Federal Ministry of Education and Research

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

TRANS-LARA
BMBF* - Joint Project

"Transport and transfer behaviour of long-lived radionuclides along the causal chain groundwater-soil-surface-plant under consideration of long-term climatic changes"

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Manuel Claus
BIOPROTA meeting
Munich, 13.- 14.05.2019

*Bundesministerium für Bildung und Forschung/Federal Ministry of Education and Research www.oeko.de

Project Partners

funded by

Federal Ministry of Education and Research

coordination

Leibniz Universität Hannover

IRS

ifb Institut für Biophysik

ZSN

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Institute of Resource Ecology

Applied Geology

Institute of Geosciences

Friedrich-Schiller-Universität Jena

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Institut für angewandte Ökologie

Institute for Applied Ecology

Institut für Umweltphysik

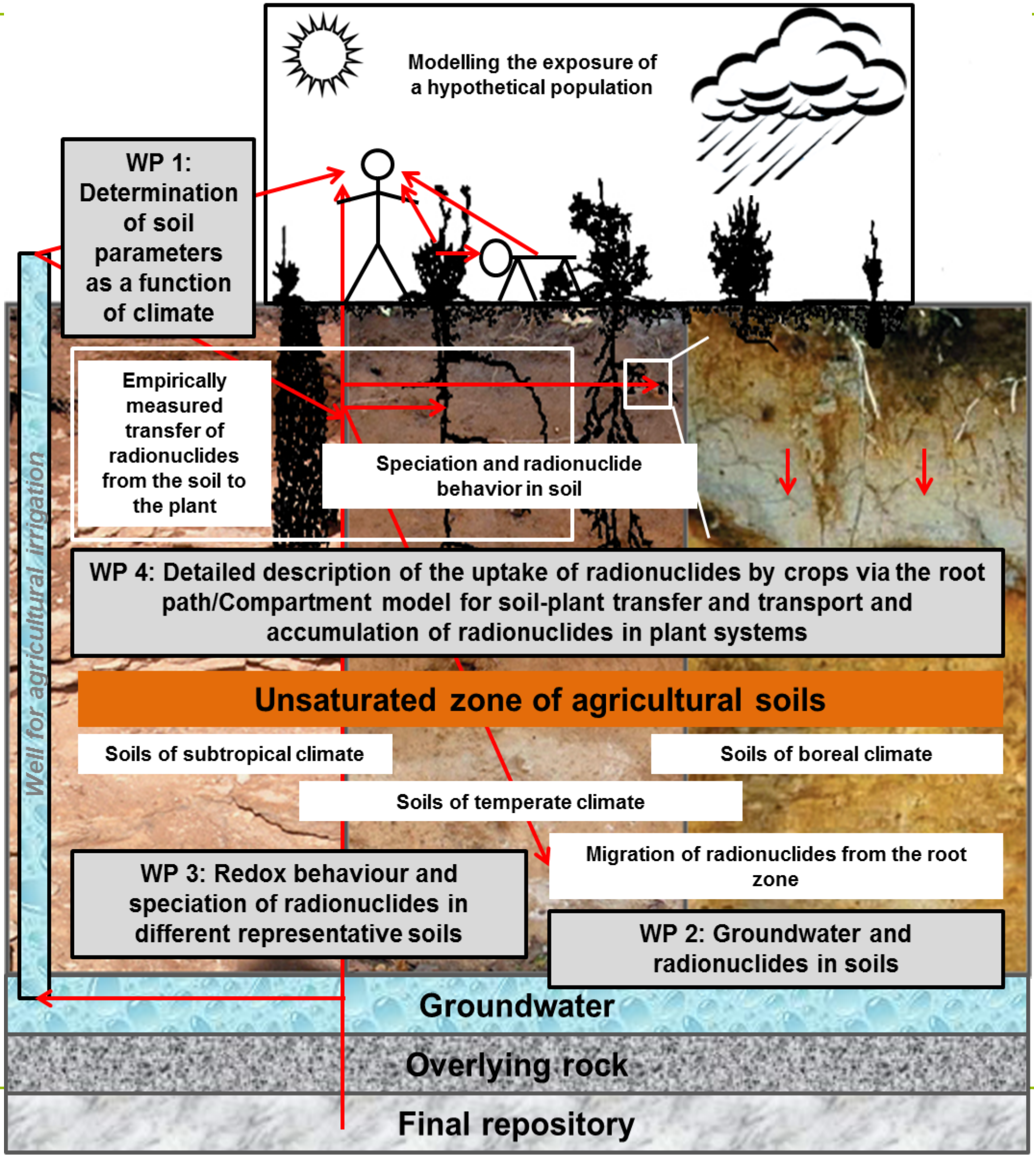
Institute of Environmental Physics

Universität Bremen

Radioactivity Measurements Laboratory

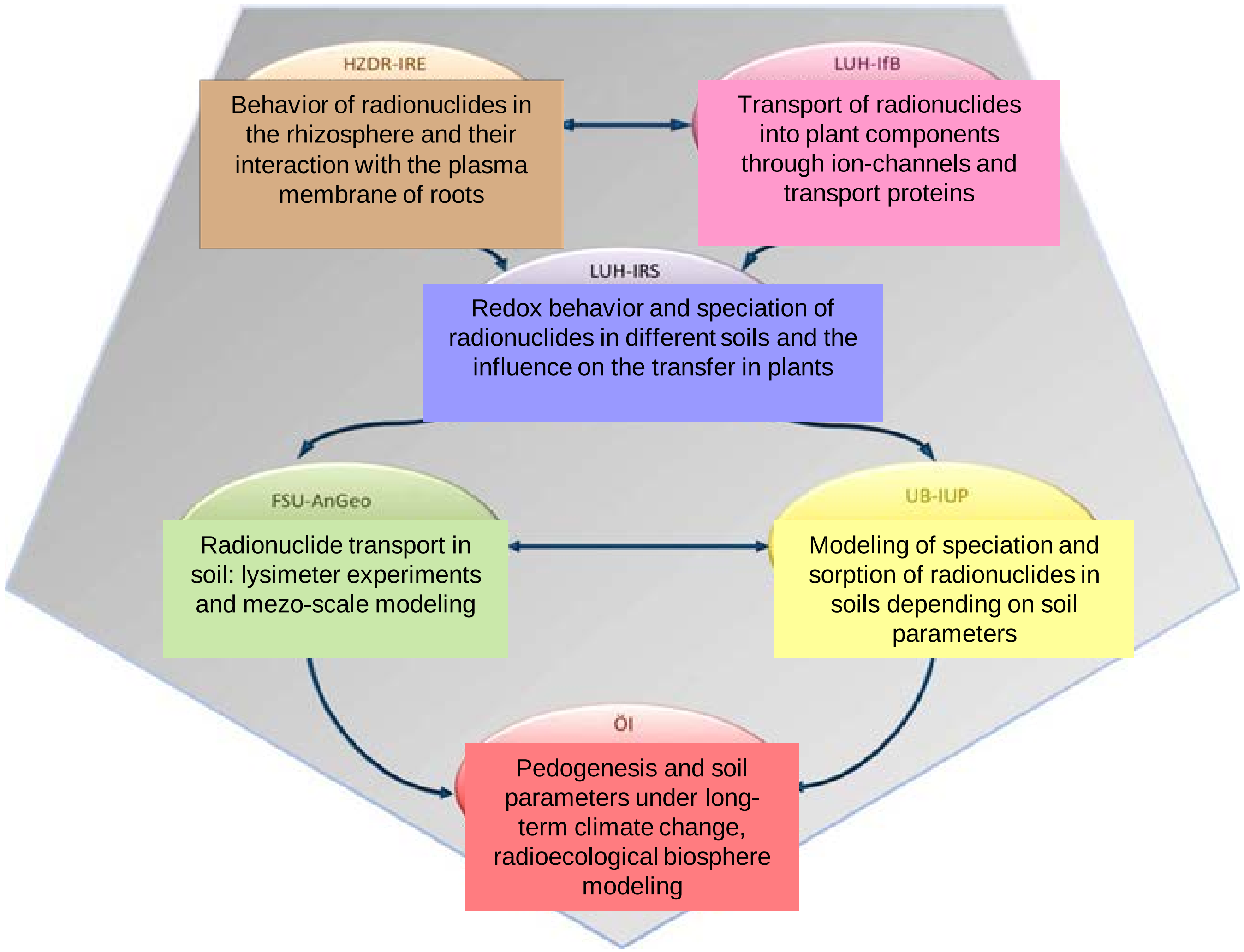
Main Tasks and Work Packages

- Mechanisms of radionuclide transport groundwater →soil →plants under long term climatic changes
- Maintain competence and promote young scientists in safety research on final disposal of radioactive waste
- Focus on radionuclides Pu, Tc, I, Se; also involved U, Cm, Am



Source picture: TRANSLARA Project Description

Works of Project Partners: Interlinking Multiple Experimental and Modeling Scales



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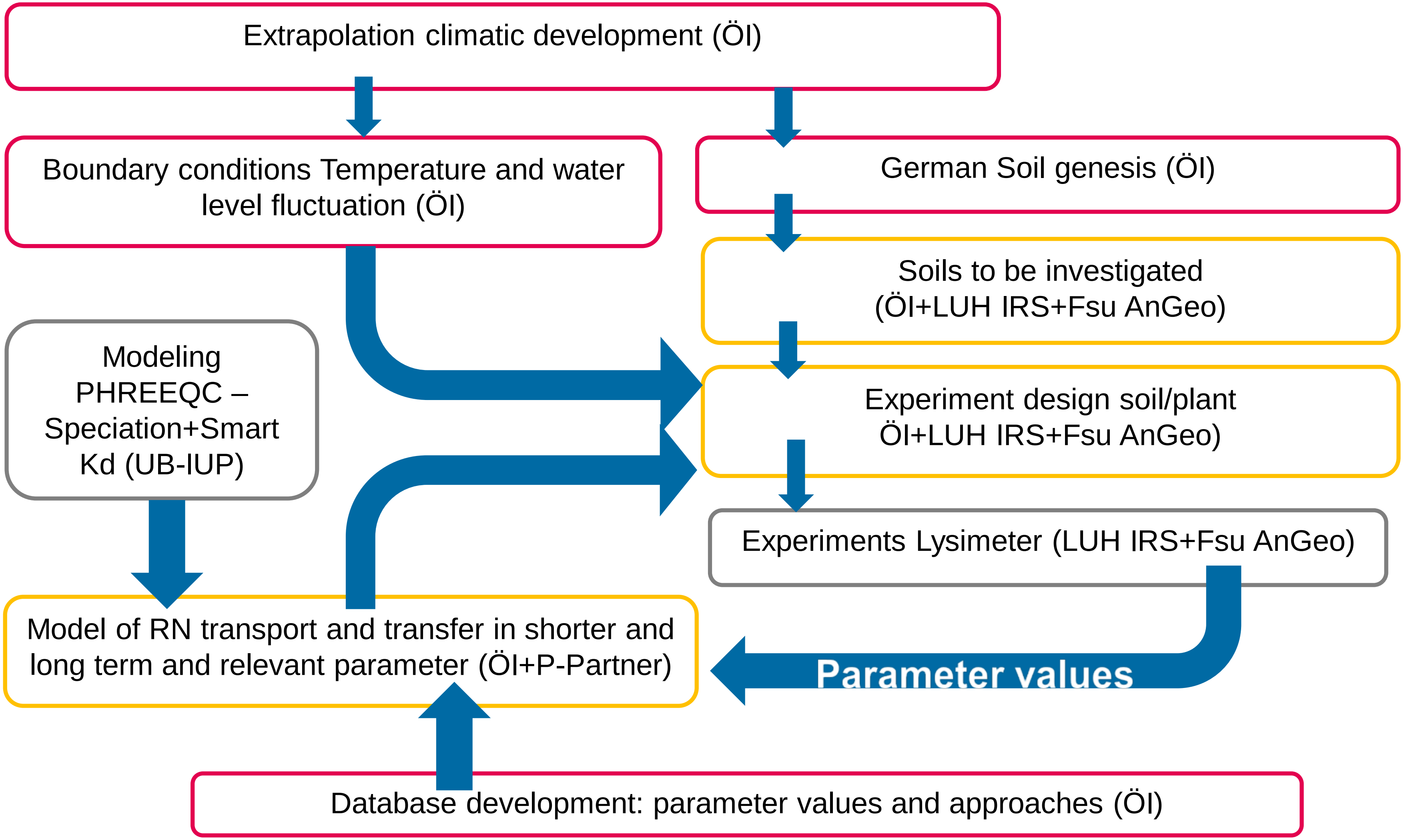
Framework Soil Experiment Design and Modeling (Öko-Institut+LUH IRS+Fsu AnGeo)



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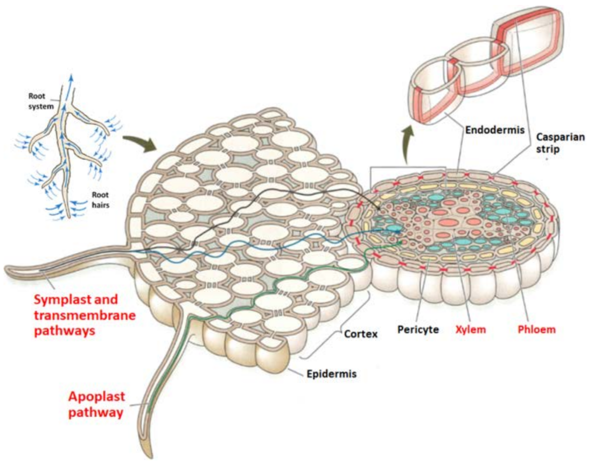
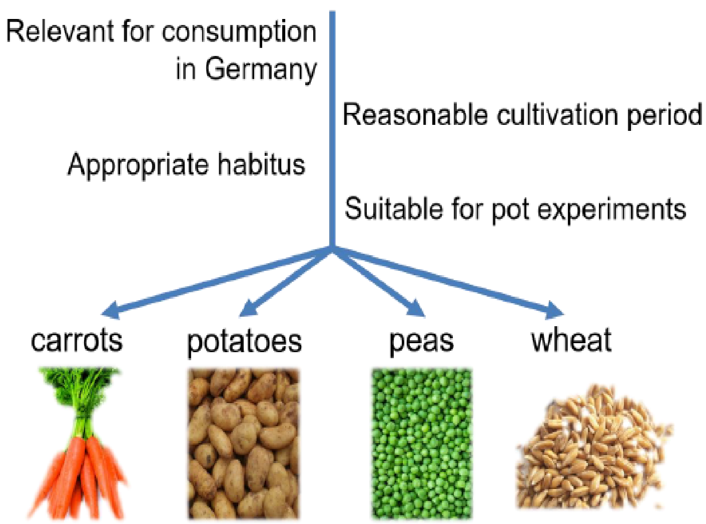
Framework Plants Uptake of RN into and within plants LUH-IRS/LUH-IfB/HZDR-IRE

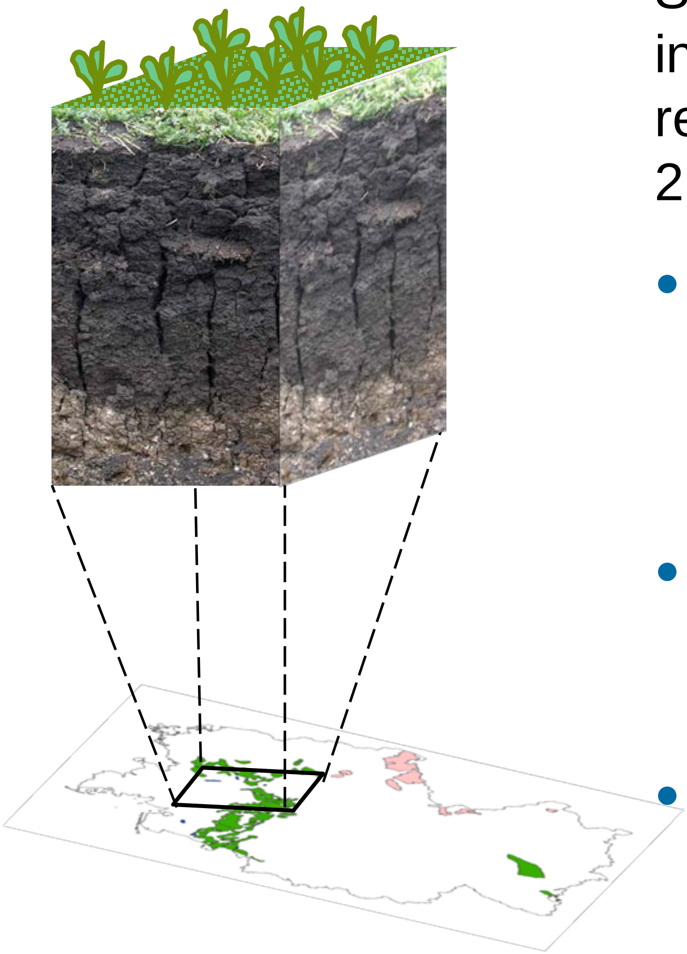




Which plant metabolite transporters are able to transport radionuclides into the plants? (e.g. Cm/Am; U; Pu, Tc)

- LUH-IRS: Transfer factors of RNs from the reference soils in selected plants, RN root uptake and interaction of RN with root exudates
- LUH-IfB/HZDR-IRE: RN-Transport into he cells by Ionentransporter und Ionenpumps / kinetics in injected oocytes

Long-term climatic developments and soil genesis



Selection of the current and predicted soils to be investigated in German regions above potential repository sites (according to document K-MAT 21b of the Repository Commission)

- ArcGIS analysis of the most common soil types (WRB/RefeSol system) above potential repository sites -> two current soils to be investigated + GW-Fluctuations
- Extrapolation warm / cold climate development of repository sites regions and influence on genesis of two selected current soils
- Identification of two predicted soils to be investigated

(AP1: Kooperation ÖI, LUH-IRS, FSU-AnGeo)

Source: Map of geological formations that are worth for investigating (crystalline, clay, salt; from K-MAT 21b of the Repository Commission)

Interfaces Experiments/Modeling

Experiments under defined conditions

Experiment Soil
Laboratory scale / lysimeter
(LUH-IRS, FSU Jena)

Water movement with GWL + RN transport
Soil Parameter: KAK, Corg, pH,
Hydraulic Parameter: Kf, pf

Experiment Plant
micro and mesoscale (lysimeter)
(LUH-IRS/IfB)

RN transfer
content in various
plant components / cells

Model

Hydraulic/Transport Model
lysimeter/shorter time scale (months)
FSU Jena

Hydraulic/Transport
RN transfer in plants
Resulting radiation exposure
Field/micro & long time scale
Öko-Institut

ECOLEGO tools:
1D Model: selected transport issues
M-C Sensitivity Analysis
RN transfer soil/plant
Radiation exposition tool

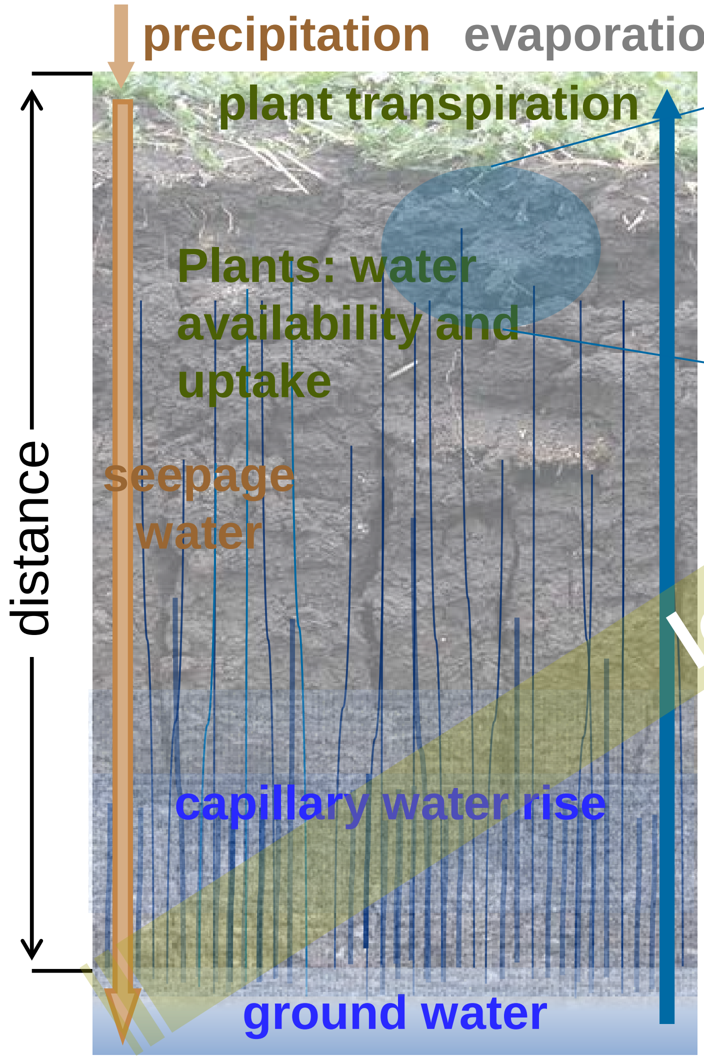
+ Database

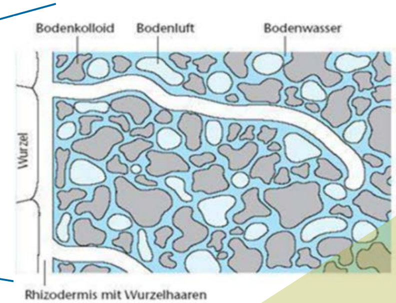
UB-IUP Interface PHREEQC

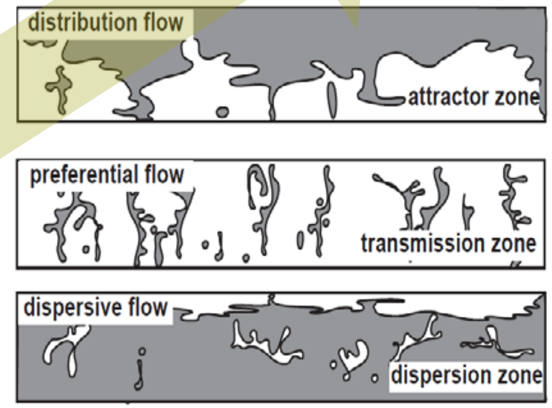
RN: Tc, Pu, Am, I, Se, Np

Source Pictures: IRS Hannover, FSU Jena

Multiple processes and scales: simplifications in time and space







Transport direction downwards (percolation) or upwards (capillary forces in pores):

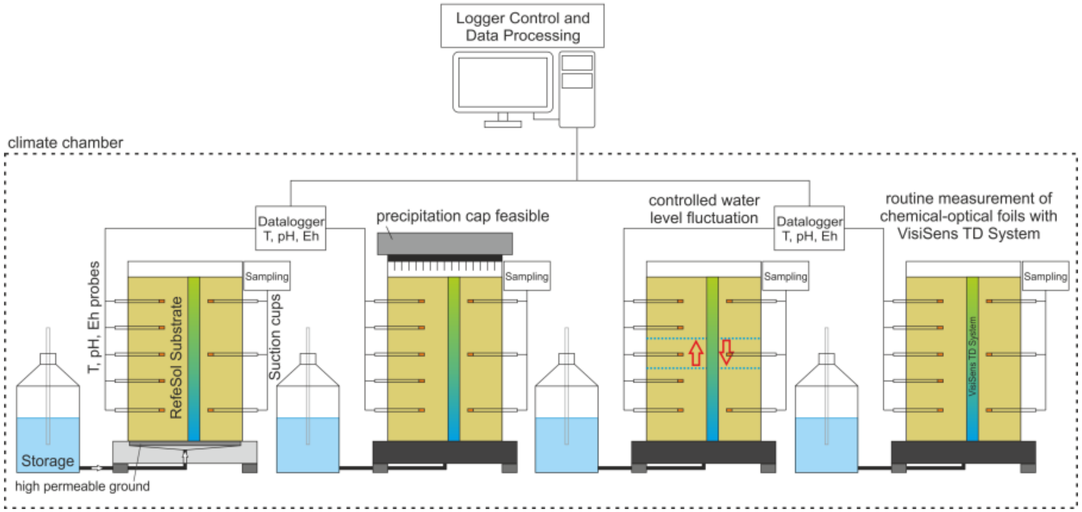
RN accumulation in long time

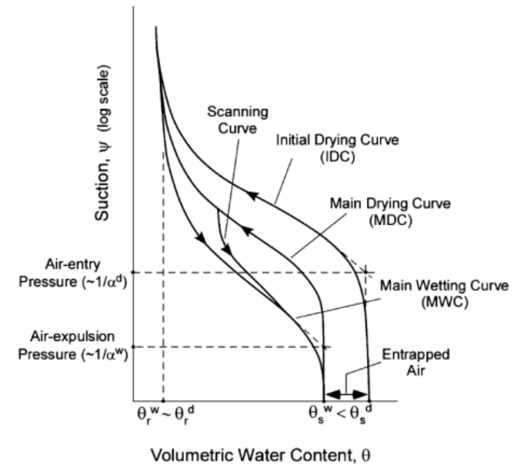
Sources pictures: Öko-Institute.V., Flühler et al. 1998, Sitte et al. 2002

Upscaling the experimental scale

- Simplification: lysimeter scale → large scale of planted agriculture area (retention curve simplification)
- Consideration of layered soil profile
- Transfer soil-plant from tracer experiments

Different experimental arrangements for laboratory lysimeters



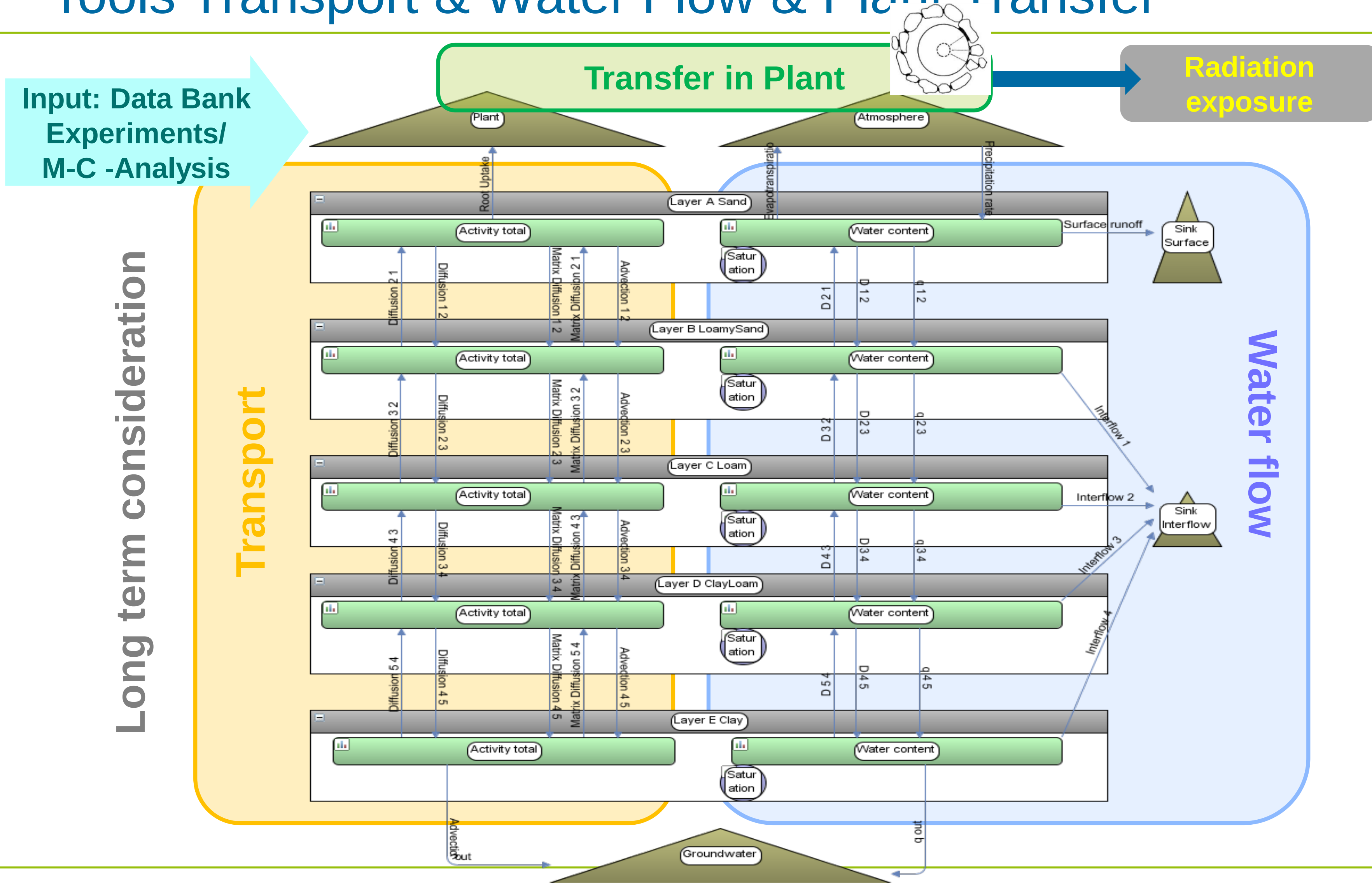


Sources pictures: FSU-AnGeo, IRS-LUH; Flühler, H.: Physik der Ungesättigten Zone, ETH, 2004

Long term radionuclide transfer at field scale in ECOLEGO: processes and model components

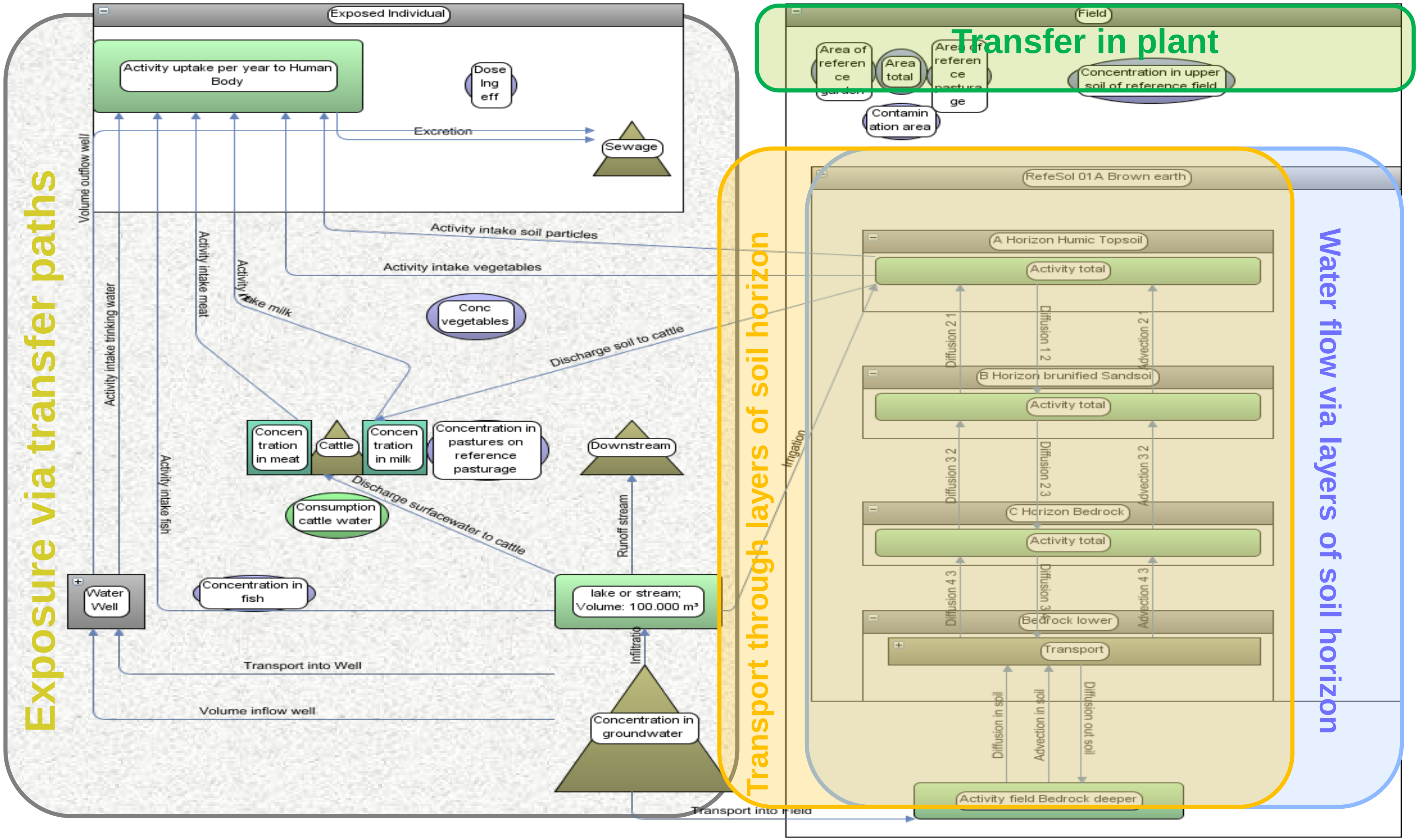
- Climate change and soil genesis: defining soil types, horizons/layers and schematization, parametrization
- Water flow: GW-level variation, capillary effects, precipitation (FSU-AnGeo / UB-IUP) $\rightarrow$ upscaling
- Radionuclide transport by soil water (FSU-AnGeo/LUH–IRS) and transfer to / within plants (LUH-IfB)
- Ingestions paths and Biosphere Dose Conversion Factors
- Upscaling / suitable averaging in time and space
- Parameter data basis development
- Parameter uncertainties – Monte Carlo Analysis: variation and probabilistic functions

ECOLEGO Model
Tools Transport & Water Flow & Plant Transfer



Source: Öko-Institut e.V.

Overall Compartment Model - Ingestions Paths and Biosphere Dose Conversion Factors



Source: Öko-Institut presentation at the Trans-LARA meeting in HZDR

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Vielen Dank für Ihre Aufmerksamkeit!
Thank you for your attention!

Haben Sie noch Fragen?
Questions are welcome!

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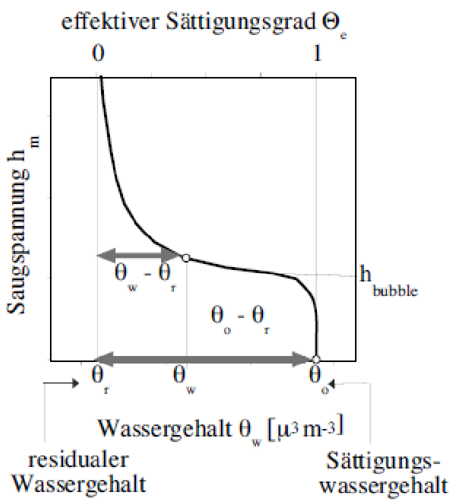
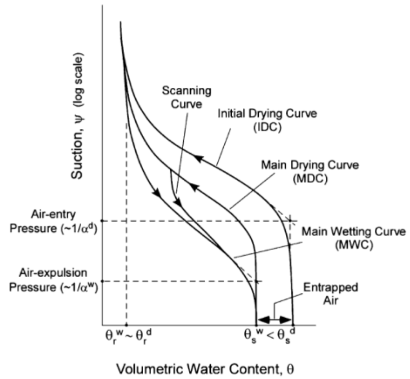
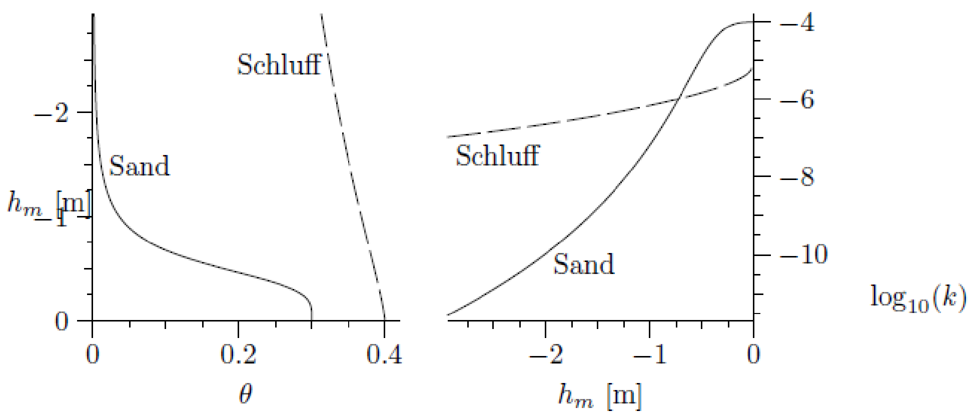
Governing parameters of Soil-Water-Retention curve







- Richards Equation:

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

- Hydraulic soil characteristic: water retention curve as relation between water content θ and water potential /suction pressure Ψ (pF curve) in dependence on pore size distribution
- Water diffusivity: hydraulic conductivity K at a given water content θ multiplied by slope of relationship between suction pressure and water content $D(\theta) = K(\theta)dh/d\theta$
- Relation between water content and water conductivity K

Sources: Flühler, H. Roth, K.: Physik der Ungesättigten Zone, ETH, 2004; Likos et all.: Hysteresis and Uncertainty in Soil Water-Retention Curve Parameters, Journal of Geotechnical and Geoenvironmental Engineering, © ASCE, 2013

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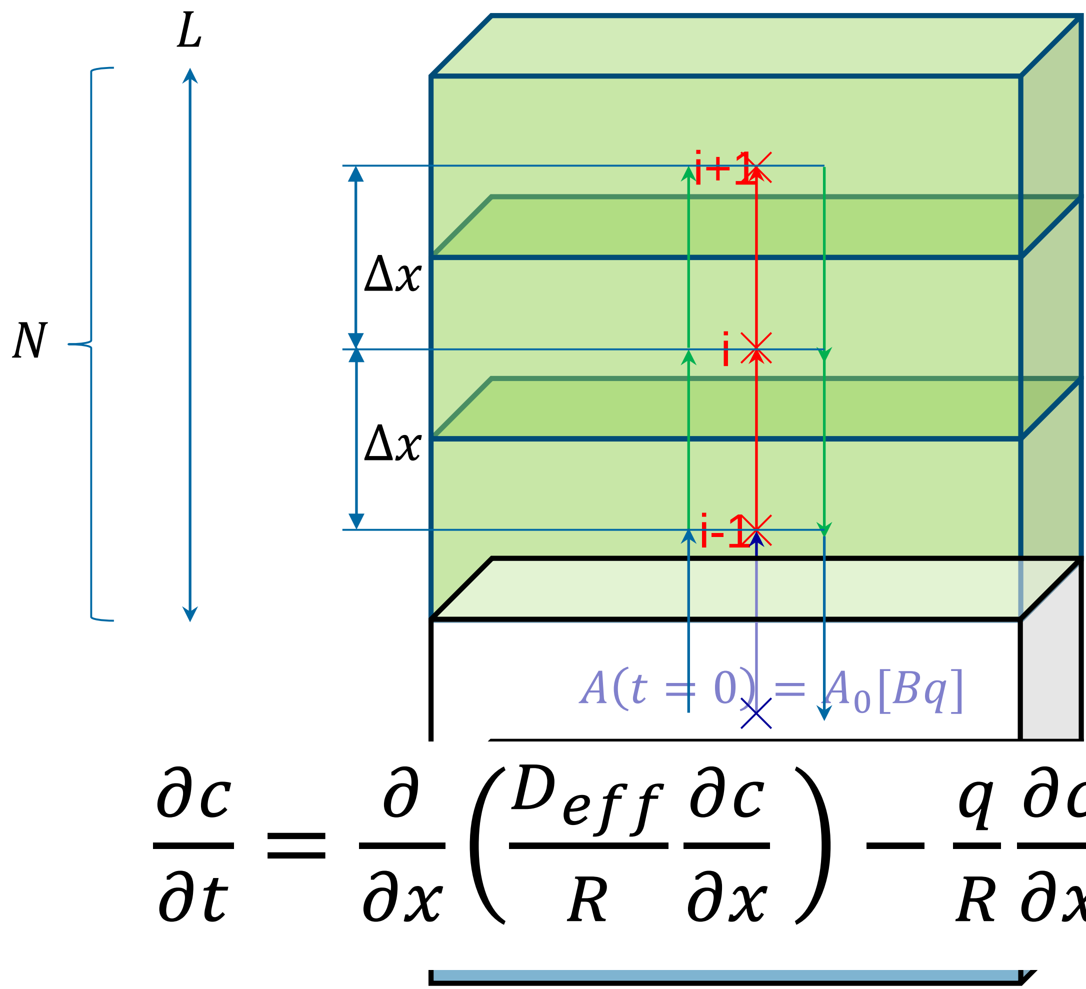
Transport: Finite Volume Method



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

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

A … $Activity$ $[Bq]$

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(\frac{D_{eff}}{R}\frac{\partial c}{\partial x}\right) - \frac{q}{R}\frac{\partial c}{\partial x} - \lambda c$$

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Symbols

- $R = 1 + \frac{\rho}{\theta}\, K_d$

$R \ldots Retardation\ factor\ [-]$
$\theta \ldots effective\ Transport\ Porosity\ (water\ content)\ [-],$
$\rho \ldots Density\ [kg\ L^{-1}]$
$K_d \ldots Partition\ coefficient\ [L\ kg^{-1}]$

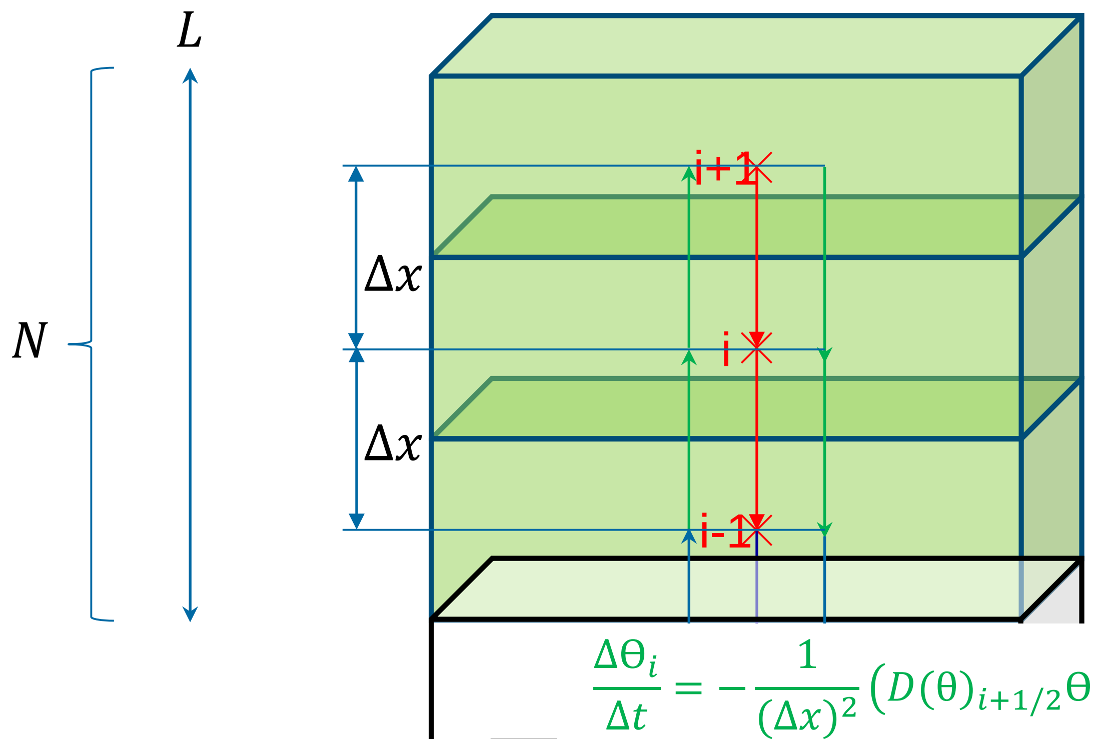
- $D_{eff} = \frac{D\theta\delta}{\tau}$

$D_{eff} \ldots \text{effective Diffusion } [\mathrm{m}^2\mathrm{d}^{-1}]$
$D \ldots \text{molecular Diffusion } [\mathrm{m}^2\mathrm{d}^{-1}]$
$\tau \ldots Tortuosity\ [-],$
$\delta \ldots Constrictivity\ [-],$

- $N_{Peclet} = \frac{L\ q}{D_{eff}}$

$N_{Peclet} \ldots Peclet\ Number$
$L \ldots Length\ of\ model$
$q \ldots Flow\ rate\ or\ Capillary\ rise\ rate\ [m\ d^{-1}]$

Water Movement (Richards Equitation): Finite Volume Method



$$\frac{\Delta\Theta_i}{\Delta t} = K(\theta)_{i+1} - K(\theta)_i$$

$$\frac{\Delta\Theta_i}{\Delta t} = -\frac{1}{(\Delta x)^2}\left(D(\theta)_{i+1/2}\Theta_{i+1} + 2D(\theta)_i\Theta_i - D(\theta)_{i-1/2}\Theta_{i-1}\right)$$

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

Source: Öko-Institut e.V./ Finite Volume Method adapted by considering Wei Mao et al.: An efficient soil water balance model based on hybrid numerical and statistical methods, Journal of Hydrology, 2018

Symbols

- θ ... water content $[m^3/m^3]$
- Θ ... water content in a finite volume / compartment [mm]
- $K(\theta) = K_s \frac{\theta-\theta_f}{\theta_s-\theta_f}$ ...unsaturated hydraulic conductivity,

  where parameters for each soil layer are

  – K_s ... *saturated hydraulic conductivity* $[\frac{m}{d}]$

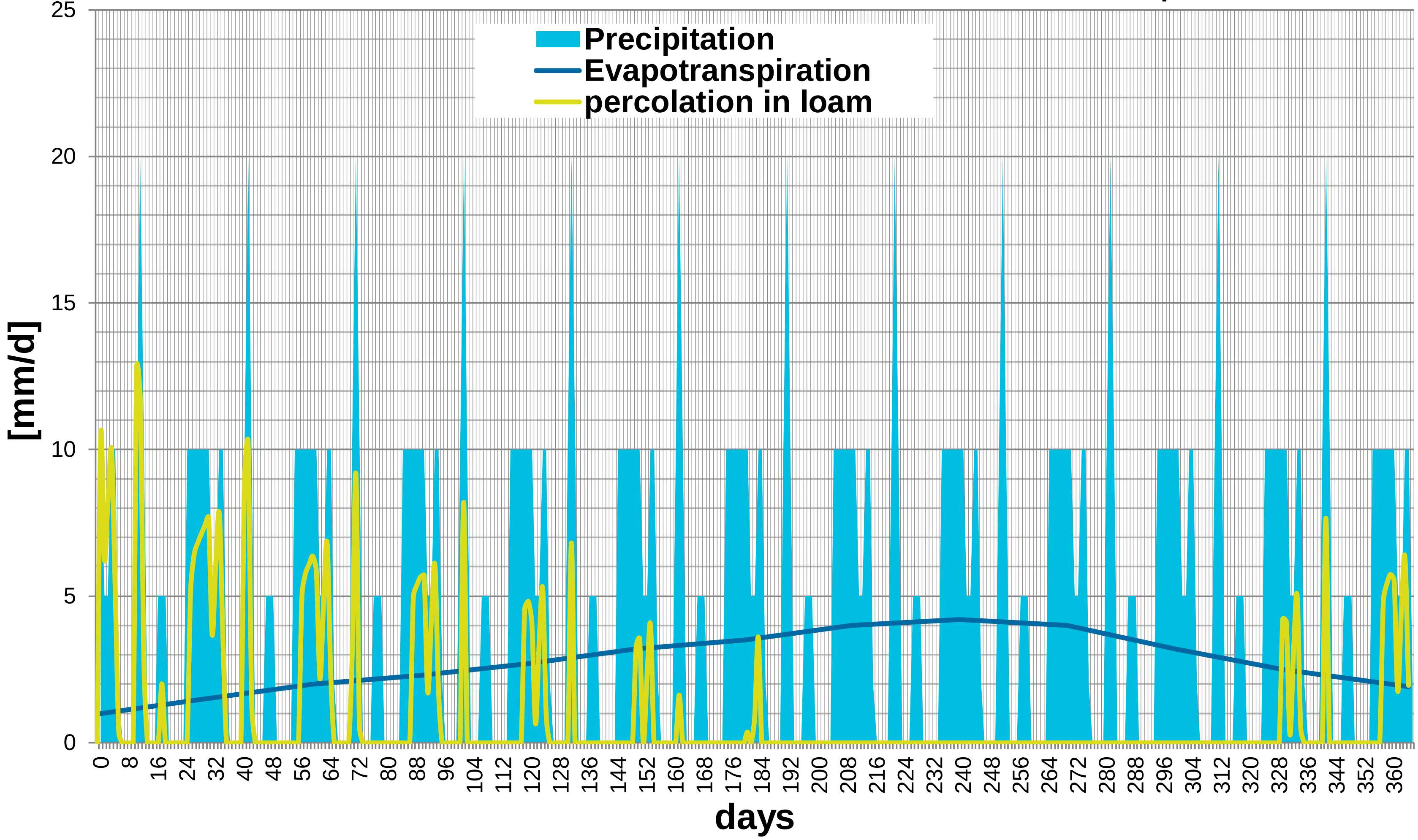
  – θ_f ... field capacity $[m^3/m^3]$

  – θ_s ... saturated water content $[m^3/m^3]$
- $D(\theta)$... Matrix Diffusion $[m^2/d]$, derived from an auxiliary function (see ref.1)
- W...the source/sink term $[d^{-1}]$ to account for soil evaporation and root uptake term of crop transpiration (estimated as reference evapotranspiration according to Penman-Monteith, see ref. 2)

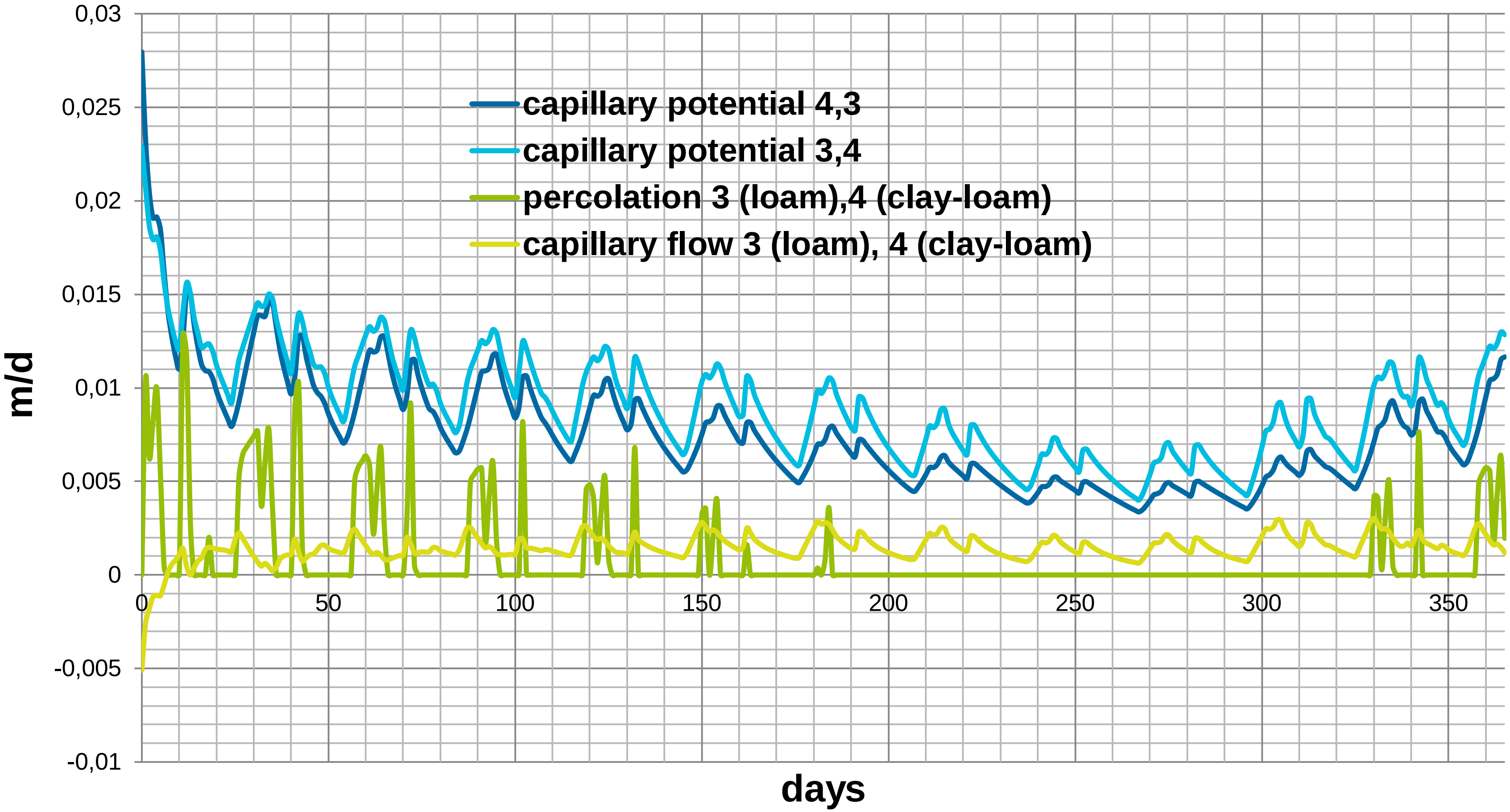
1) Wei Mao et al.: An efficient soil water balance model based on hybrid numerical and statistical methods, Journal of Hydrology, 2018
2) http://www.fao.org/3/X0490E/x0490e08.htm#TopOfPage

Exemplifying results (1)

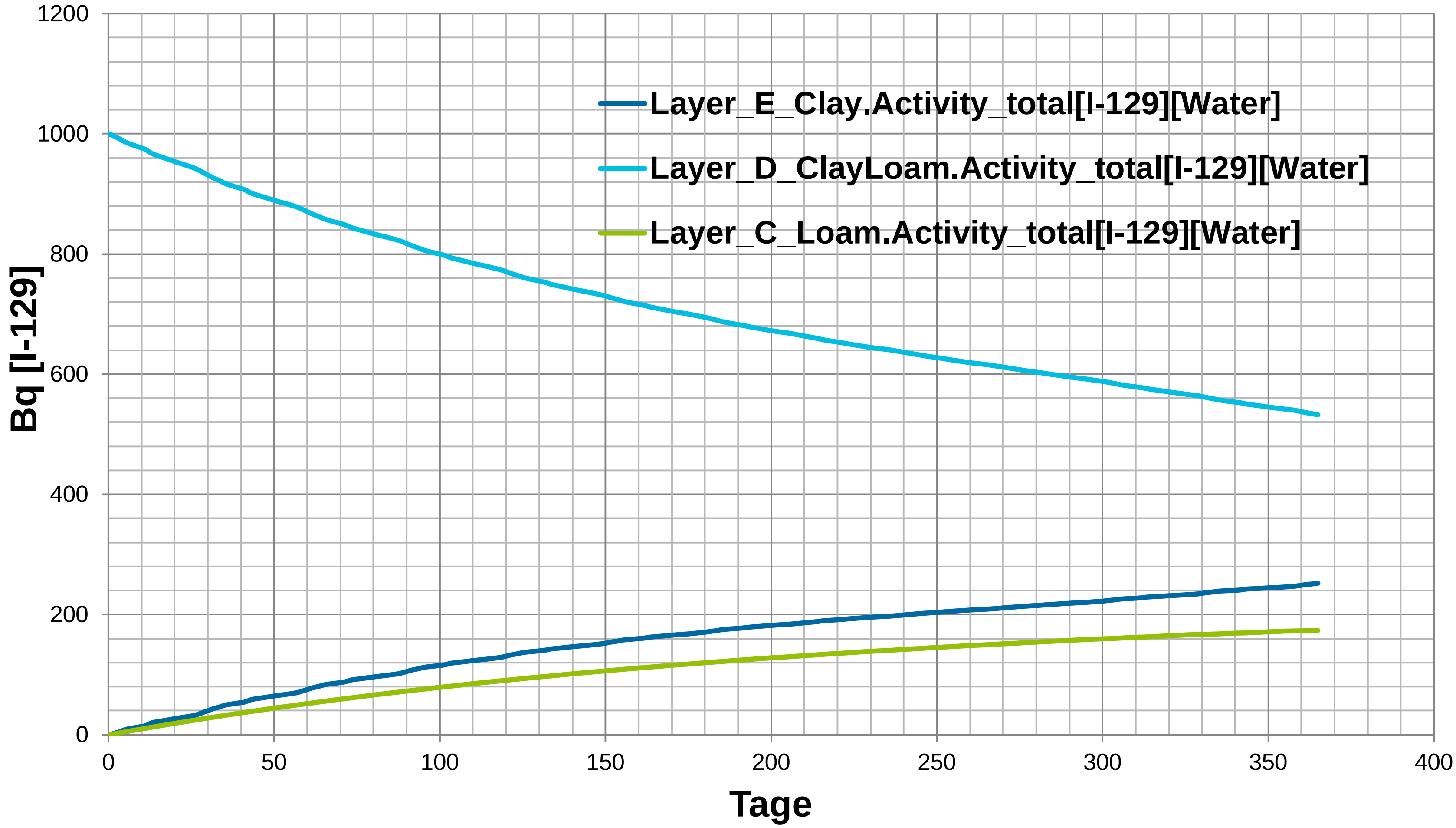
- Precipitation



Preliminary results (1)



Preliminary results (2)



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Typical Analysis: DCC in Sv for I-129 per Bq/m³ GW