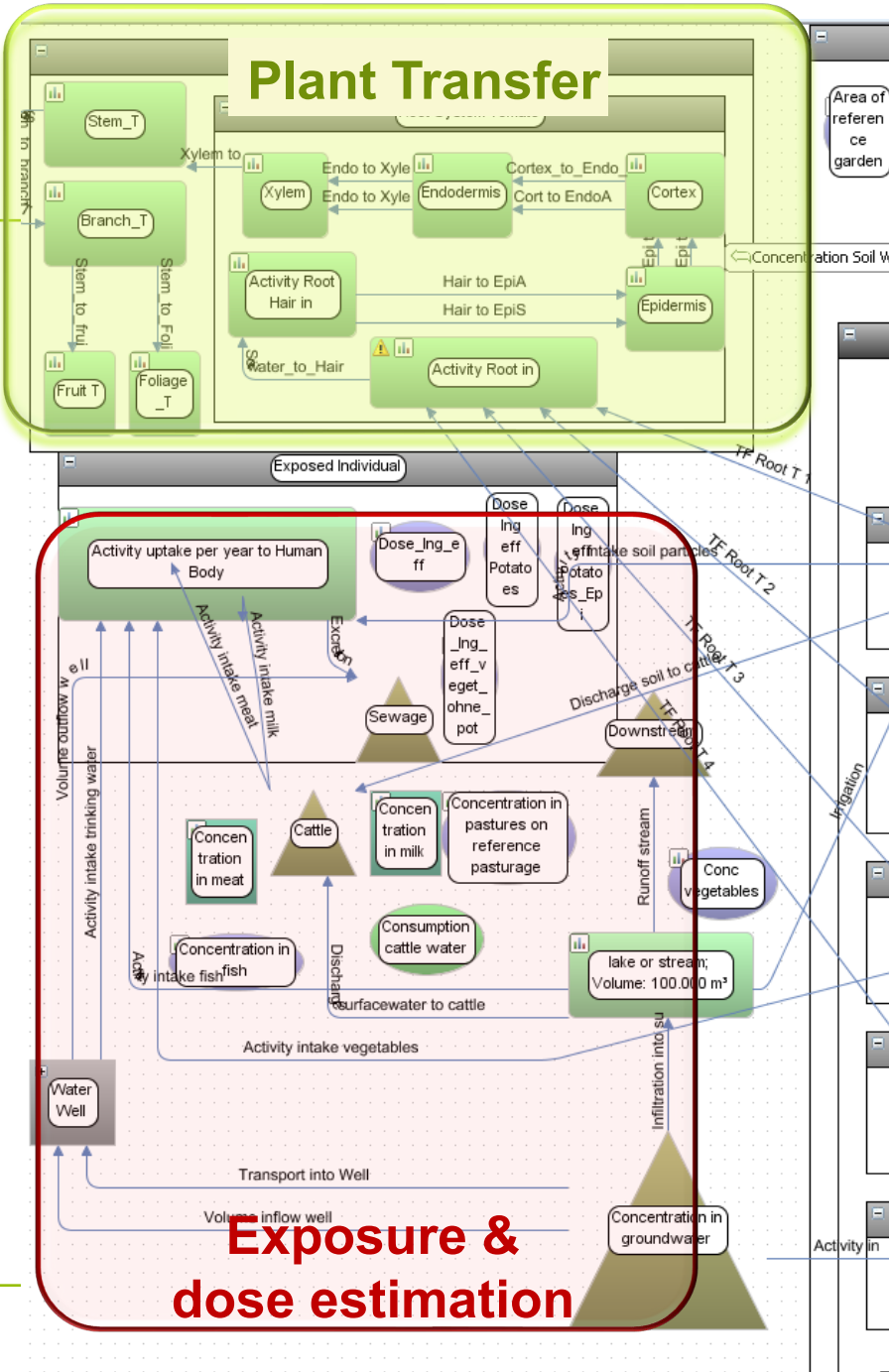
Agreement with project partners on the experimental design and procedure for the experiments: linkage with the process description and relevant parameter in the biosphere model

Model PHREEQC

Delivering basis for look up table describing dependencies of radionuclide sorption on pH-Value or organics

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Water movement + RN-Transport

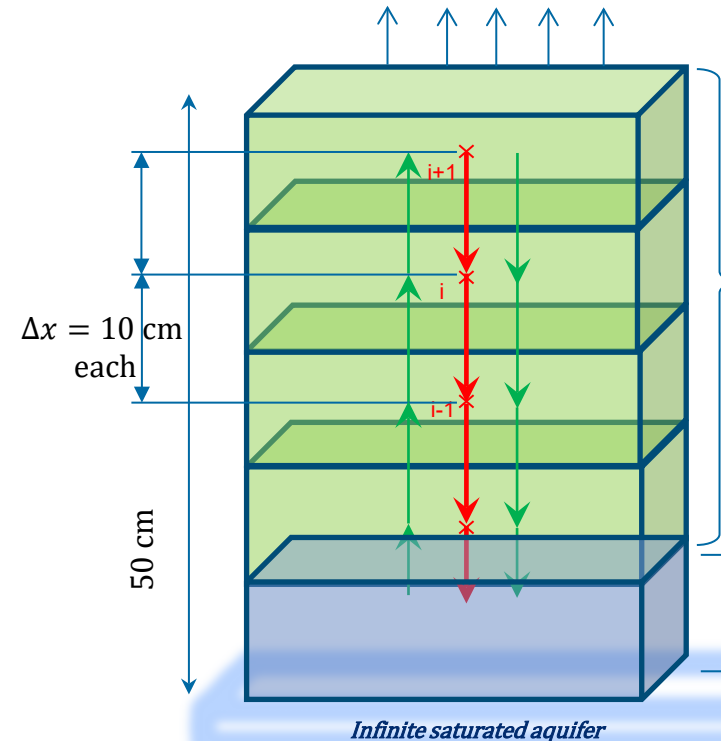
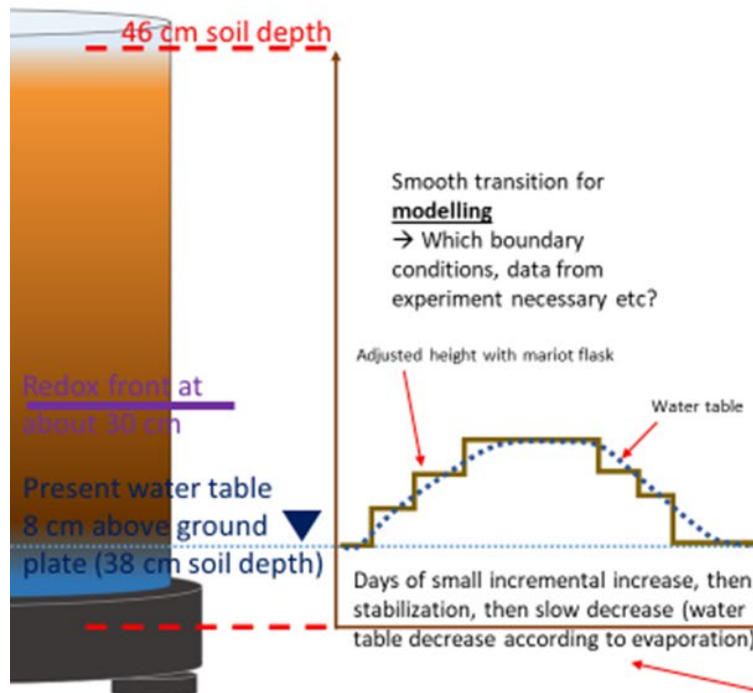
Input from project partners: process understanding, parameter values

Water movement and radionuclide transport under water level fluctuations: finite volume method

Discussion on water table fluctuations (IRS, FSU, UB, ÖI)

→ goal: modelling of hydrological changes in soil substrate and investigation of associated RN mobilization

Concept/scheme of implementation as basis for discussion:



Water content form of Richards-Equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left(D(\theta) \frac{\partial \theta}{\partial x} \right) - K(\theta) \frac{\partial \theta}{\partial x} - w$$

$$q_{i \rightarrow i+1}^D = \theta_i (0,5 [D_i(\theta) + D_{i+1}(\theta)]) / (\Delta x)^2$$

$$q_{i \rightarrow i+1}^A = K_s \left(\frac{\theta_i - \theta_f}{\theta_s - \theta_f} \right) / \Delta x$$

- Advective flow due to gravity (red)
- /
- diffusive flow due to capillarity (green)

-Radionuclides move with water

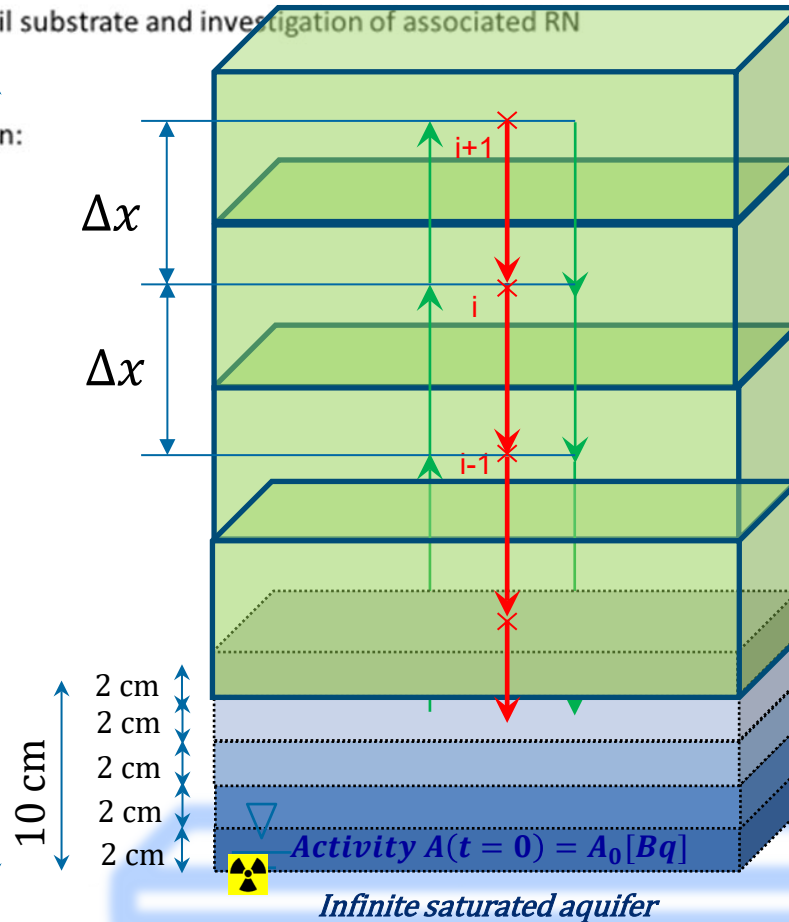
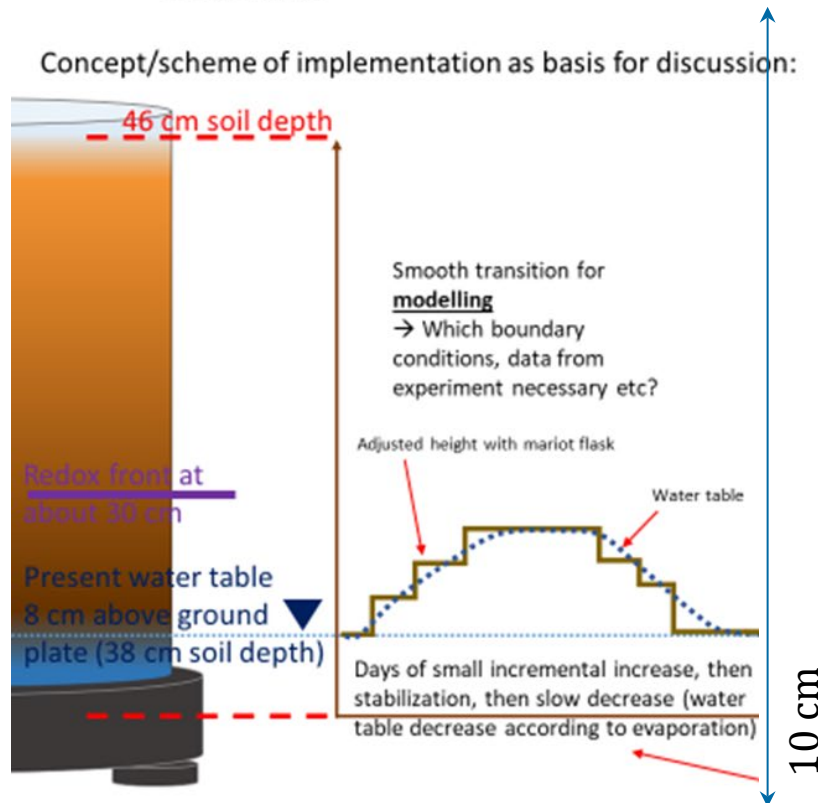
Initial condition $\theta(t=0) = \theta_s$

Water movement and radionuclide transport under water level fluctuations: finite volume method

Discussion on water table fluctuations (IRS, FSU, UB, ÖI)

→ goal: modelling of hydrological changes in soil substrate and investigation of associated RN mobilization

Concept/scheme of implementation as basis for discussion:



Convection-Dispersion-Equation

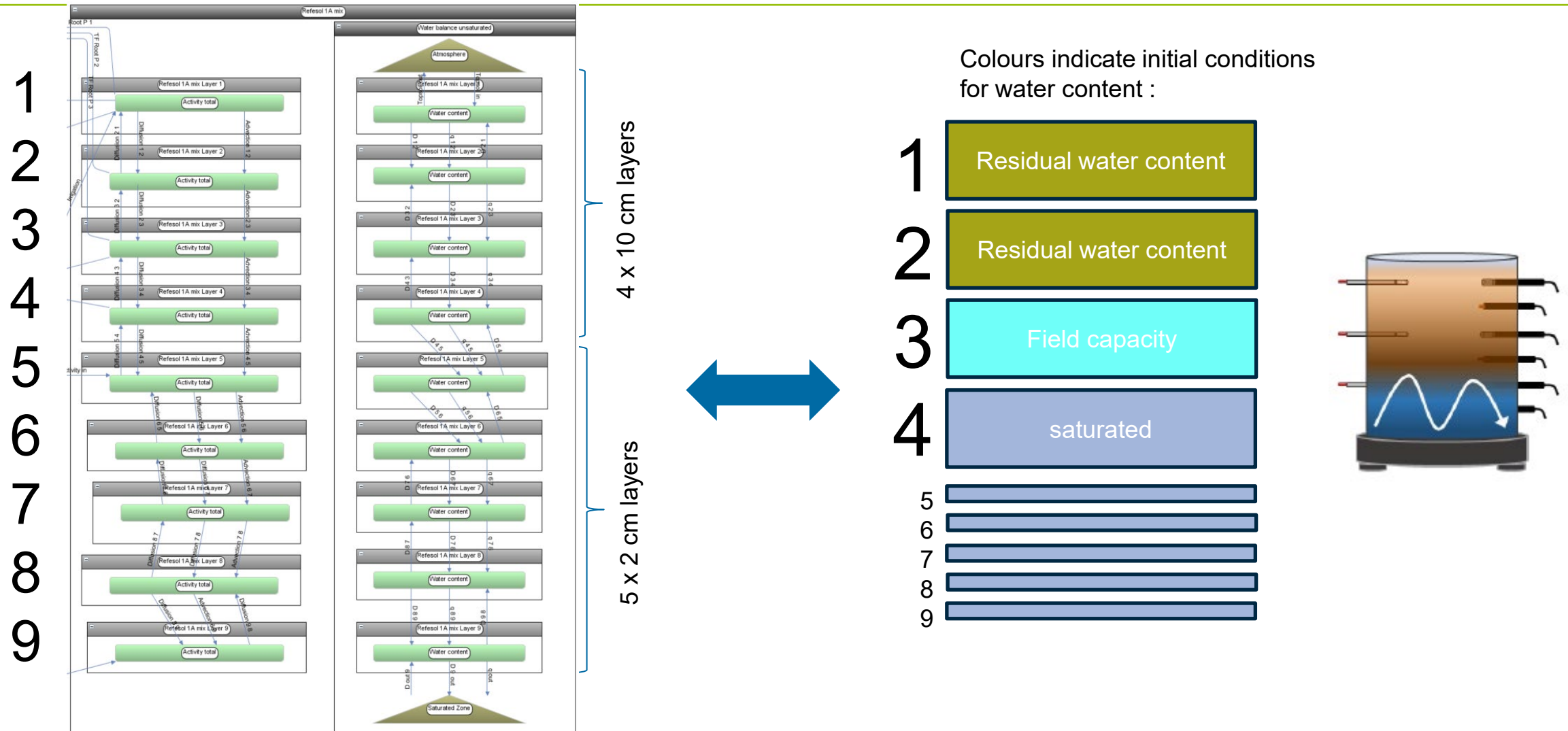
$$\frac{\partial c_n}{\partial t} = \frac{\partial q}{R_n} \frac{\partial c_n}{\partial x} (I) + \frac{\partial}{\partial x} \left(\frac{D_{eff,n}}{R_n} \frac{\partial c_n}{\partial x} \right) (II) - \lambda_n c_n (III)$$

$$\frac{\Delta A_i}{\Delta t} = \frac{\sum q}{R \Delta x} (A_{i-1} - A_i)$$

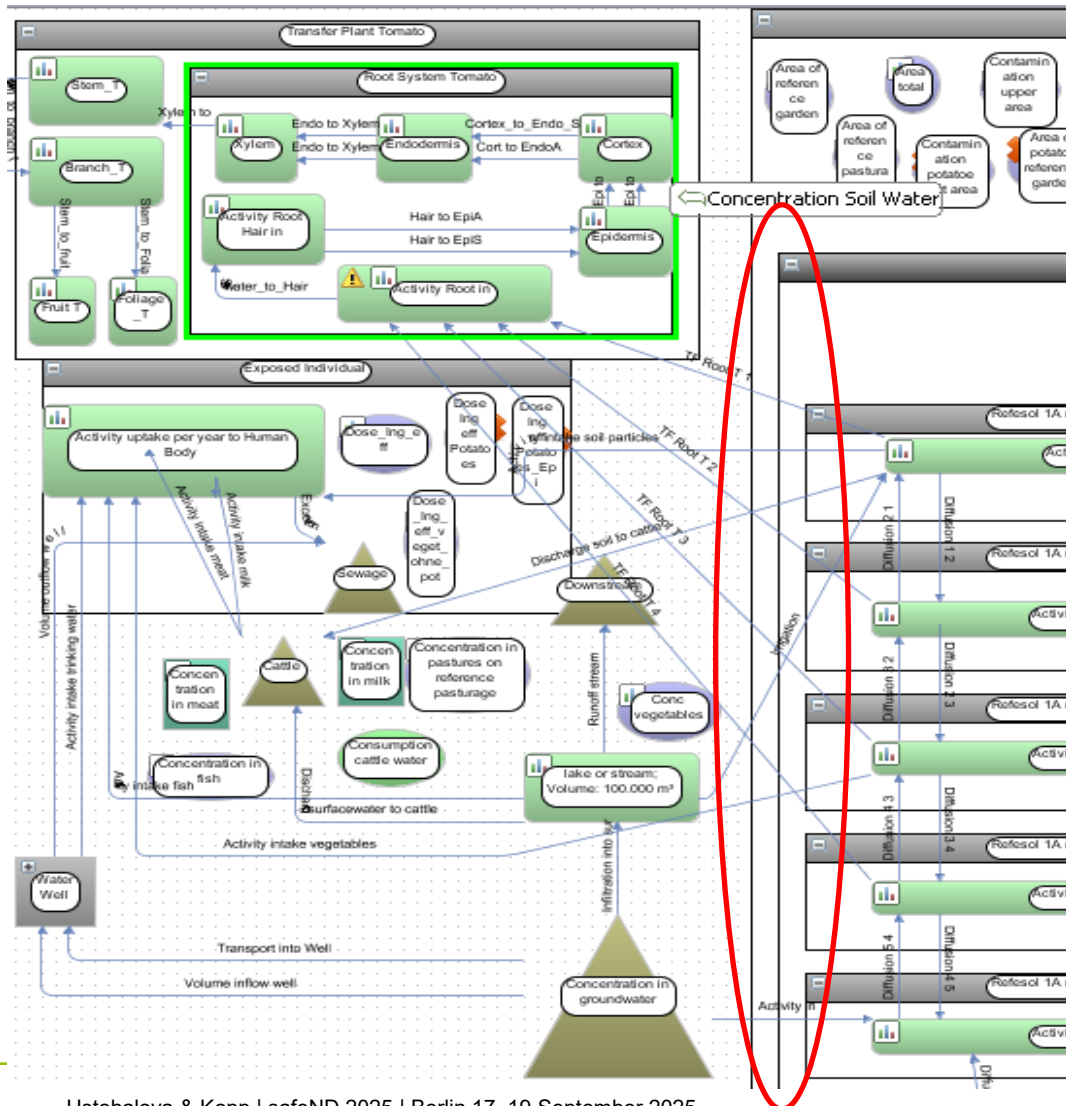
$$\frac{\Delta A_i}{\Delta t} = \frac{D_{eff}}{R(\Delta x)^2} (A_{i+1} - 2A_i + A_{i-1})$$

Subsystem water fluctuation with $\Delta x_f = 2\text{cm}$

Water and radionuclide transport under water level fluctuations



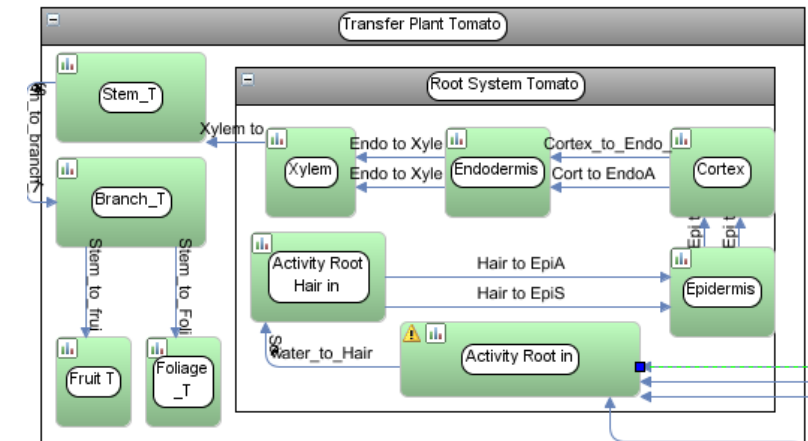
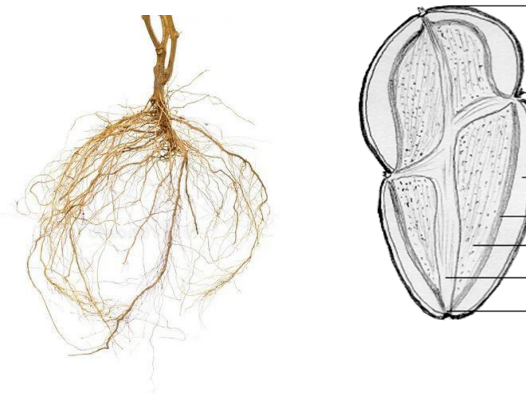
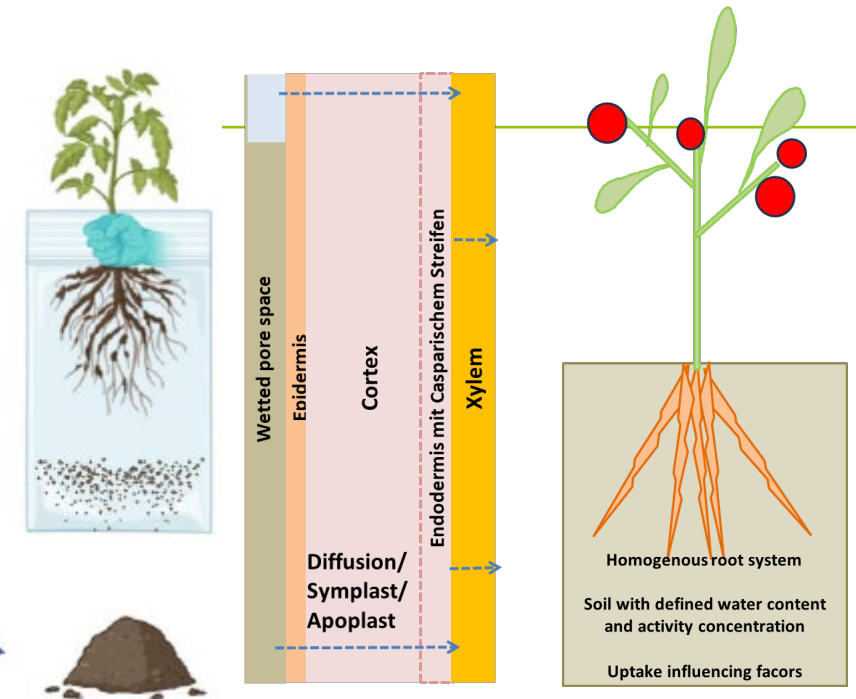
AfryISM model structure – model parts plant and dose estimation



- Model structure of the plant
- Radionuclide uptake from several soil layers by considering the water content and radionuclide concentration
- Dose calculation according to German AVV* based on the resulting contamination of edible parts

Model part Plant

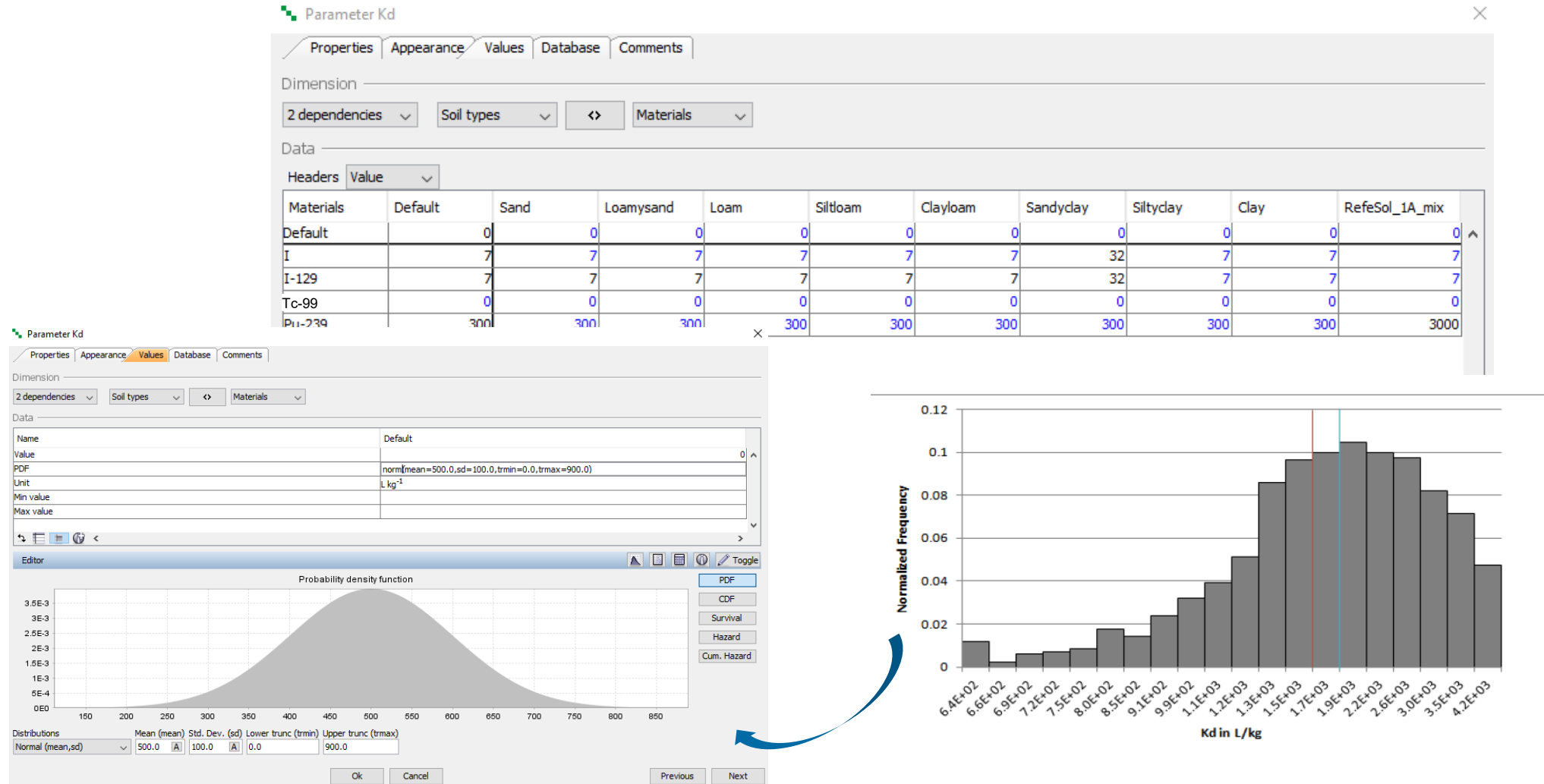
- Plant type and radionuclide
 - Tomato - root depth 0,6 – 1,2m
 - Potato tuber - depth 0,2 – 0,5m
- Vegetation period/growth phase and radionuclide uptake
 - 1. implementing transfer factors (RN like Tc-99 dependence on the growth phase)
 - 2. influencing factors on the root/tuber exchange with the soil: soil properties (pH, P) and root exudates or transponterers



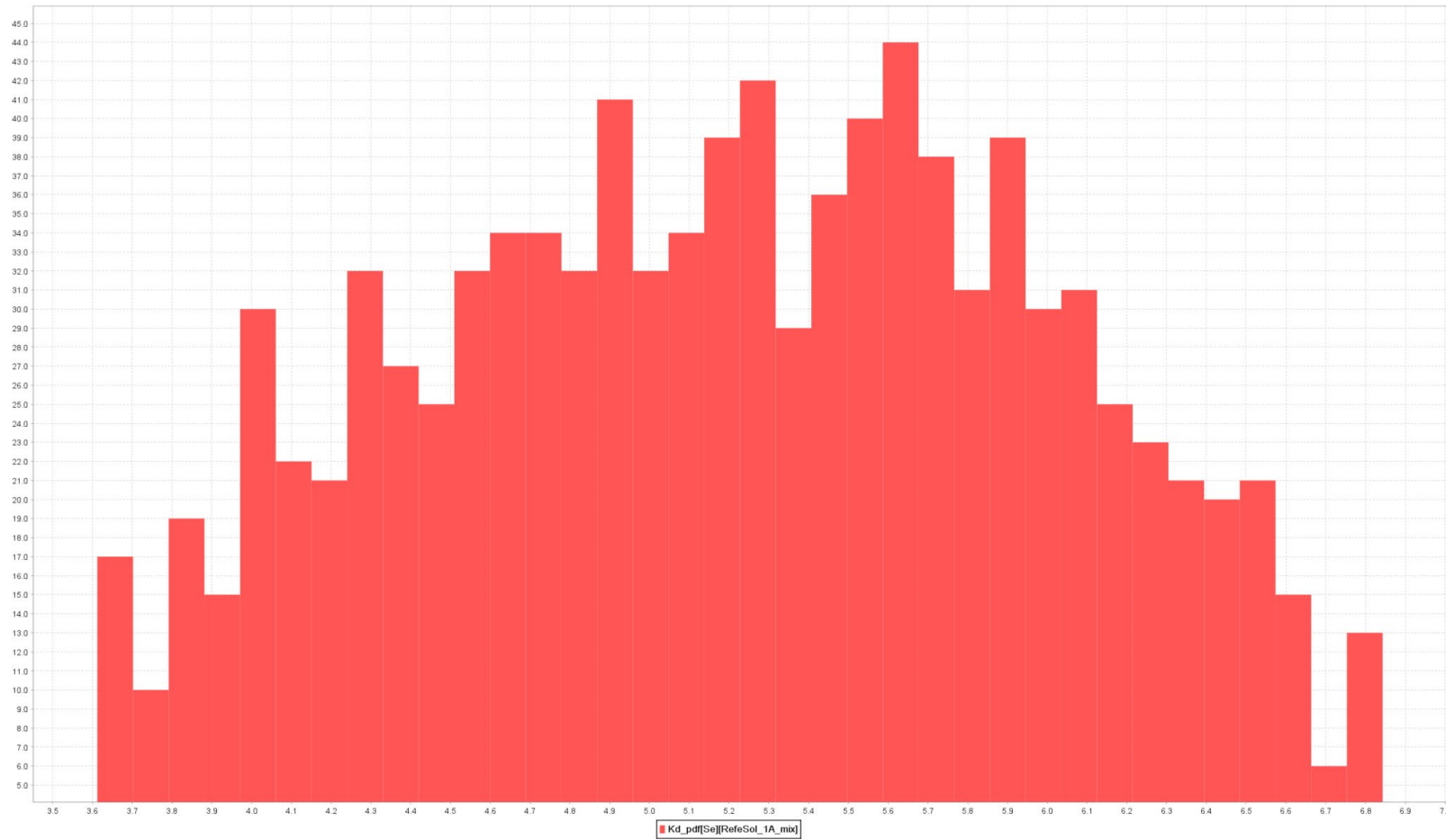
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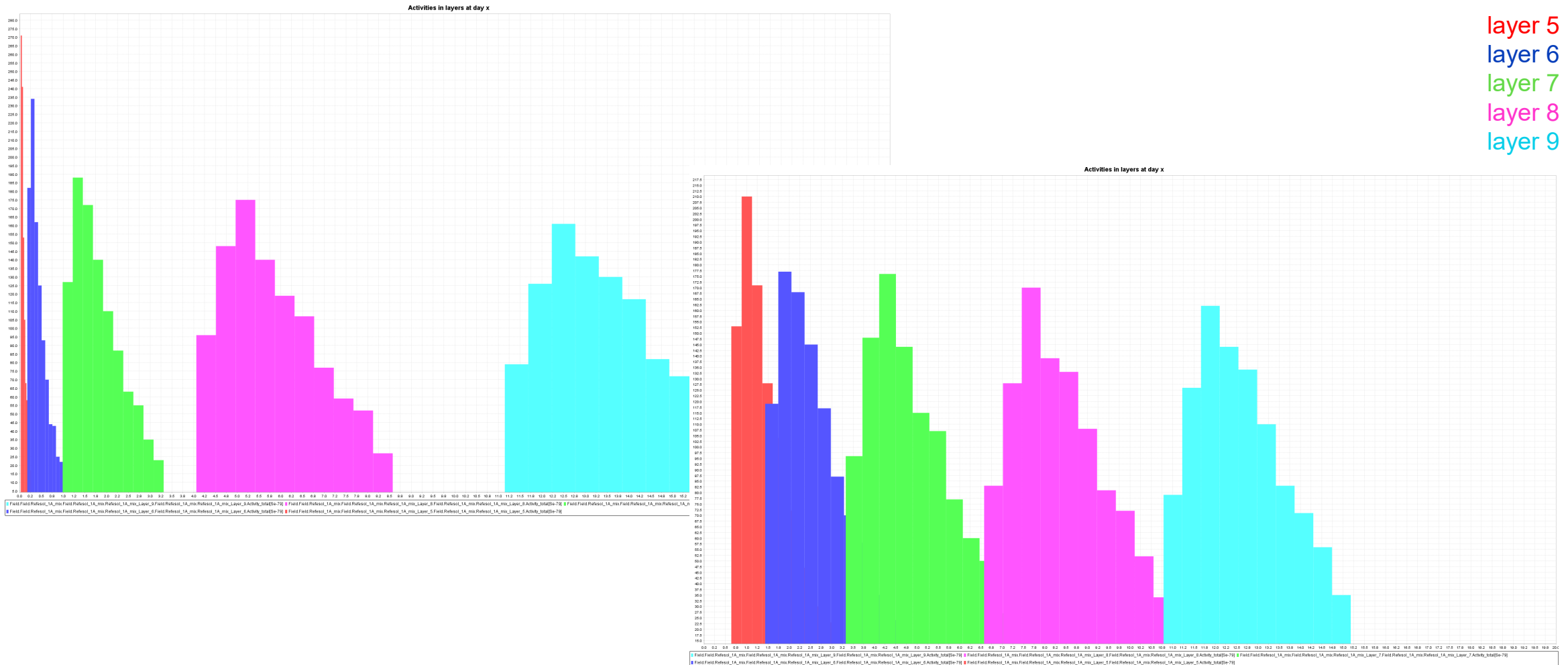
Deterministic / probabilistic simulation: Example of implementation of Kd-value variability



Example of K_d distribution for Selenium



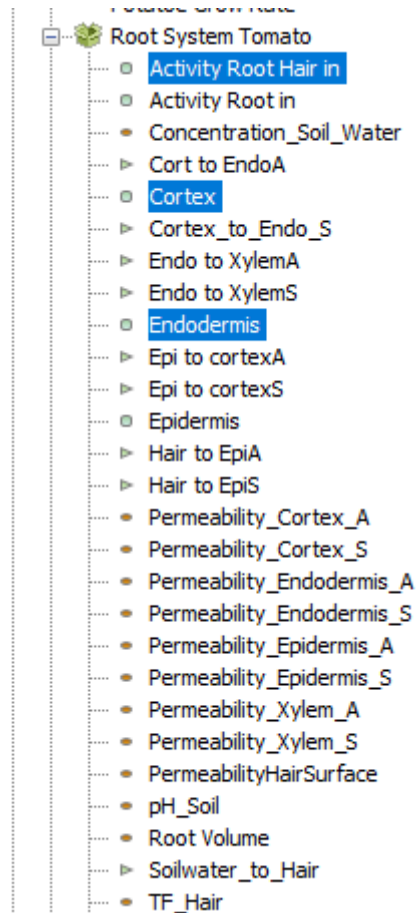
Frequency of Activities in layers at day 50 and 300



Uptake in the root system

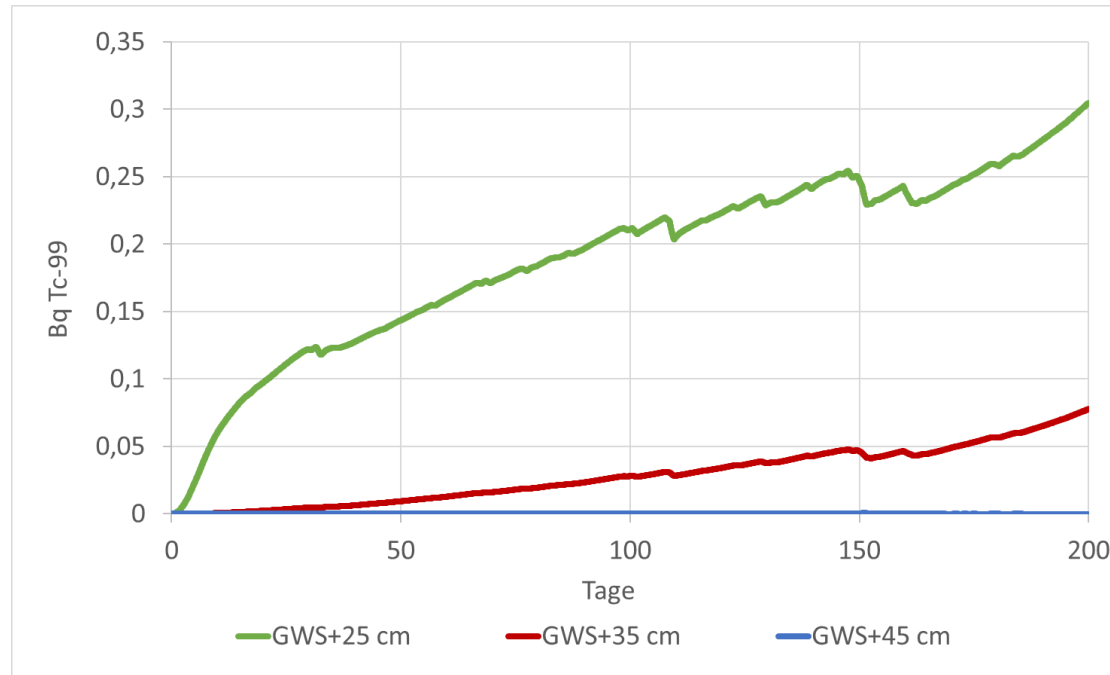
Parameter		Dependencies				Data	Referen ces	Export info	
Name	Unit	Eleme nts	Plant_spezie s	Plant_Comp onent	Soil_Texture	Value	Referen ce	Tags	ID
TF		I	potatoes	Root	Refesol_1Amix	16,69	IRS		Field.TF
TF		Tc	potatoes	Root	Refesol_1Amix	4,253	IRS		Field.TF
TF		Am	potatoes	Root	Refesol_1Amix	9,317	IRS		Field.TF
TF		Pu	potatoes	Root	Refesol_1Amix	6,14	IRS		Field.TF
TF		I	potatoes	EdibleP	Refesol_1Amix	0,267	IRS		Field.TF
TF		Tc	potatoes	EdibleP	Refesol_1Amix	0,418	IRS		Field.TF
TF		Am	potatoes	EdibleP	Refesol_1Amix	0,083	IRS		Field.TF
TF		Pu	potatoes	EdibleP	Refesol_1Amix	0,007	IRS		Field.TF

$$\frac{dc_{root,i,n}}{dt} = TF_{root,soil,n} * c_{Soil,i,n} - Tf_{Hair} * c_{Root,n,i}$$

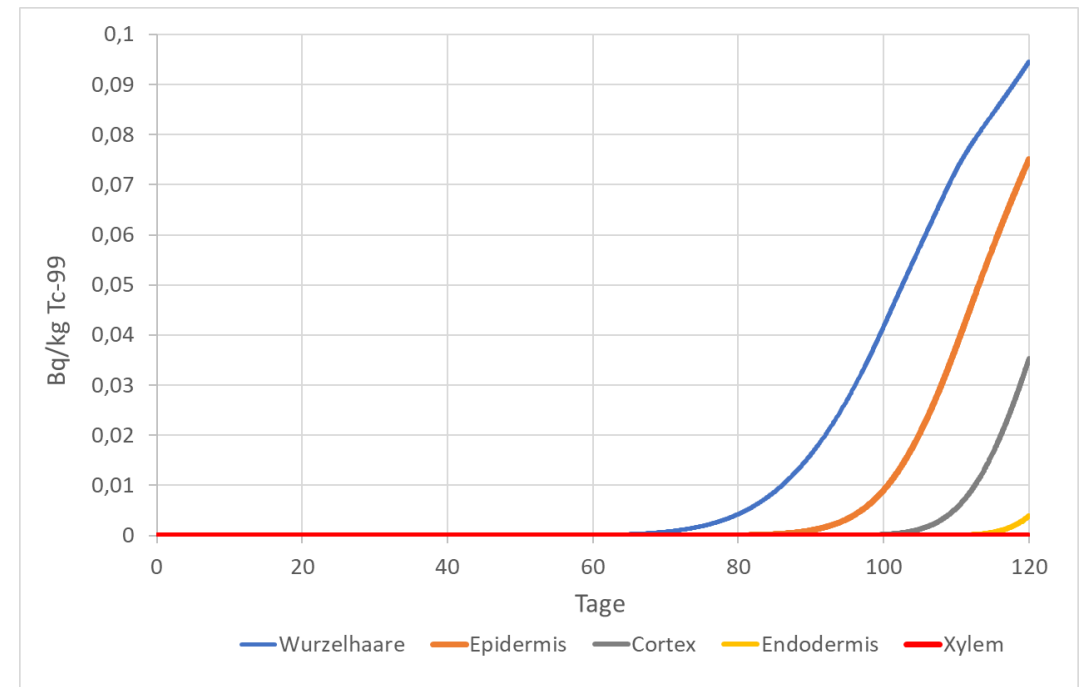


Uptake in the root system

Reduction in Tc-99 activity in the three soil layers above the GWL as a result of Tc-99 uptake by potato roots in the layers GWL+25 cm, GWL+35 cm, and GWL+45

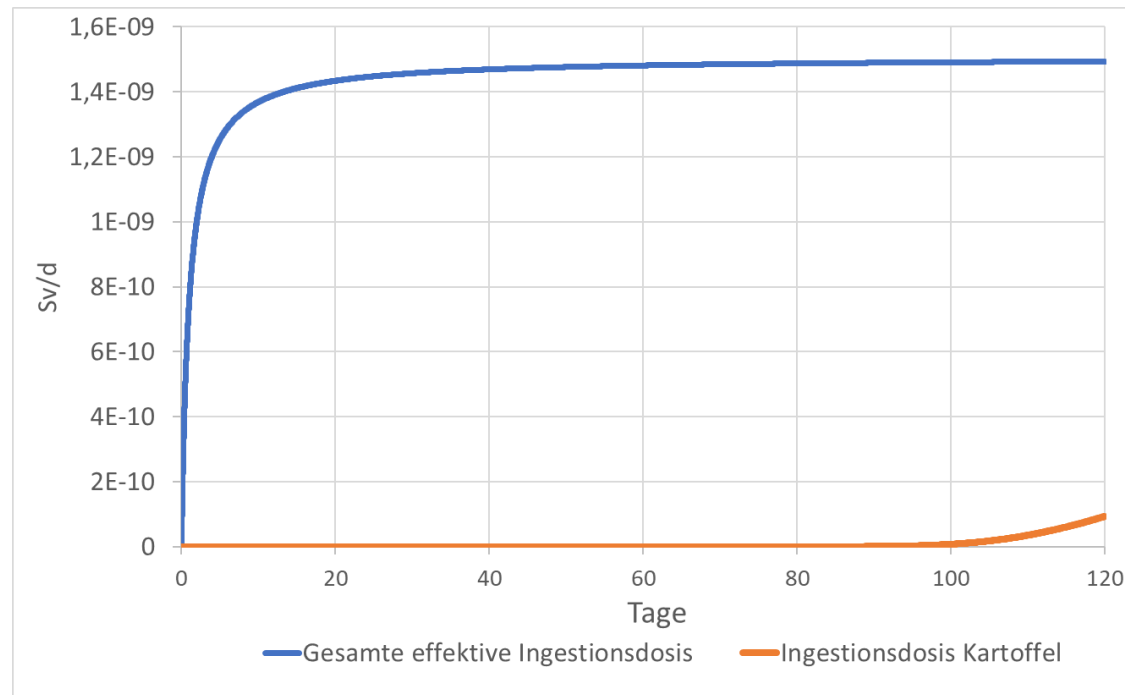


Development of Tc-99 activity concentrations in the cell layers of the potato root until harvest (layer GWL+15 cm)

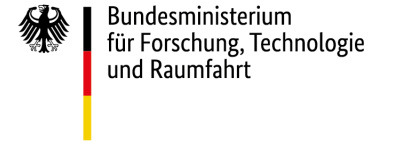


Dose estimation

- Hypothetical dose for Tc-99 for the most unfavourable age group <1 year compared to the total effective dose through ingestion



Gefördert durch:



Thank you for your attention!

Do you have any questions?



Your contacts

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