



Food and Agriculture
Organization of the
United Nations

International Network of
Salt-Affected Soils



Optimization of crop irrigation under the risk of salinization using agro-hydrological tools

Session 1: Understanding reactive transport models in soils

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(22/10/2024)



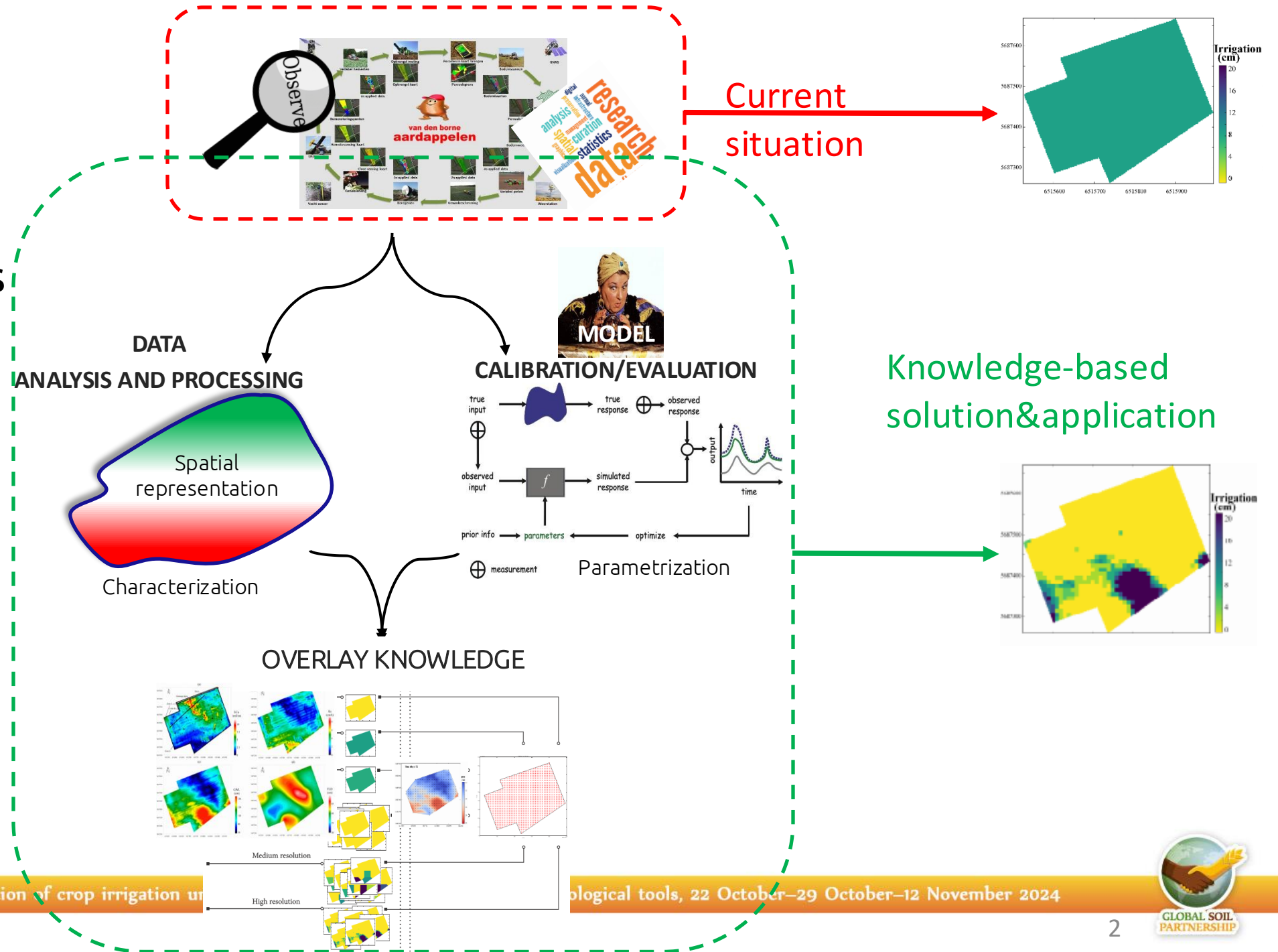
GSP Webinars

Optimization of crop irrigation under the risk
of salinization using agrohydrological tools

22 October–29 October–12 November 2024



General strategy Problem statements



What observing?

Forcing data

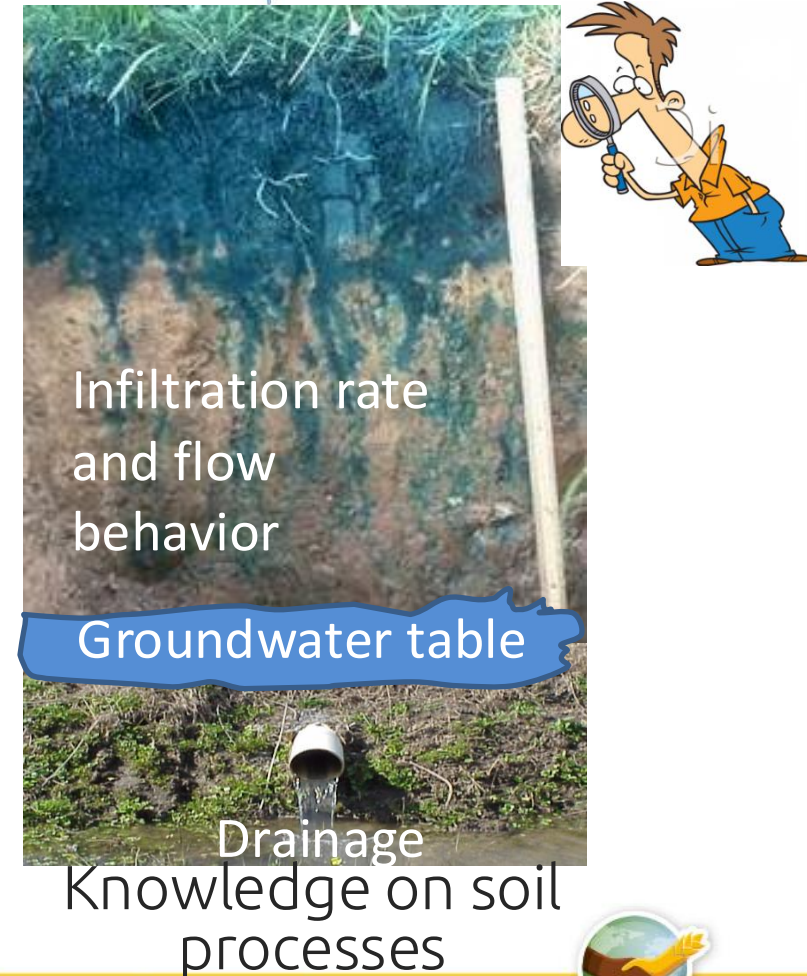
precipitation, net radiation, wind speed, temperature, ...

Monitoring data

flow rate, soil moisture content, solute concentration, soil hydraulic conductivity, groundwater depth (upper and bottom boundary conditions), evapotranspiration, flood depth, root growth and pattern

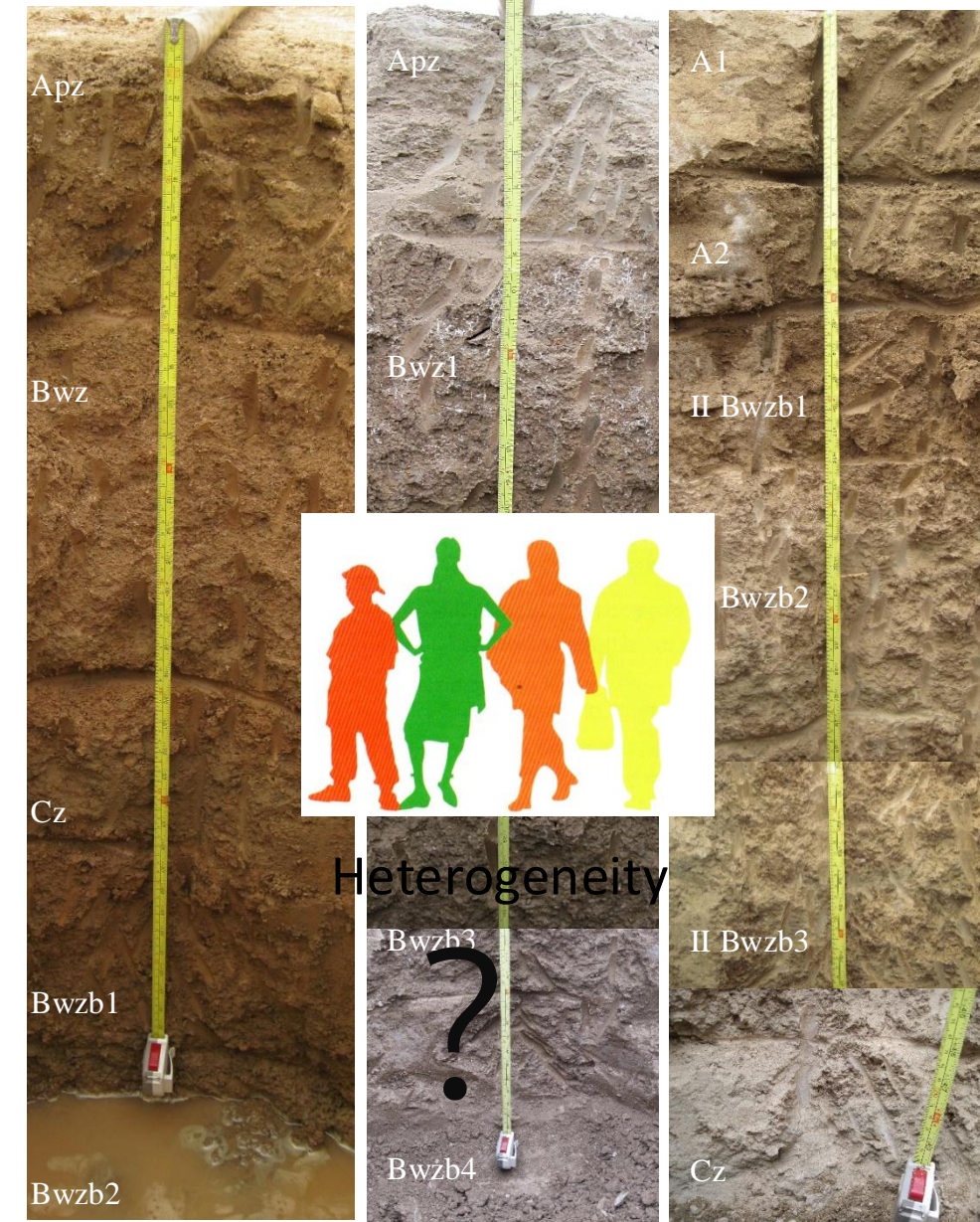
Types of observations?

direct:	in situ
	in the lab
indirect:	Using proxy data, PTFs

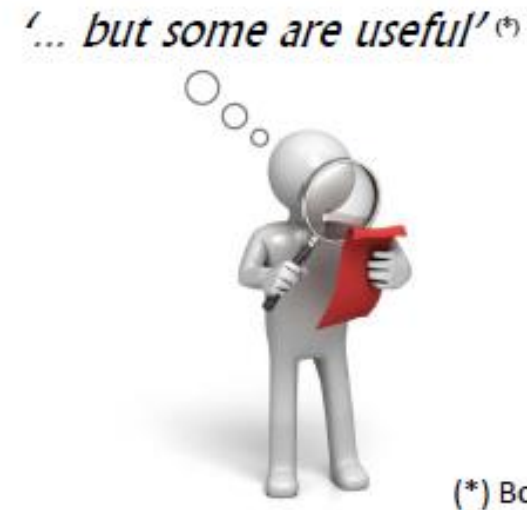


Why modeling?

- Part of the action takes place underground
 - The spatial and temporal variability is too complex to correctly describe with mathematical formulas
 - Various processes are non-linear and / or are stochastic
 - Answer different questions: solute movement, water management (irrigation, leaching), crop yield...
-
- ✓ To predict (simulate the real world situation)
 - ✓ To understand/simplify the hydrology of a complex system
 - ✓ To constructions or mitigating measures against extremes
 - ✓ To scenario analysis and decision making



(Rezaei et al, 2021)

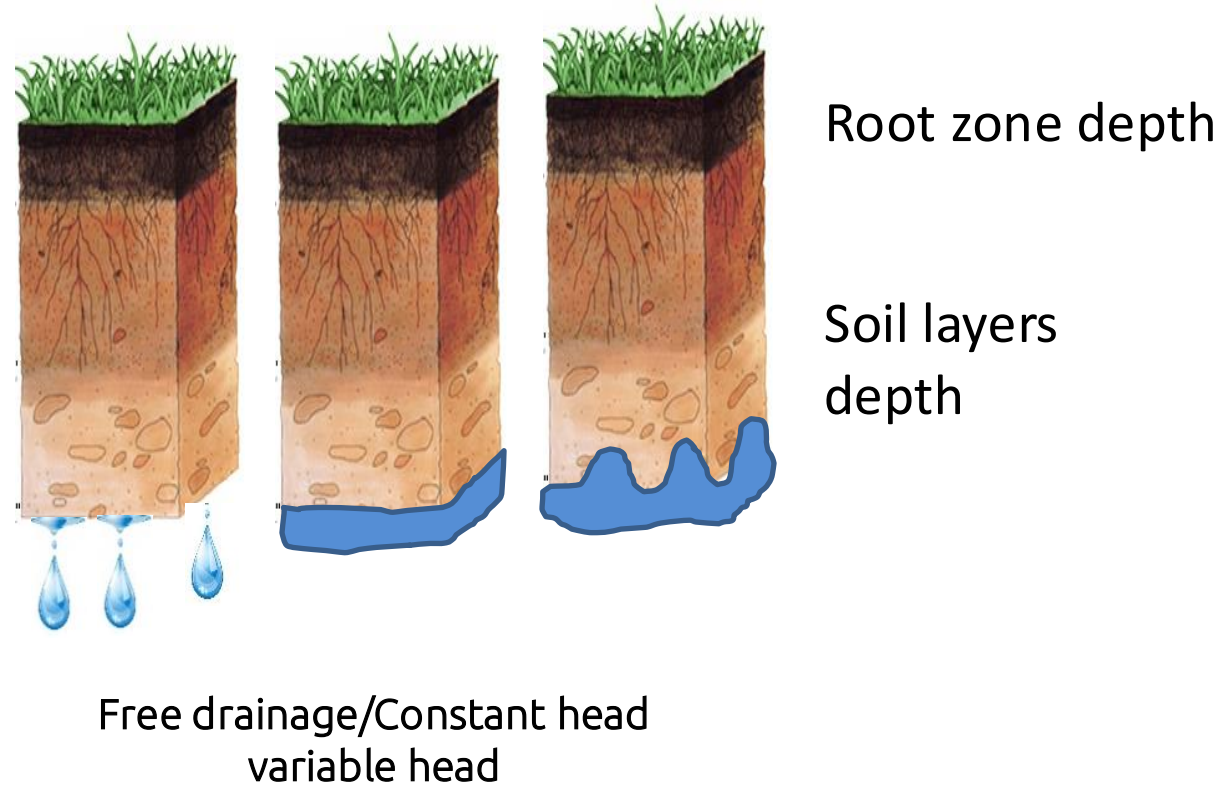


(*) Box and Draper (1987)

“WHAT TYPE OF MODEL MUST BE USED?”
Large dataset or good model?

Modeling approach

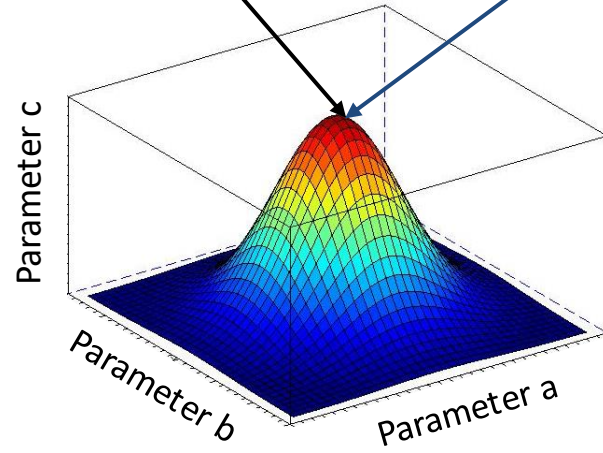
Model conceptualization



Modeling approach

Model parametrization

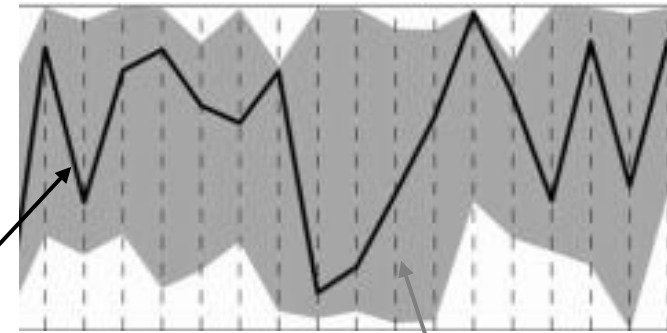
Real word
parameter set
(true value)



Initial/estimated
parameter set



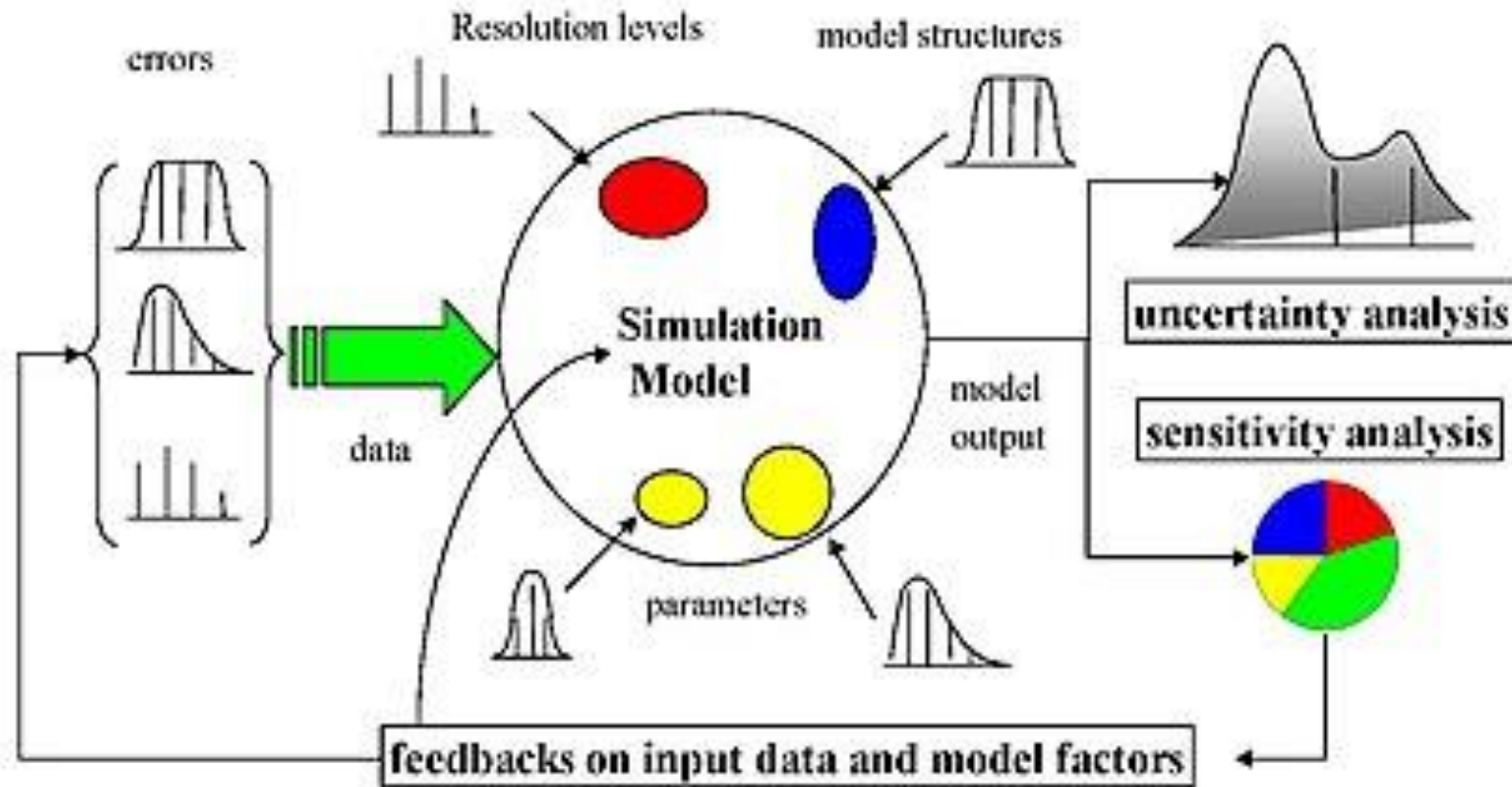
Prediction of true
parameter
set/observation



Predictions of
different
parameter sets

Modeling approach

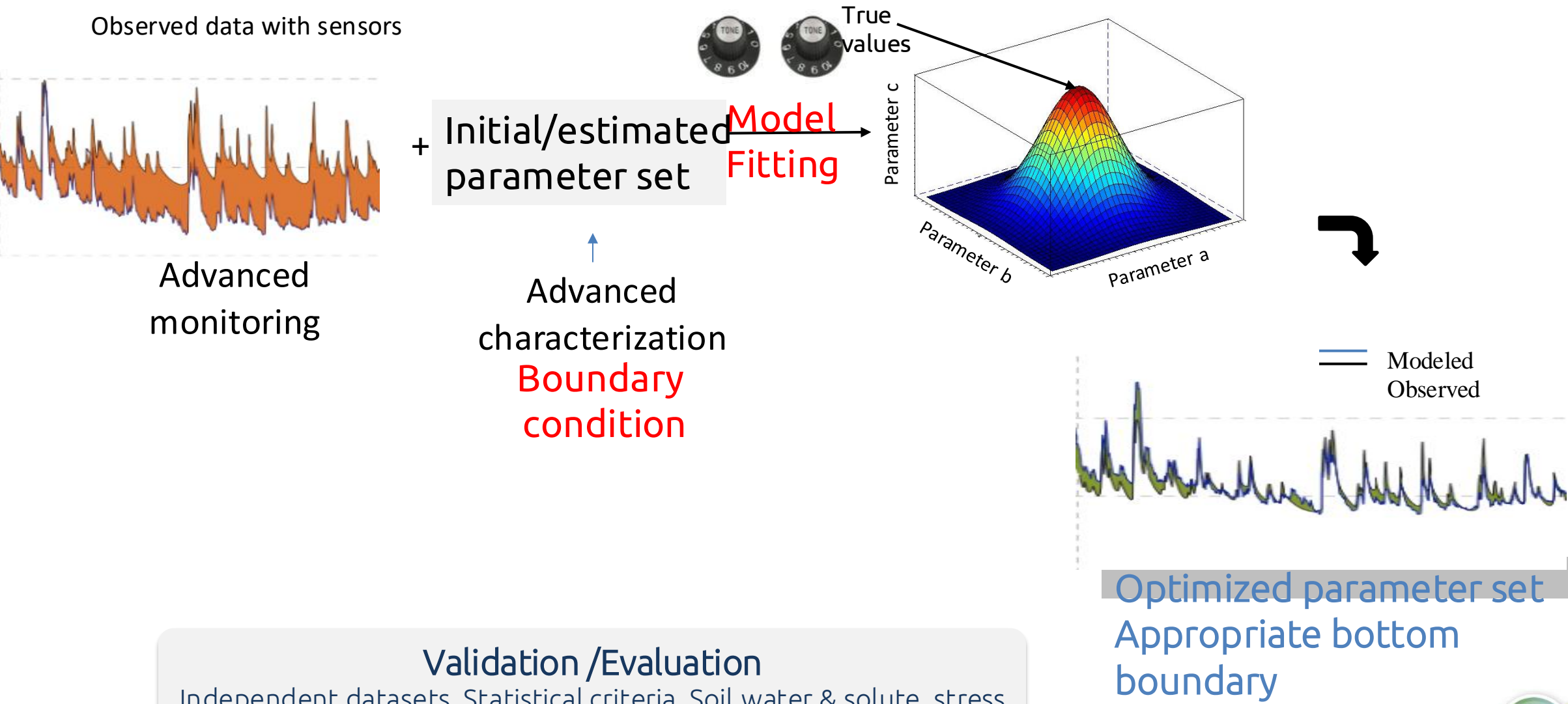
Sensitivity & uncertainty analysis



(Saltelli et al, 2019)

Modeling approach

Inverse modeling Inverse optimization scenarios



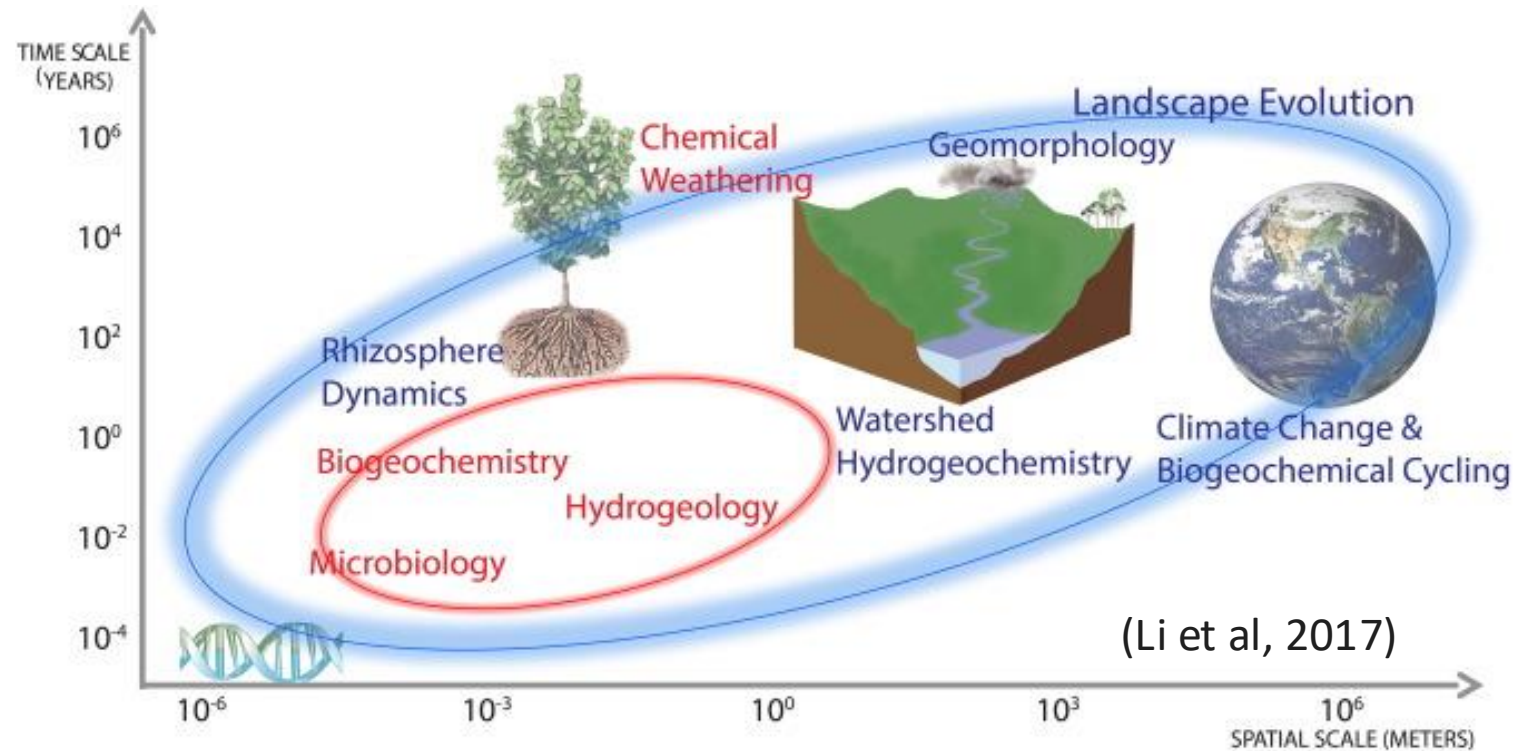
“Reactive transport model”

Computer models are integrating chemical species (solutes) reaction with transport of fluids (water phase) through the porous medium. Such models predict the distribution in space (1/2/3D) and time of the chemical reactions that occur along a flowpath.

(Guimarães, 2002; Jung et al., 2009; Wallis et al., 2011).

- (1) equilibrium models,
- (2) partial equilibrium models, and (3)
- kinetic models.

Coupling models
Hydrological models
Crop growth models



“Reactive transport modelling”

Interactions in Soil Systems

Atmosphere: Influences soil moisture, temperature, and gas exchange

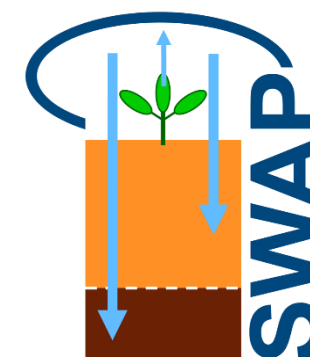
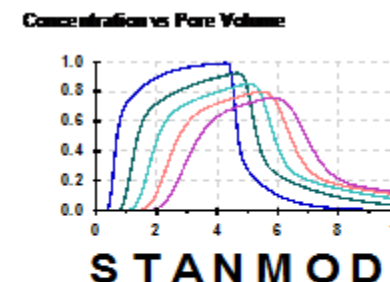
Plants: Affect water uptake, nutrient cycling, and root exudates

Groundwater: Affects soil saturation, chemical transport, and salinity

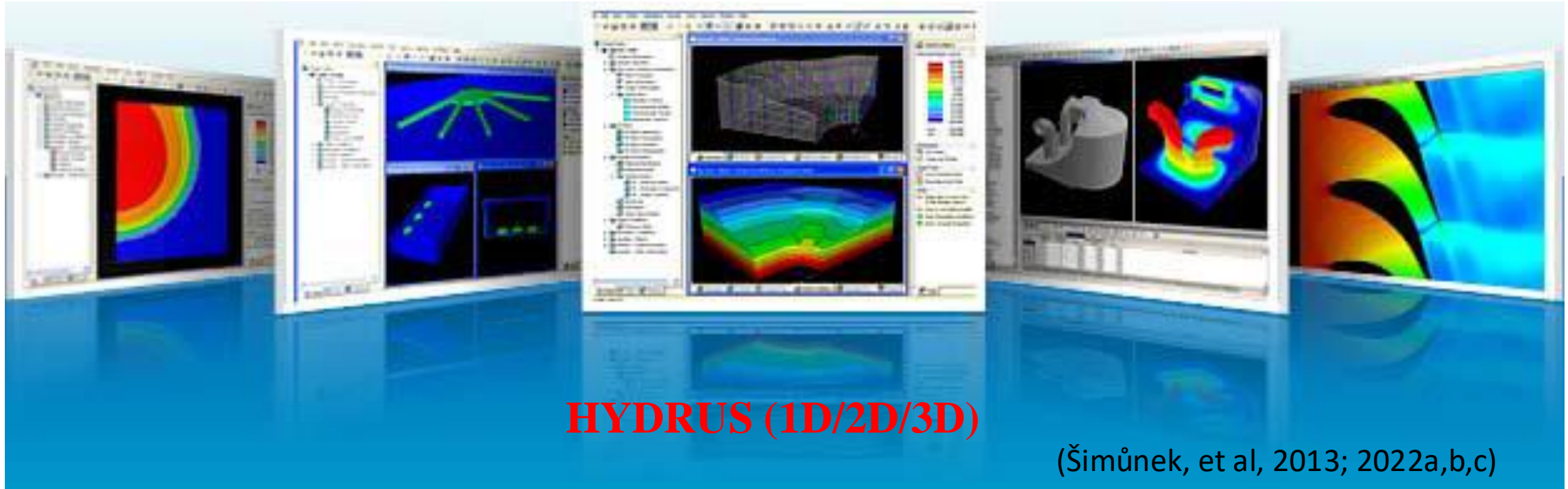
Coupling/integrating models

Hydrological models

Crop growth models



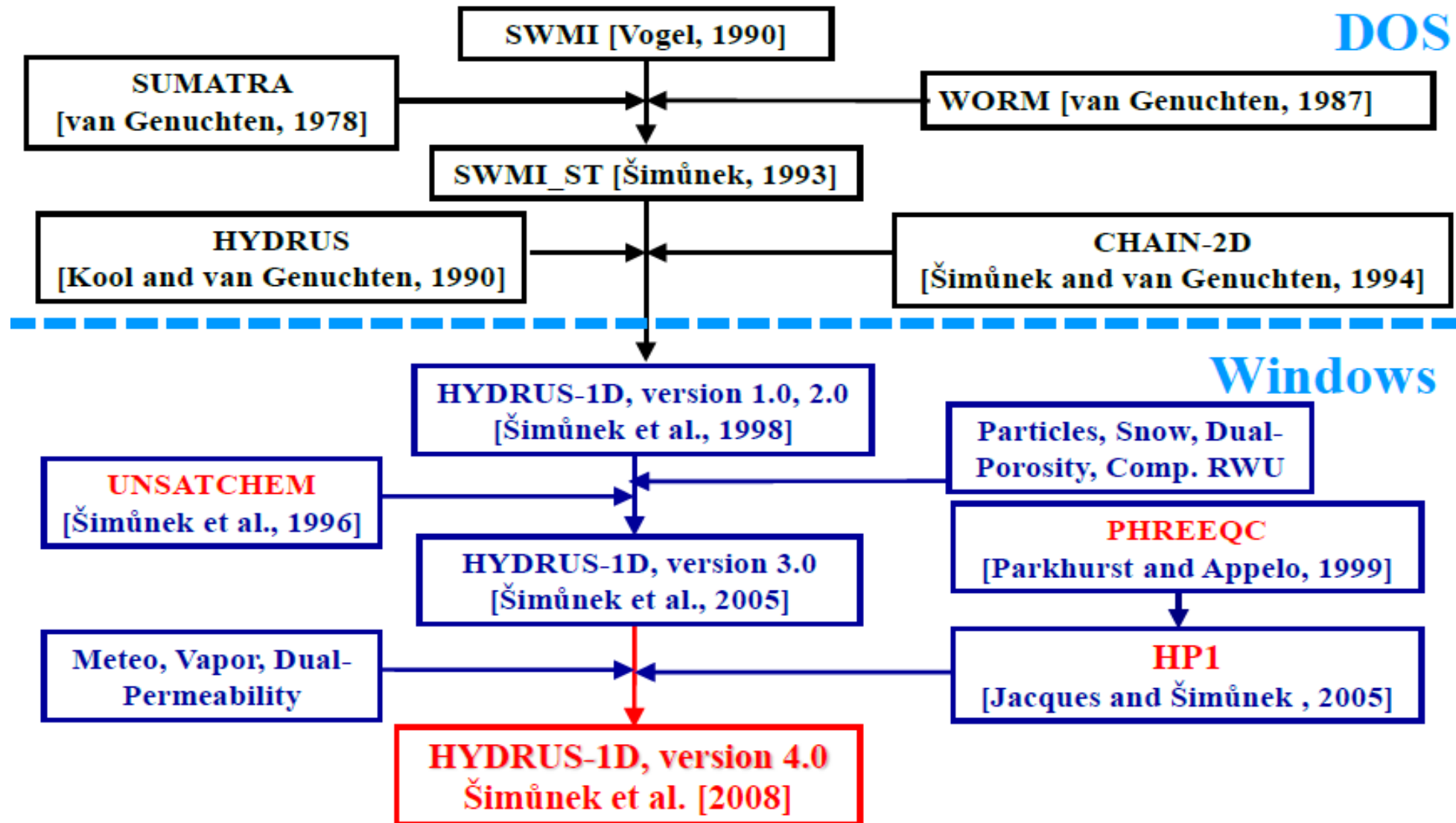
<https://soil-modeling.org/resources-links/model-portal>



Software for Simulating Water Flow and Solute Transport in **One/Two/Three -
Dimensional Variably-Saturated Soils Using **Numerical** Solutions**

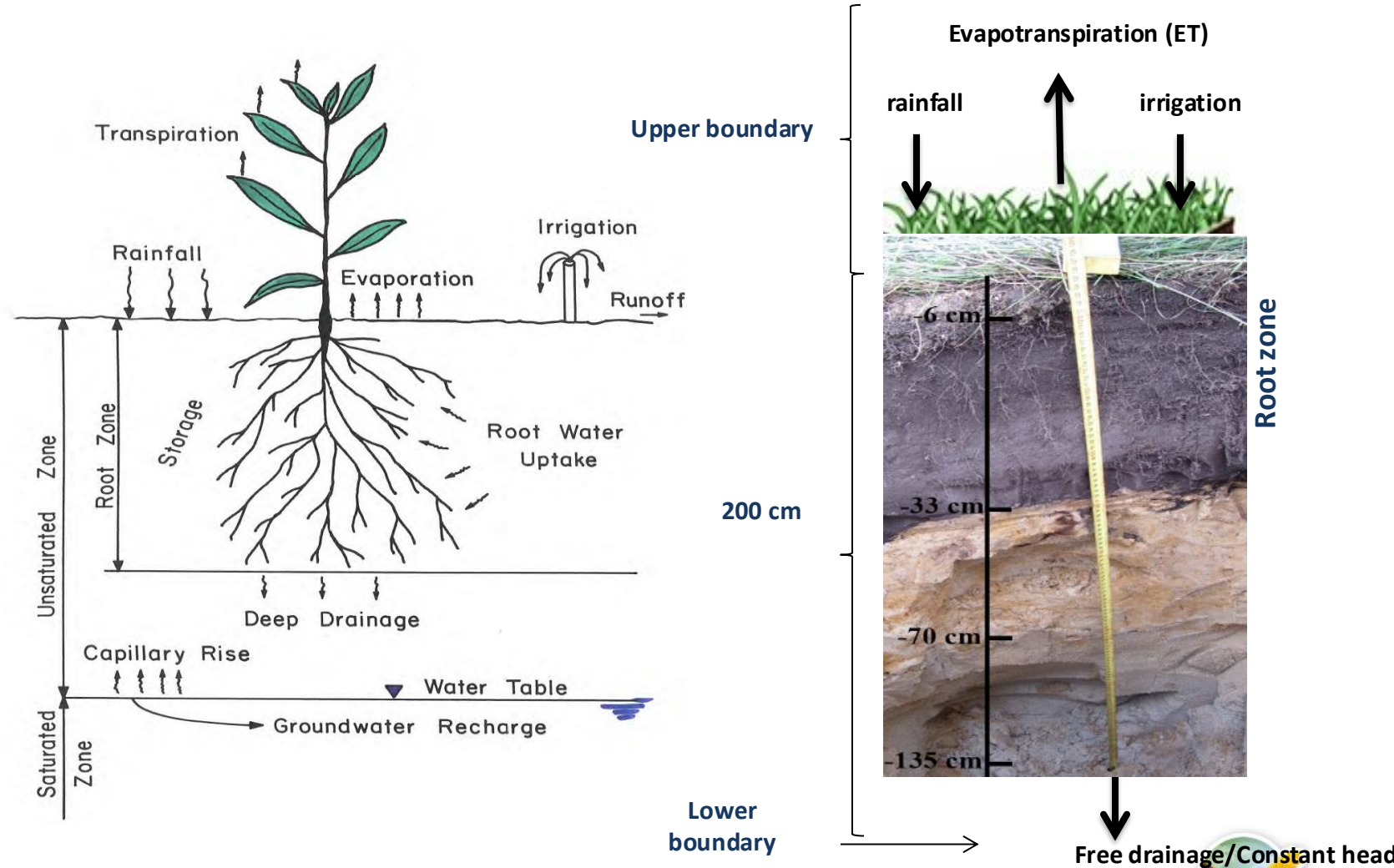
- thousands of users around the world
- thousands of applications published
- used by scientists, students, and/or practicing professionals

Brief history and development of Hydrus-1D



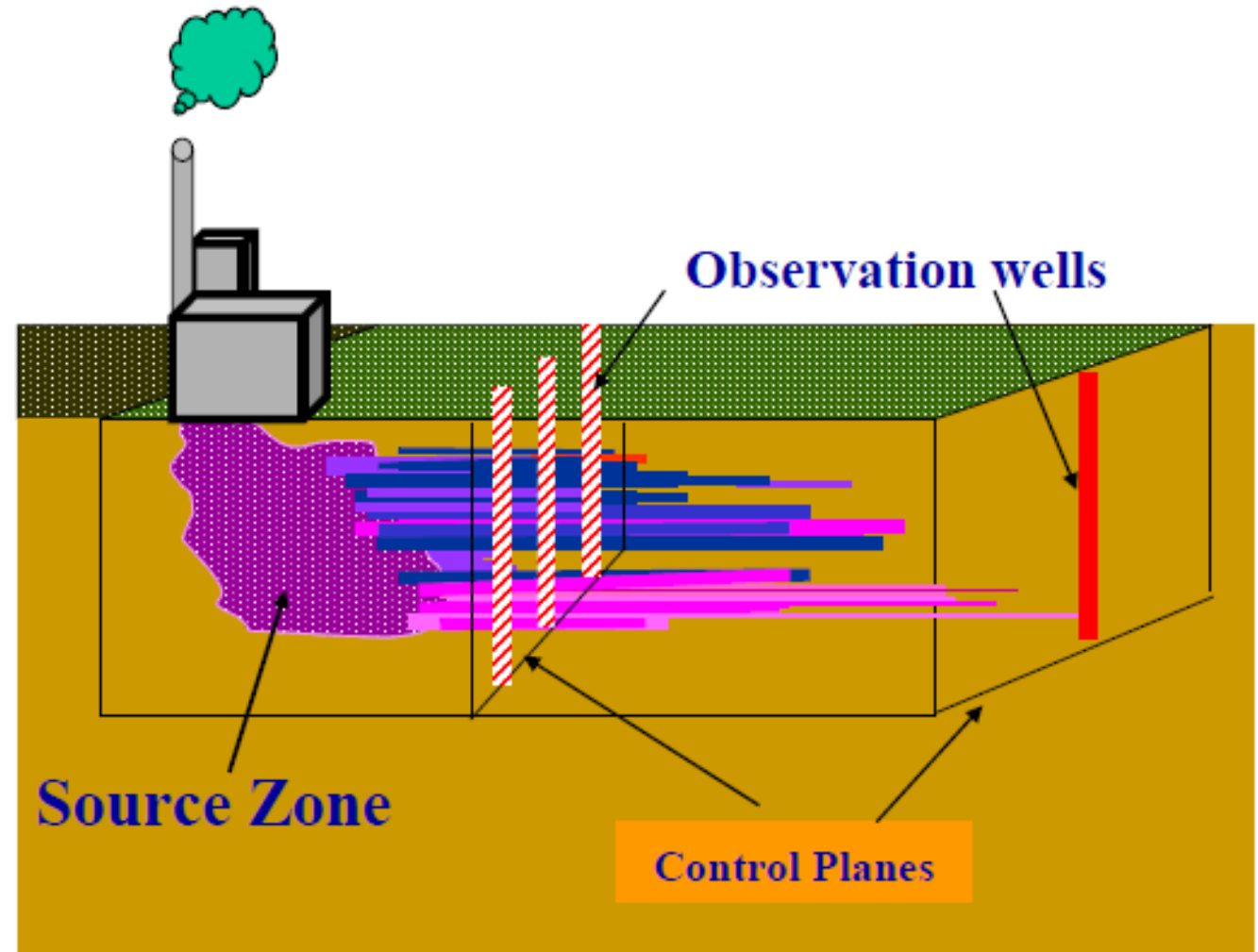
Agricultural Applications

- Precipitation
- Irrigation
- Runoff
- Evaporation
- Transpiration
- Root Water Uptake
- Capillary Rise
- Deep Drainage
- Solute transport
- Fertigation
- Pesticides
- Fumigants
- Colloids
- Pathogens
- Nanoparticles



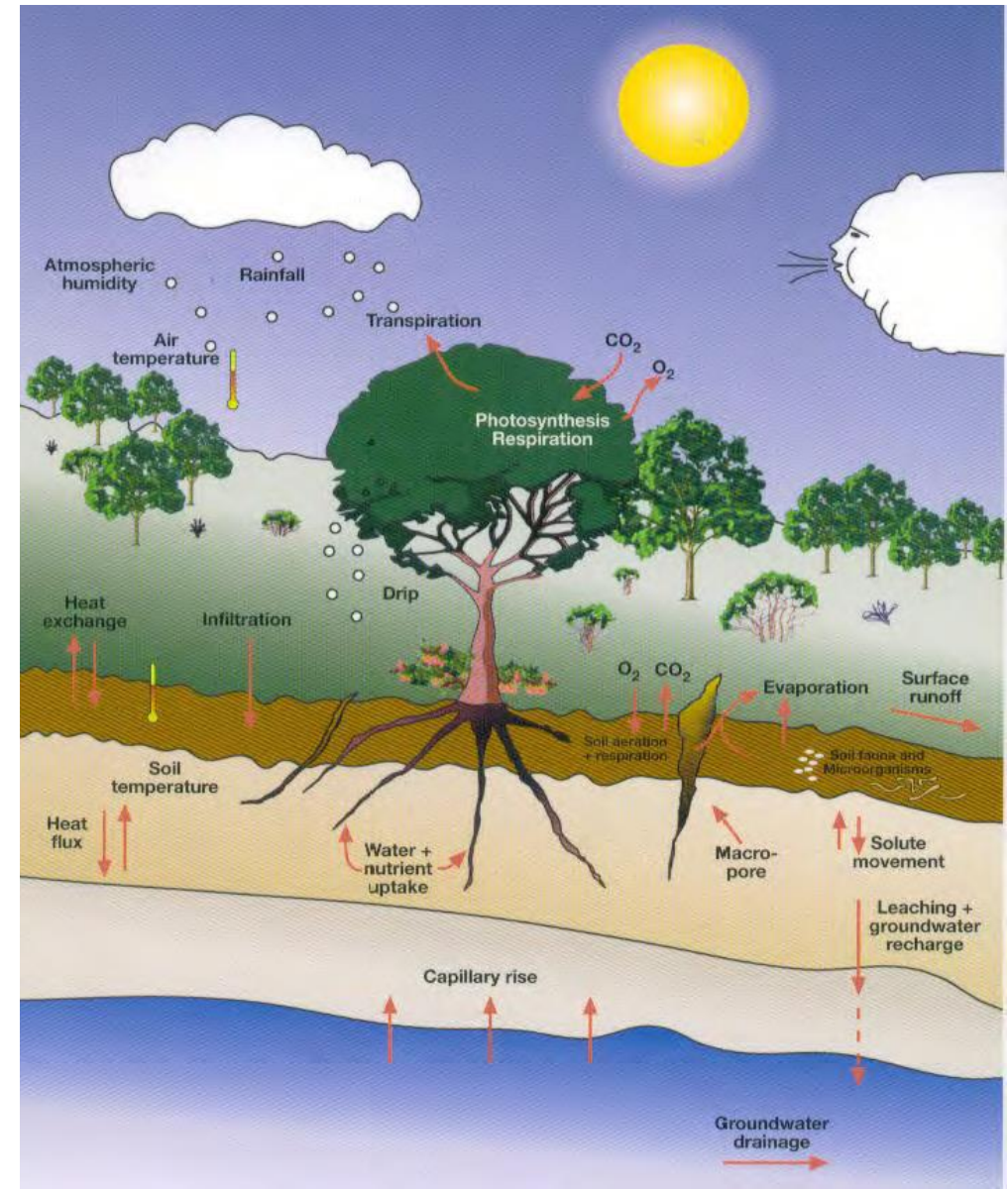
Industrial Applications

- Industrial Pollution
- Municipal Pollution
- Landfill Covers
- Waste Repositories
- Radioactive Waste Disposal Sites
- Remediation
- Brine Releases
- Contaminant Plumes
- Seepage of
- Wastewater from Land Treatment Systems



Environmental Applications

- Ecological Apps
- Carbon Storage and Fluxes
- Heat Exchange and Fluxes
- Nutrient Transport
- Soil Respiration
- Microbiological Processes
- Effects of Climate Change
- Riparian Systems
- Stream-Aquifer Interactions

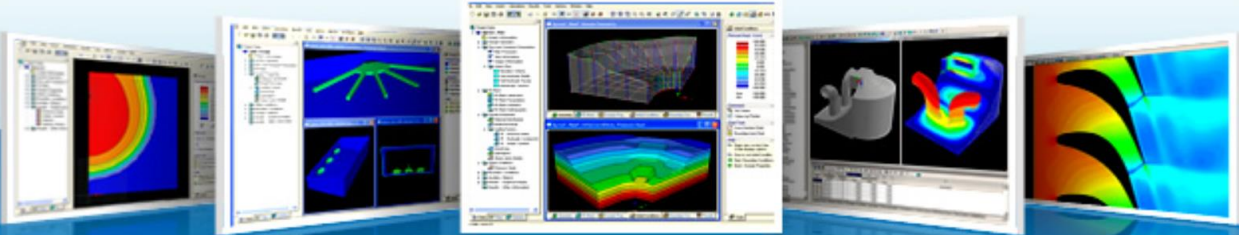



Hillel (2003)

pc-progress.com/en/Default.aspx?h3d-applications

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HYDRUS Applications

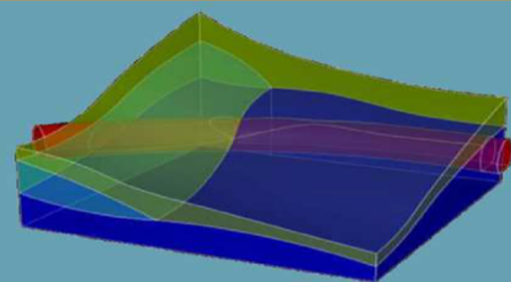
- [HYDRUS Applications](#)
- [HYDRUS References - References to peer-reviewed journal articles in which HYDRUS has been used](#)
- [One-Dimensional Examples distributed with the model](#)
- [Two-Dimensional Examples distributed with the model](#)
- [Three-Dimensional Examples distributed with the model](#)
- [Public Library of HYDRUS projects for version 1](#)
- [Public Library of HYDRUS projects for version 2](#)
- [Public Library of HYDRUS projects for version 3](#)
- [Public Library of HYDRUS projects for version 5](#)
- [Standard Add-on HYDRUS Modules \(e.g., C-Ride, UnsatChem, DualPerm\)](#)
- [Non-Standard Add-on HYDRUS Modules \(e.g., CO2, OverLand\)](#)

HYDRUS Applications

- [Home](#)
- [Programs](#)
- [HYDRUS](#)
- [Applications](#)
 - [Drip](#)
 - [Drip3D](#)
 - [Drip3Da](#)
 - [Root Uptake](#)
 - [Special BC Examples](#)
 - [Triggered Irrigation](#)
 - [Stony Soils](#)
 - [Reservoir BC](#)
 - [Root Growth Examples](#)
 - [Unsatchem Examples](#)
 - [C-Ride Examples](#)

Brief history and development of Hydrus-1D

Review and Analysis



Core Ideas

- Review of selected capabilities of HYDRUS implemented since 2008
- New standard and nonstandard specialized add-on modules significantly expanded capabilities of the software
- Review of selected applications of

Recent Developments and Applications of the HYDRUS Computer Software Packages

Jiří Šimůnek,* Martinus Th. van Genuchten, and Miroslav Šejna

The HYDRUS-1D and HYDRUS (2D/3D) computer software packages are widely used finite-element models for simulating the one- and two- or three-dimensional movement of water, heat, and multiple solutes in variably saturated media, respectively. In 2008, Šimůnek et al. (2008b) described the entire history of the development of the various HYDRUS programs and related models and tools such as STANMOD, RETC, ROSETTA, UNSODA, UNSATCHEM, HP1, and others. The objective of this manuscript is to review selected capabilities of HYDRUS that have been implemented since 2008. Our review is not limited to listing additional processes that were implemented in the standard computational modules, but also describes many

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Vadose Zone Journal

REVIEW

Special Section: Tribute to Rien van Genuchten, Recipient of the 2023 Wolf Prize for Agriculture

Developments and applications of the HYDRUS computer software packages since 2016

Jiří Šimůnek¹  | Giuseppe Brunetti² | Diederik Jacques³ | Martinus Th. van Genuchten^{4,5}  | Miroslav Šejna⁶

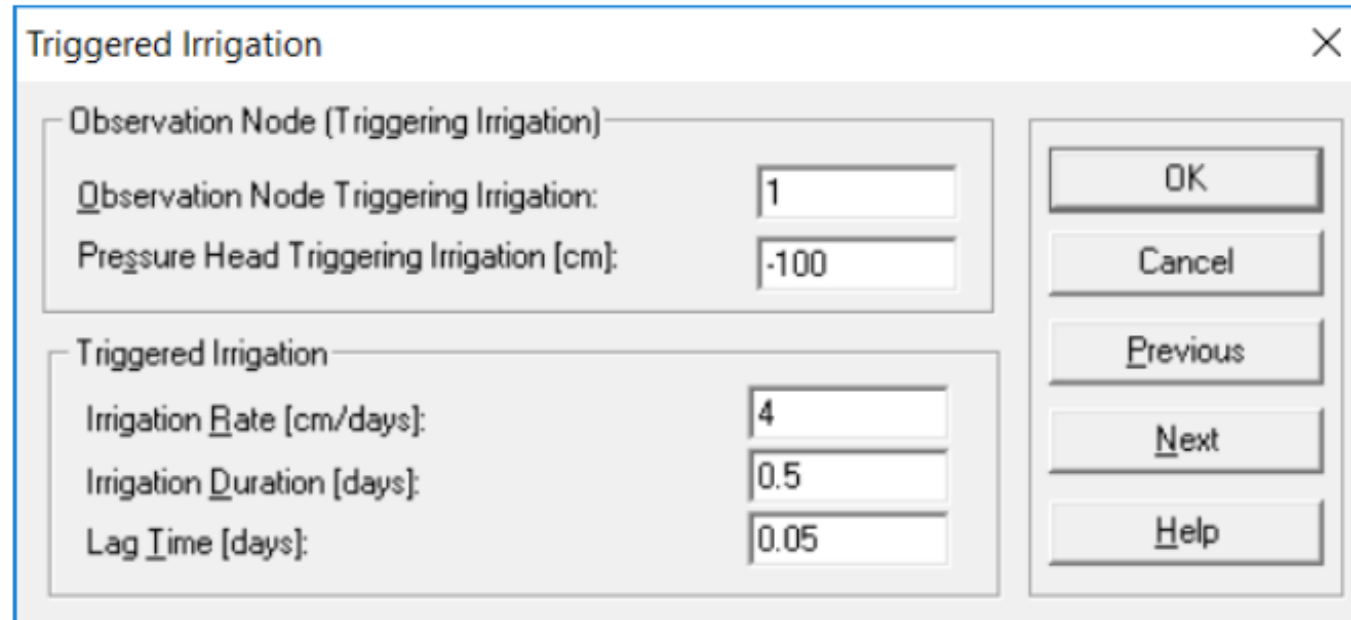
October–29 October–12 November 2024



Development of HYDRUS-1D

Version 4.16, February 2013

◆ Triggered irrigation, Irrigation Scheduling



Triggered Irrigation

Observation Node (Triggering Irrigation)

Observation Node Triggering Irrigation: 1

Pressure Head Triggering Irrigation [cm]: -100

Triggered Irrigation

Irrigation Rate [cm/days]: 4

Irrigation Duration [days]: 0.5

Lag Time [days]: 0.05

OK

Cancel

Previous

Next

Help

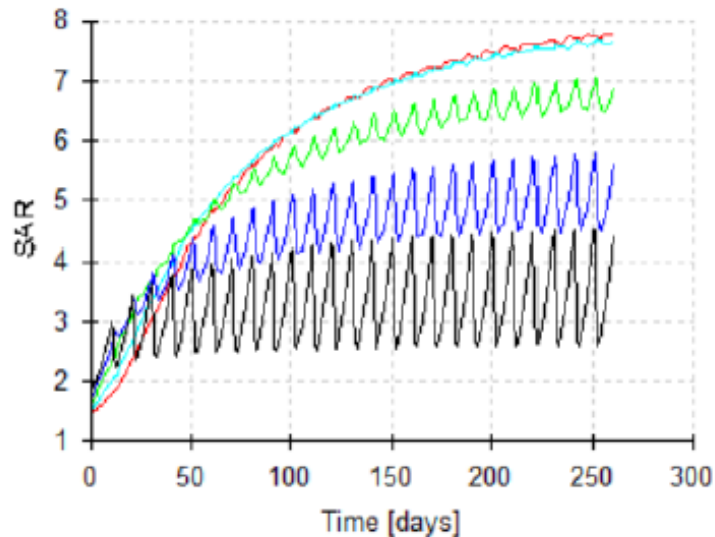
Rezaei, M., De Pue, J., Seuntjens, P., Joris, I., Cornelis, W. 2017. Quasi 3D modelling of vadose zone soil-water flow for optimizing irrigation strategies: challenges, uncertainties and efficiencies. *Environmental modelling and software*. 93: 59-77.

Development of HYDRUS-1D

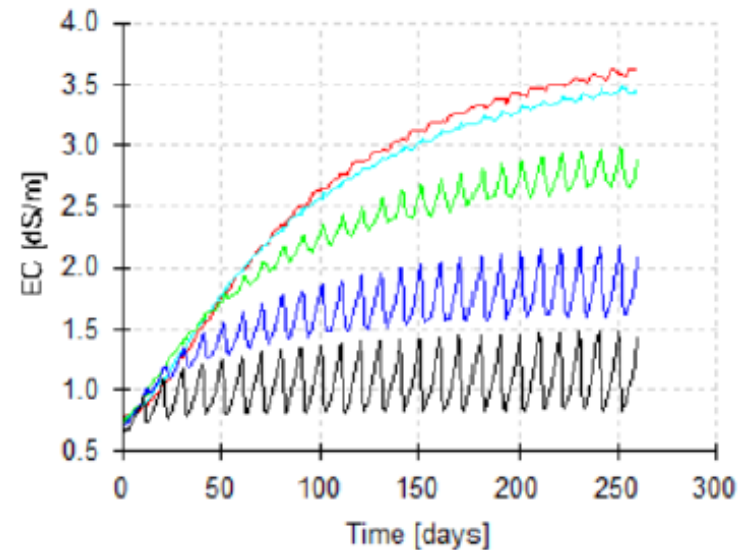
Version 4.17, 2017

- ◆ **Graph of major ions, EC, and SAR in observation nodes**

Observation Nodes: SAR

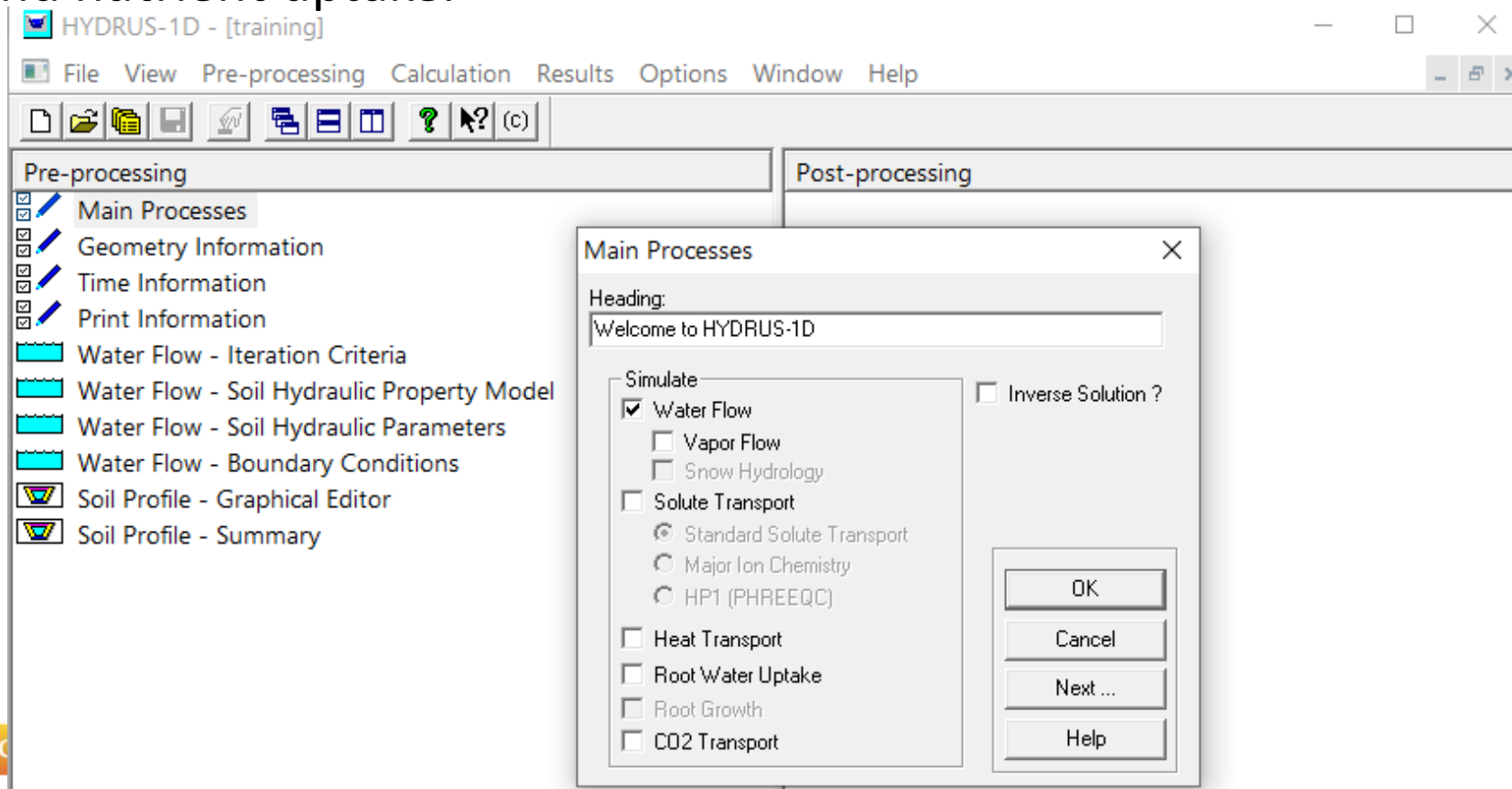


Observation Nodes: Electric Conductivity



Key Features of Hydrus-1D

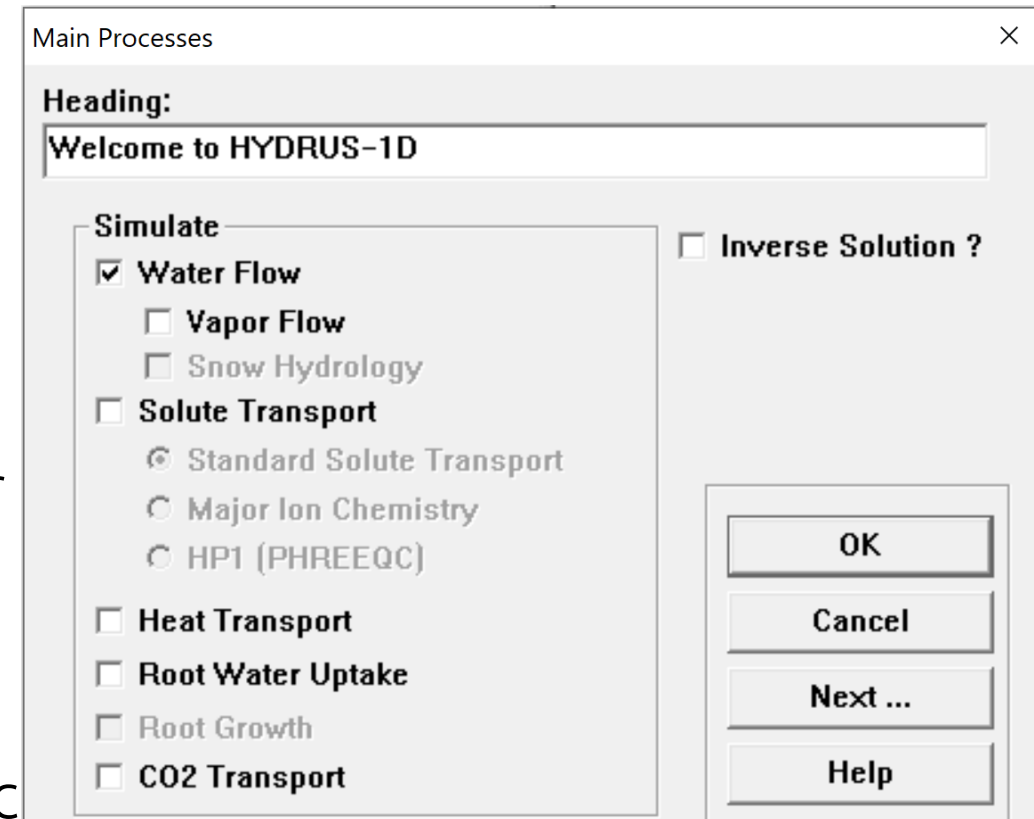
- Modeling water flow (saturated and unsaturated).
- Solute transport (including reactive and non-reactive solutes).
- Heat transport and coupling with water/solute movement.
- Root water and nutrient uptake.



HYDRUS-1D Modules

Standard Modules (fully supported by and distributed with HYDRUS-1D GUI):

- **Inverse** – Marquardt-Levenberg algorithm to optimize soil hydraulic, solute transport and reaction, and heat transport parameters.
- **UnsatChem** – carbon dioxide transport and production, and reactions and transport of major ions (Šimůnek and Suarez, 1993, 1994).
- **HP1** – coupling with PHREEQC, allowing to consider the transport and general biogeochemical reactions between many different ions (Jacques and Šimůnek, 2005).



HYDRUS-1D Modules: UNSATCHEM

1	Aqueous components	7	Ca^{2+} , Mg^{2+} , Na^{+} , K^{+} , SO_4^{2-} , Cl^{-} , NO_3^{-}
2	Complexed species	10	CaCO_3° , CaHCO_3^{+} , CaSO_4° , MgCO_3° , MgHCO_3^{+} , MgSO_4° , NaCO_3^{-} , NaHCO_3° , NaSO_4^{-} , KSO_4^{-}
3	Precipitated species	6	CaCO_3 , $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, $\text{MgCO}_3 \cdot 3\text{H}_2\text{O}$, $\text{Mg}_5(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}$, $\text{Mg}_2\text{Si}_3\text{O}_{7.5}(\text{OH}) \cdot 3\text{H}_2\text{O}$, $\text{CaMg}(\text{CO}_3)_2$
4	Sorbed species (exchangeable)	4	Ca, Mg, Na, K
5	CO_2 - H_2O species	7	P_{CO_2} , $\text{H}_2\text{CO}_3^{*}$, CO_3^{2-} , HCO_3^{-} , H^{+} , OH^{-} , H_2O
6	Silica species	3	H_4SiO_4 , $\text{H}_3\text{SiO}_4^{-}$, $\text{H}_2\text{SiO}_4^{2-}$

Kinetic reactions: calcite precipitation/dissolution, dolomite dissolution

Activity coefficients: extended Debye-Hückel equations, Pitzer expressions

HYDRUS-1D Modules

Non-Standard Modules (not fully supported by and not distributed with HYDRUS-1D GUI):

- **Centrifugal Forces**: considers centrifugal forces, in addition to gravitation and capillarity (Šimůnek and Nimmo, 2005).
- **Freezing/Thawing** – considers the effects of freezing and thawing on water flow and solute/heat transport processes (Hansson et al., 2004).
- **C-Ride (C-hitch)** – considers particle transport and particle-facilitated solute transport (Šimůnek et al., 2006).
- **Fumigant** – considers additional factors important for the fate and transport of fumigants (e.g., tarp; Spurlock et al., 2013).

HYDRUS-1D Modules

Non-Standard Modules:

Colloid Transport with Changing Water Contents: considers the effects of changes in the water content on particle transport and attachment/detachment to/from solid-water and air-water interfaces (e.g., Bradford et al., 2015).

Isotope Transport: accounts for isotope transport (Stumpp et al., 2012). Neglects fractionation processes and does not increase the relative concentration of isotopes (their δ content) at the upper boundary due to evaporation.

Root Growth: simulates root growth and its dependence on various environmental factors (Hartmann and Šimůnek, 2015).

Governing Equations

Variably-Saturated Water Flow (**Richards Equation**)

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z} \left[K(h) \left(\frac{\partial h}{\partial z} - 1 \right) \right] - S(h)$$

Solute Transport (**Convection-Dispersion Equation**)

$$\frac{\partial(\rho s)}{\partial t} + \frac{\partial(\theta c)}{\partial t} = \frac{\partial}{\partial z} \left(\theta D \frac{\partial c}{\partial z} - qc \right) - \phi$$

Heat Movement

$$\frac{\partial C_p(\theta)T}{\partial t} = \frac{\partial}{\partial z} \left[\lambda(\theta) \frac{\partial T}{\partial z} \right] - C_w \frac{\partial qT}{\partial z} - C_w ST$$

HYDRUS – Main Processes

Water Flow:

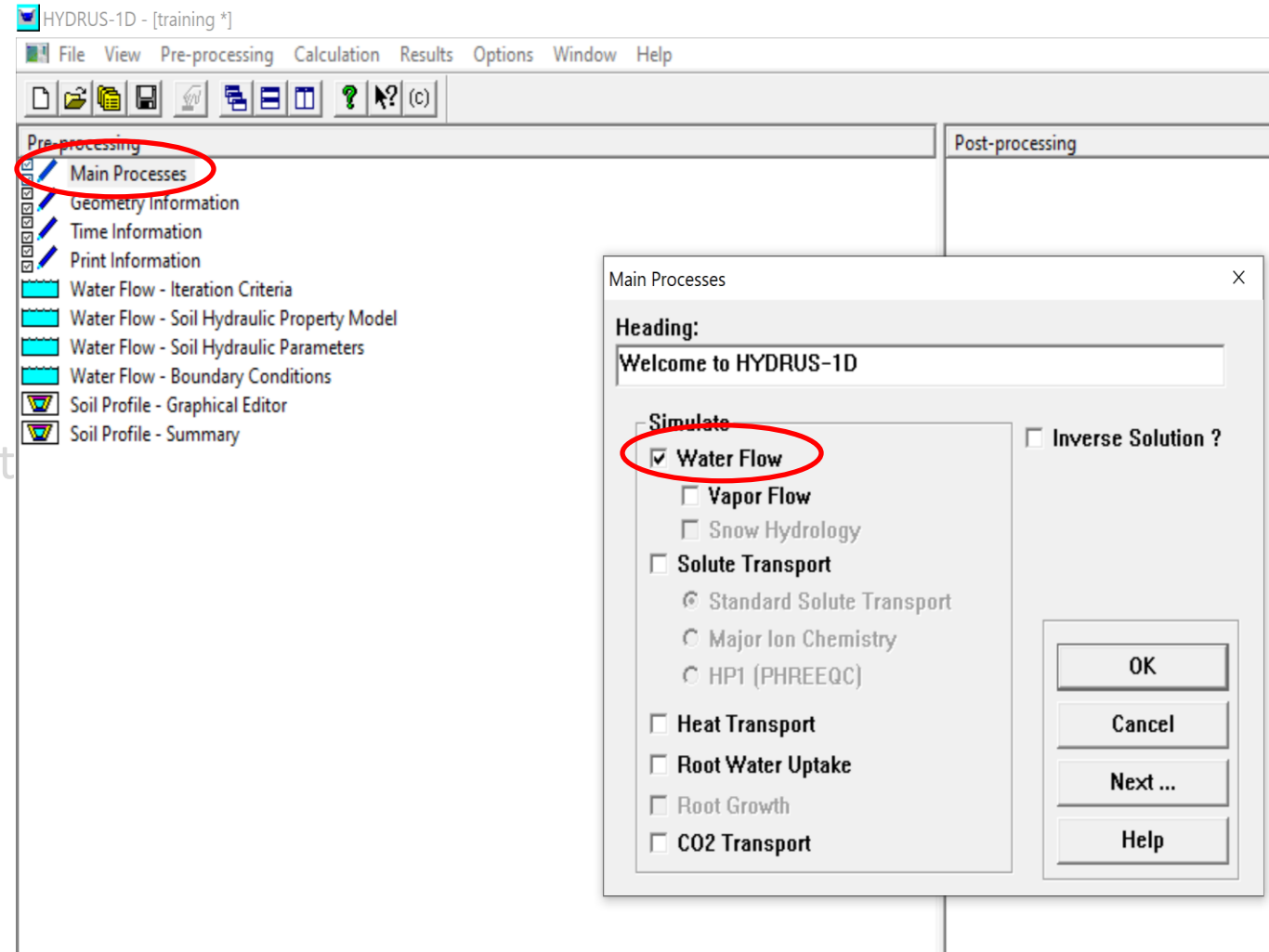
Richards equation for variably-saturated water flow

Various models of soil hydraulic properties

Hysteresis

Sink term, accounting for water uptake by plant roots

(uncompensated and compensated; reduced due to osmotic and pressure stress)



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Water Flow:

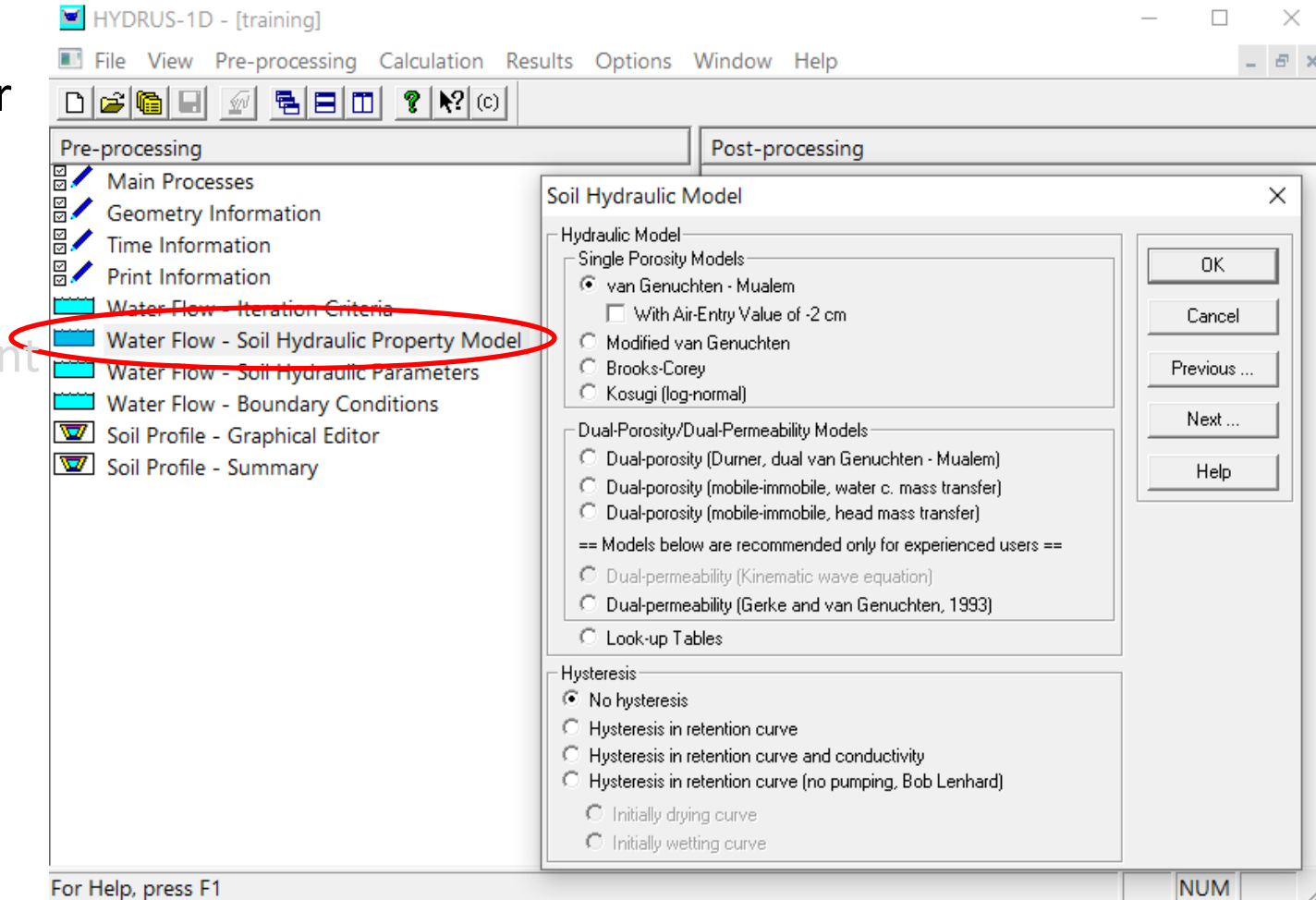
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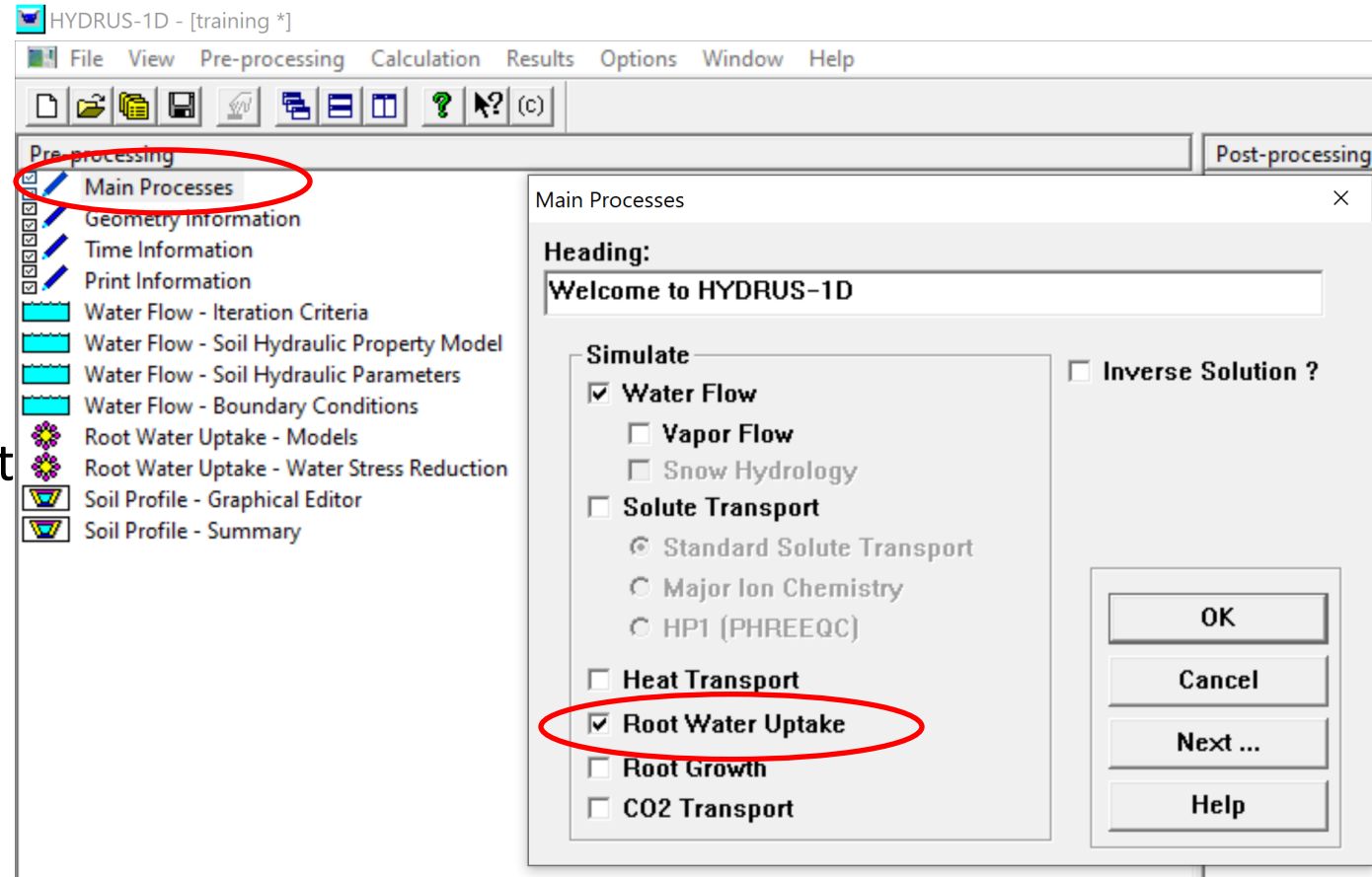
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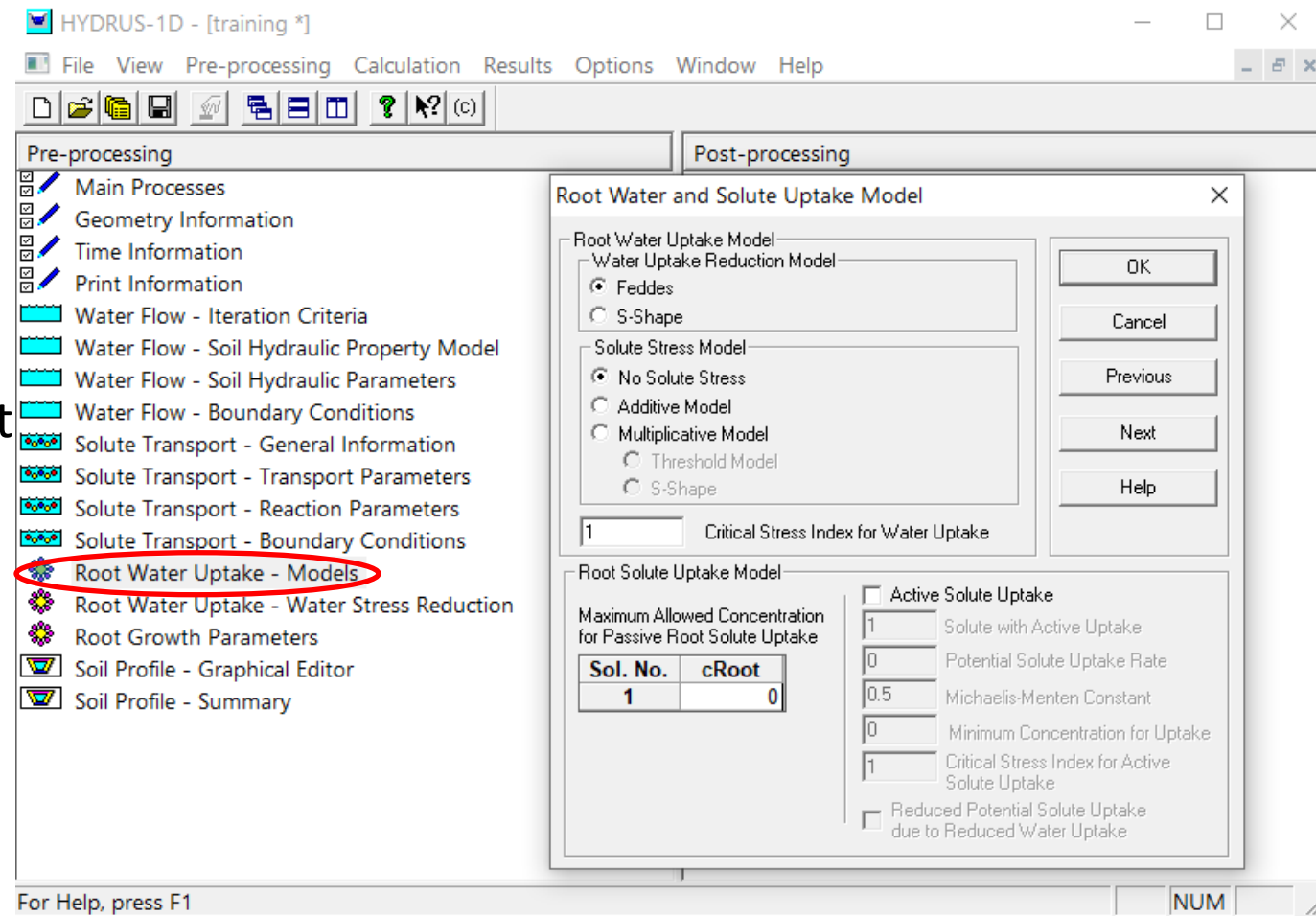
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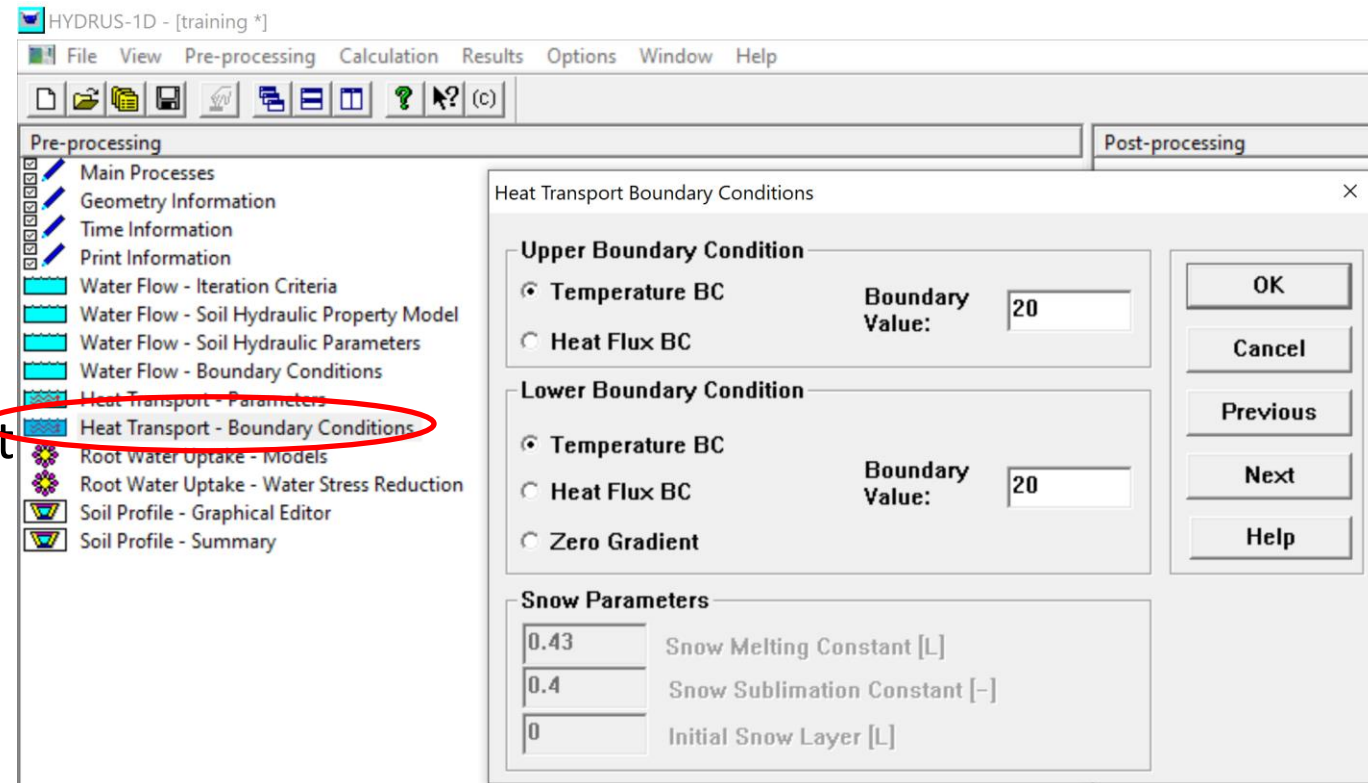
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Preferential flow

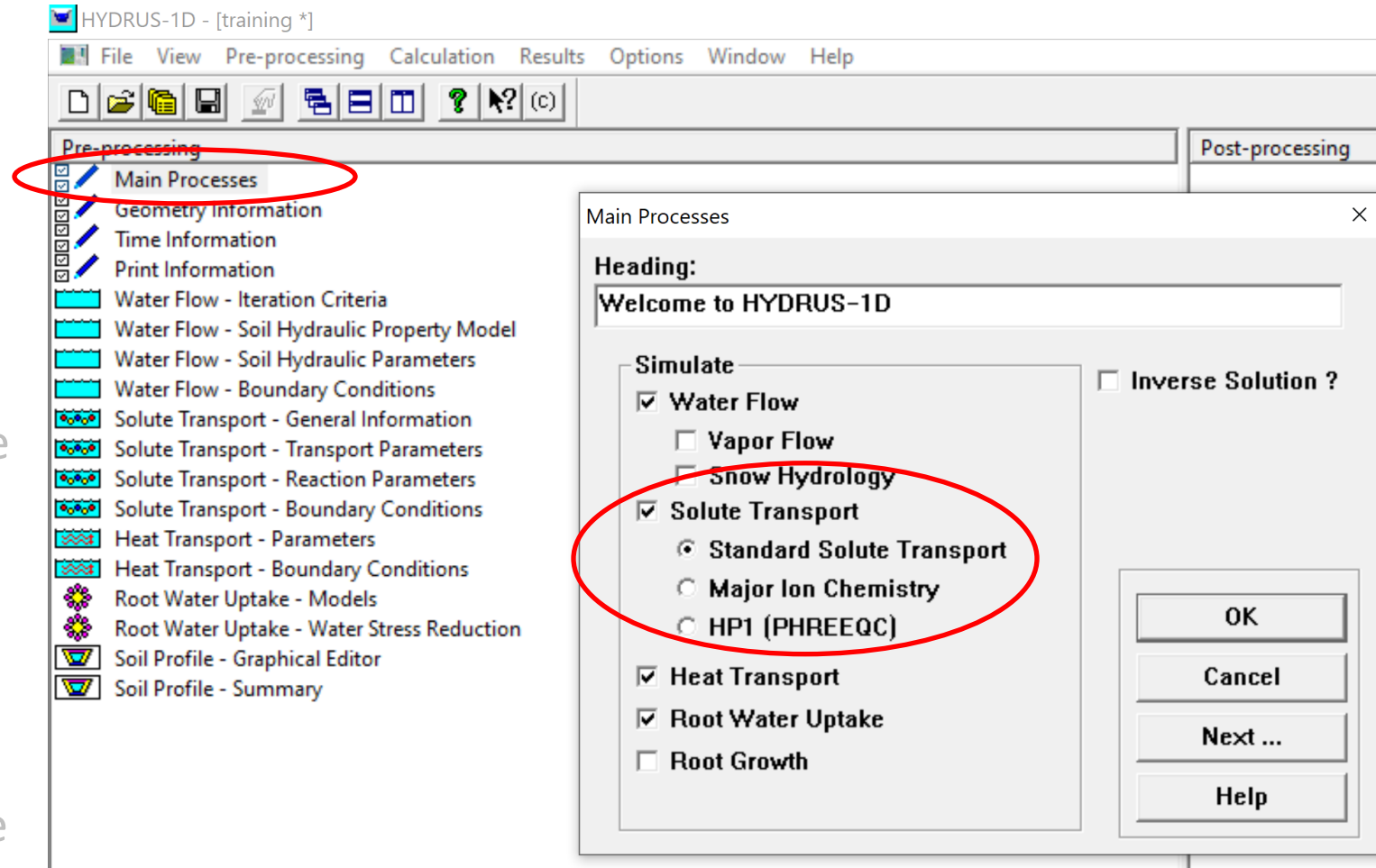
Isothermal and thermal liquid and vapor flow



HYDRUS – Main Processes

Solute Transport (standard mode):

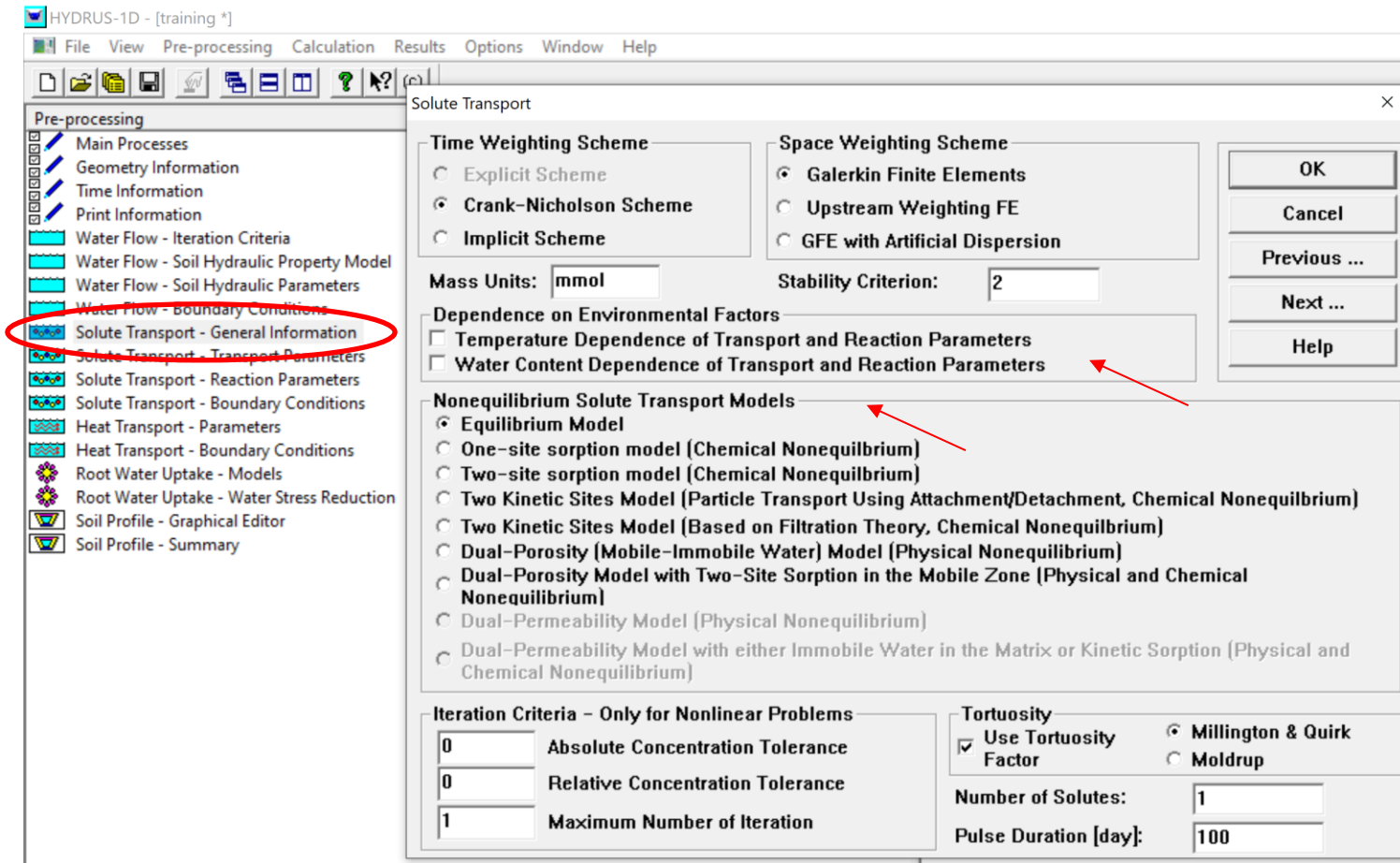
- Convective-dispersive transport in the liquid phase
- Diffusion in the gaseous phase
- Linear and nonlinear reactions between the solid and liquid phases
- Linear equilibrium reactions between the liquid and gaseous phases
- Zero-order production, First-order degradation
- Physical and chemical nonequilibrium solute transport
- Sink term, accounting for nutrient uptake by plant roots (active and passive)



HYDRUS – Main Processes

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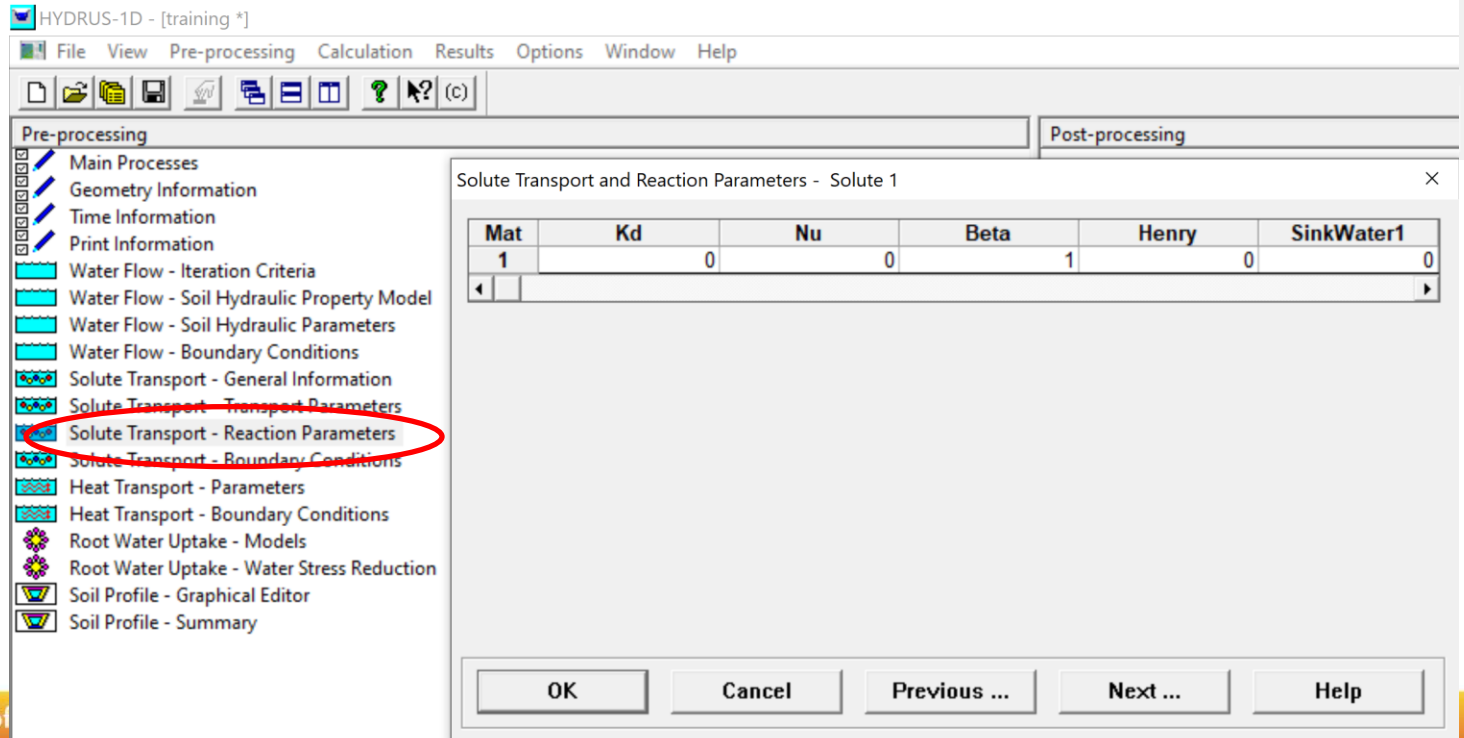
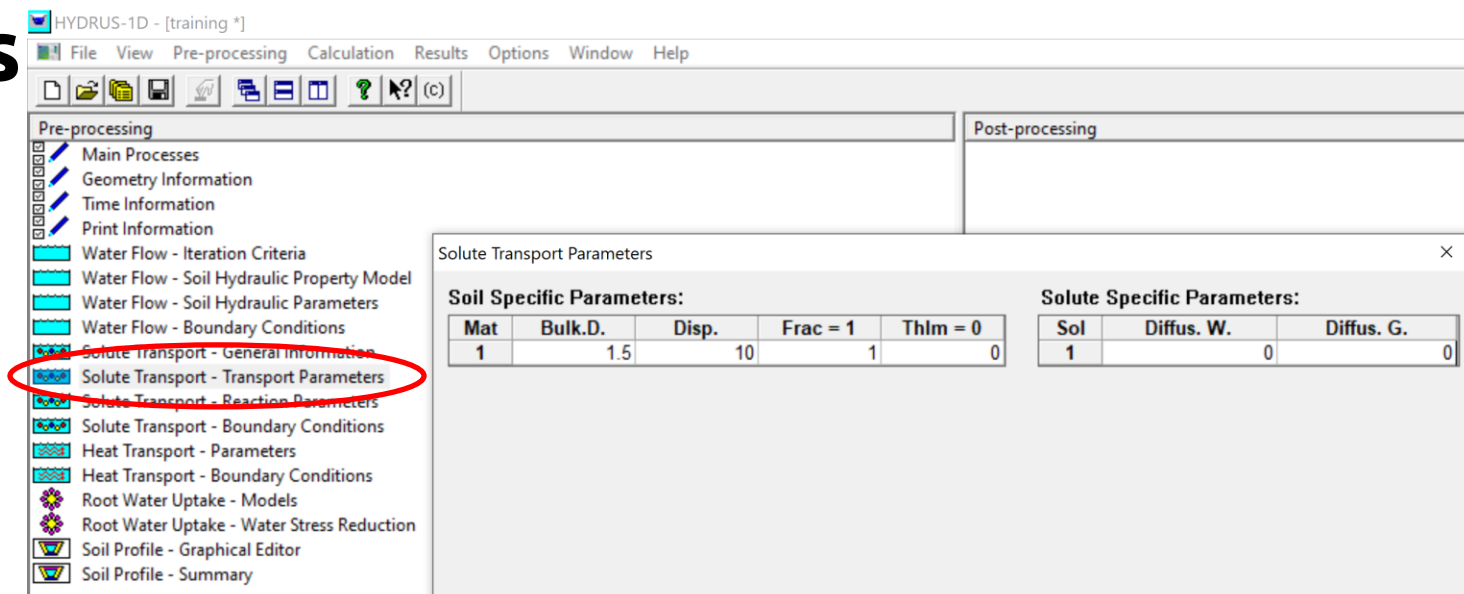
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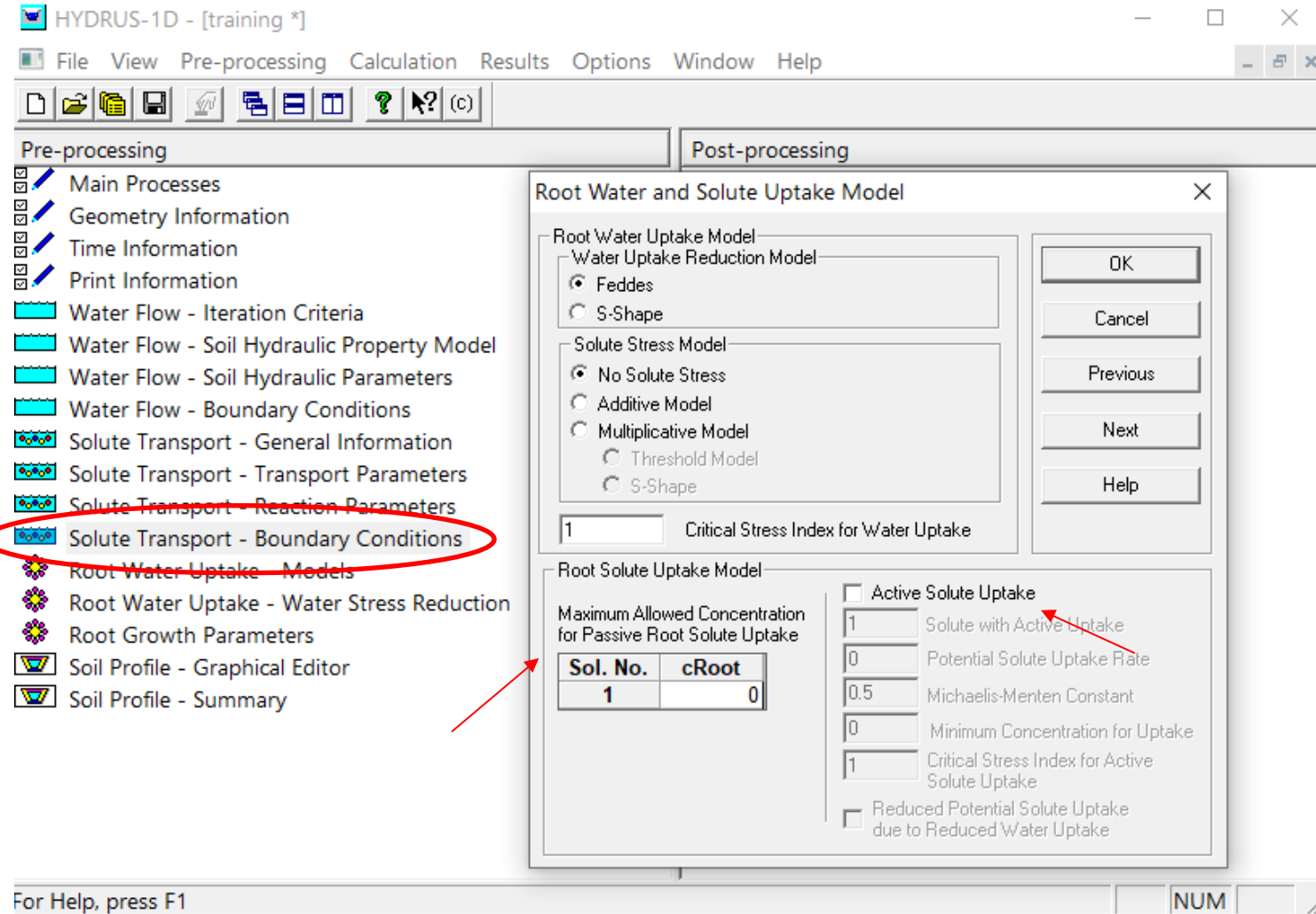
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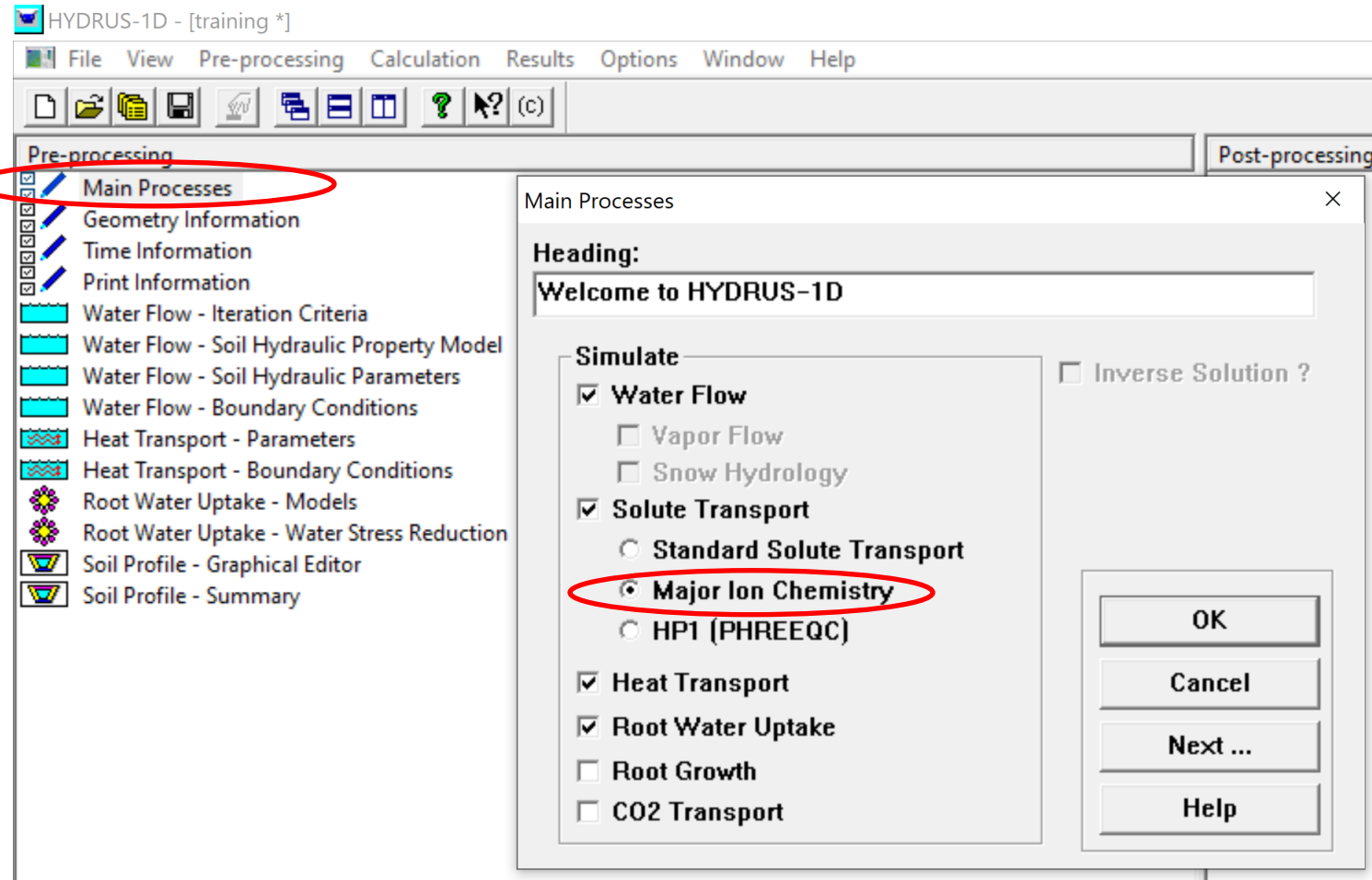
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HYDRUS – Main Processes

Solute Transport (UNSATCHEM):

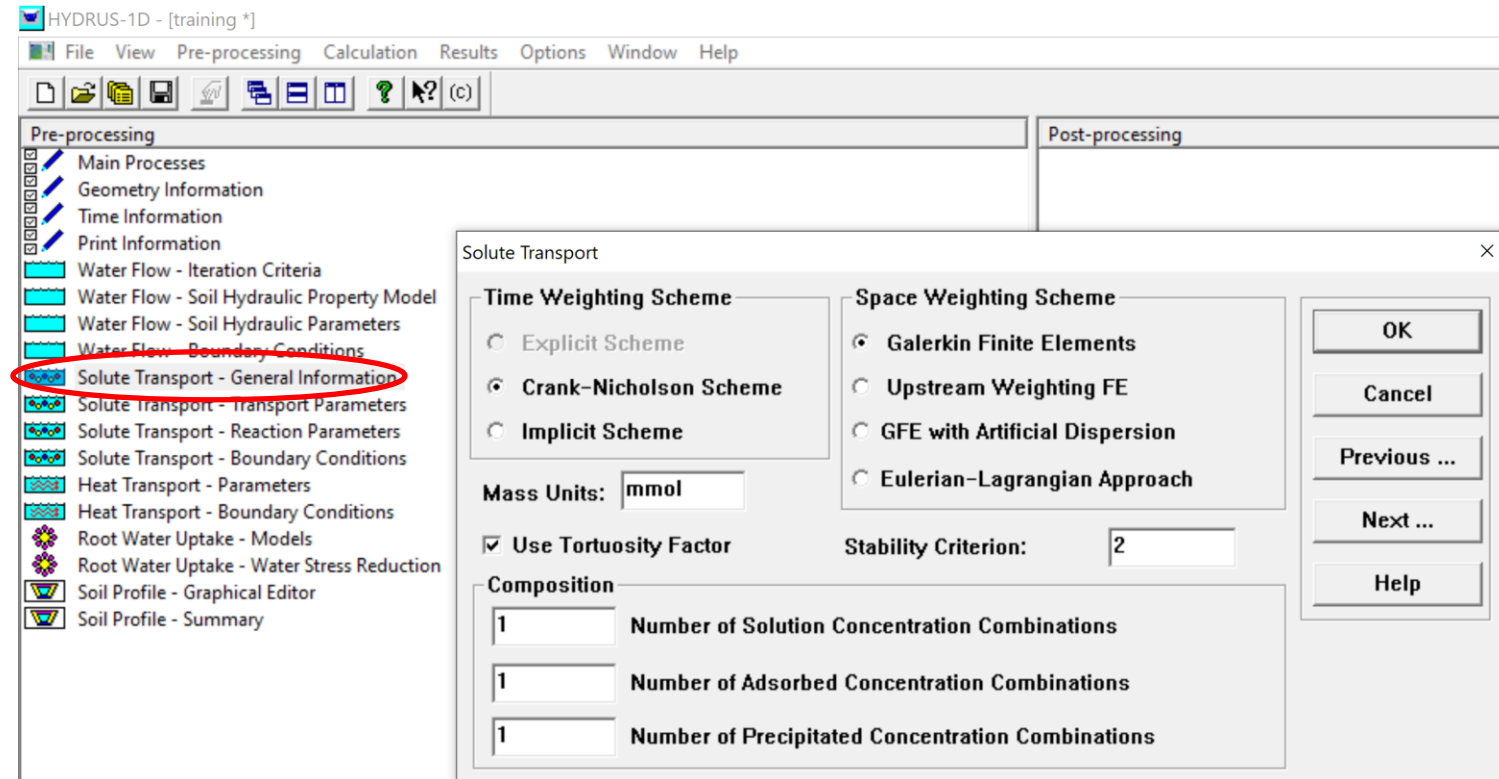
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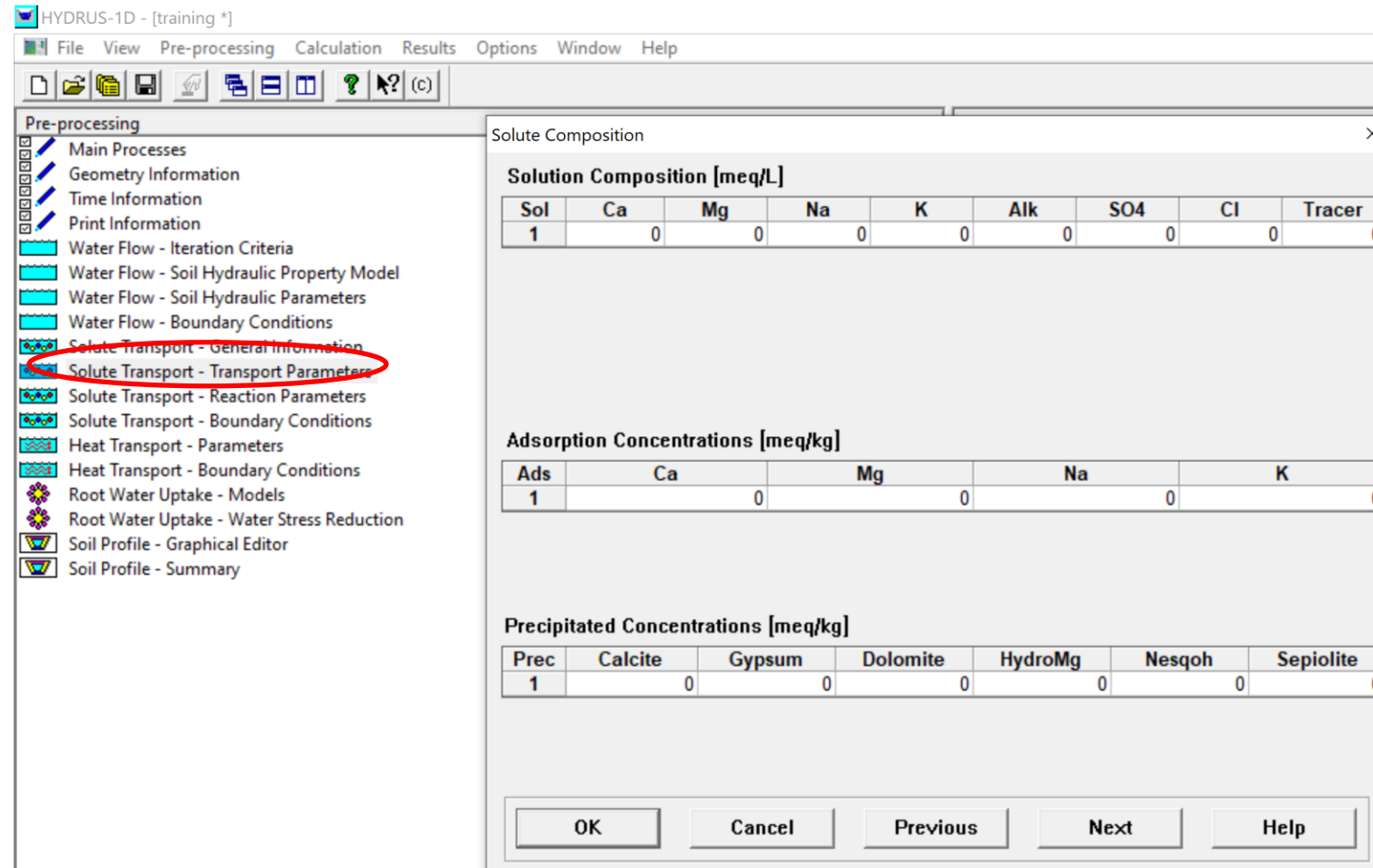
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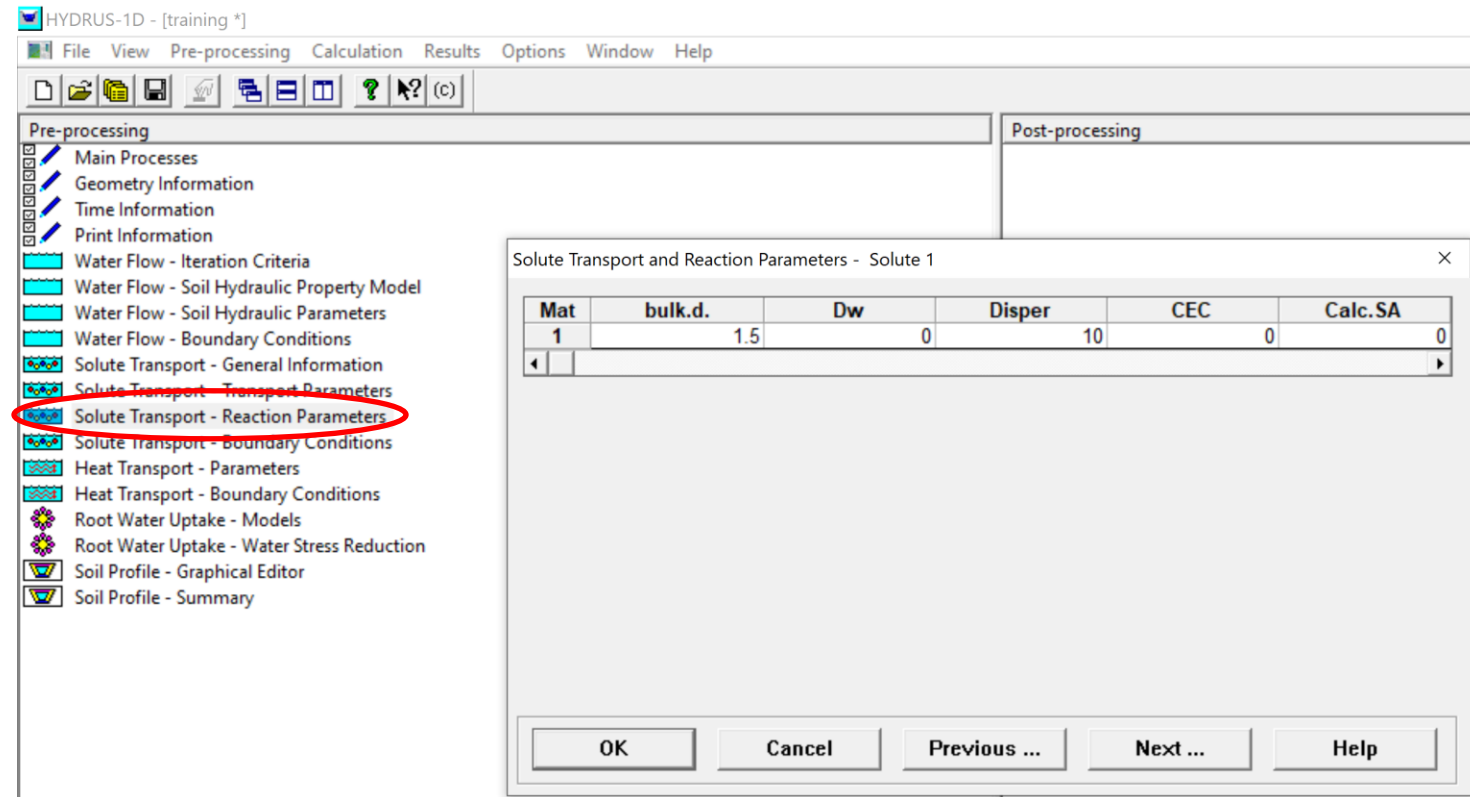
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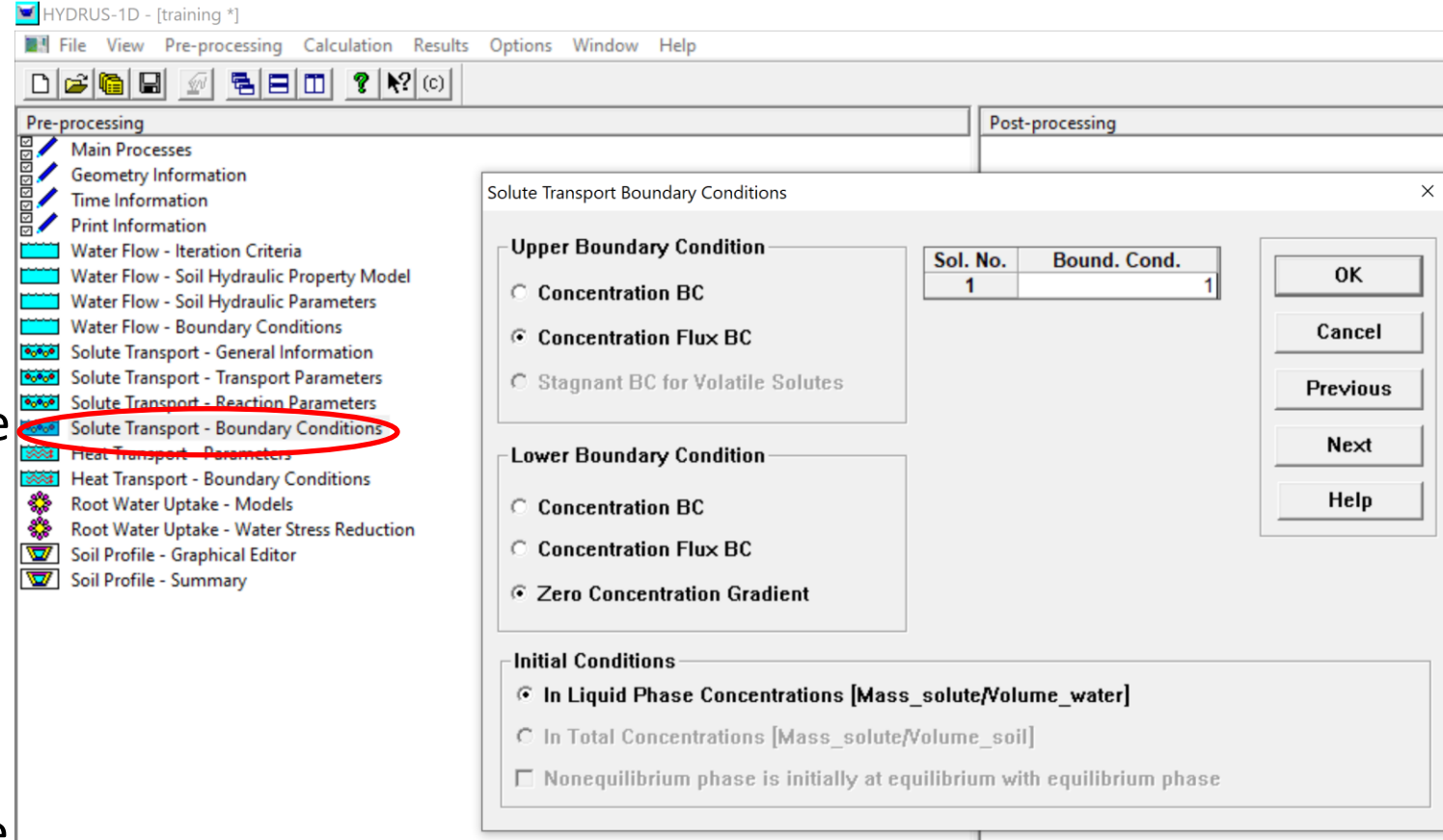
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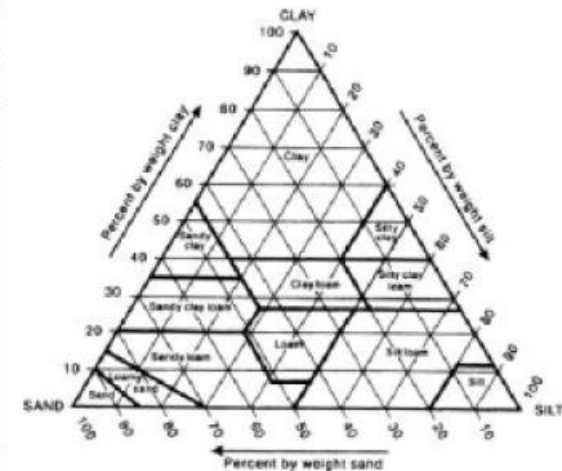
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HYDRUS – Main Processes: PTFs by Carsel and Parrish (1988)

Average values of selected soil water retention parameters for 12 major soil textural groups

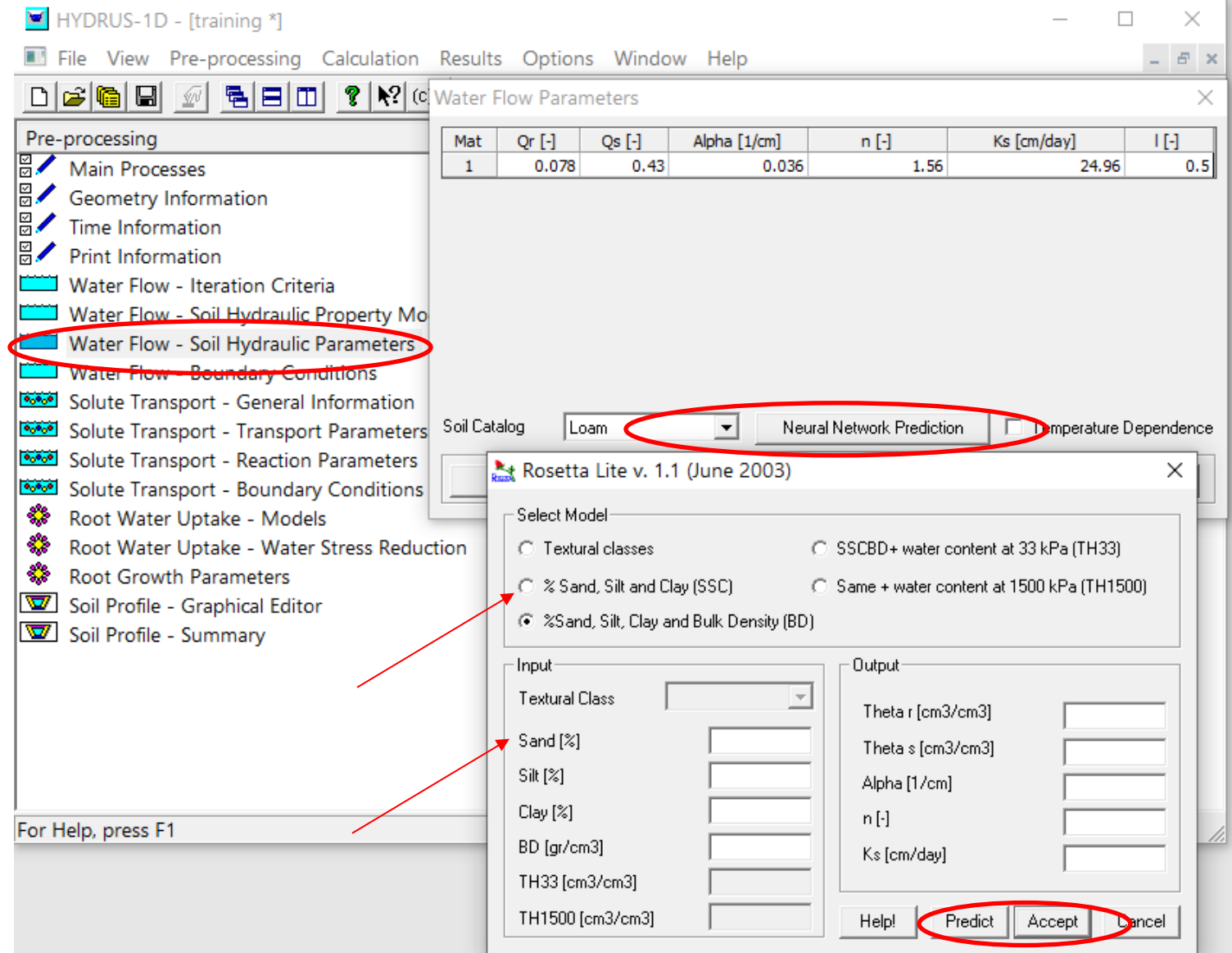
Texture	θ_r	θ_s	α 1/cm	n	K_s cm/d
Sand	0.045	0.43	0.145	2.68	712.8
Loamy Sand	0.057	0.41	0.124	2.28	350.2
Sandy Loam	0.065	0.41	0.075	1.89	106.1
Loam	0.078	0.43	0.036	1.56	24.96
Silt	0.034	0.46	0.016	1.37	6.00
Silt Loam	0.067	0.45	0.020	1.41	10.80
Sandy Clay Loam	0.100	0.39	0.059	1.48	31.44
Clay Loam	0.095	0.41	0.019	1.31	6.24
Silty Clay Loam	0.089	0.43	0.010	1.23	1.68
Sandy Clay	0.100	0.38	0.027	1.23	2.88
Silty Clay	0.070	0.36	0.005	1.09	0.48
Clay	0.068	0.38	0.008	1.09	4.80



USDA Soil Textural Triangle

HYDRUS – Main Processes: ROSETTA

- **Soil hydraulic parameters**
(van Genuchten, 1980)
- **Soil texture parameters**
(Schaap et al, 2001)



Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Geometry: 100 cm, 4 layers

Upper boundary: atmospheric BC with surface layer

Bottom boundary: free drainage

Type the **Name** of the project: “nim2-9”

- Type the **Description** of the project: “Water flow and solute transport ”.
- Length Unit: cm
- Assuming: 8,500 m³ of water, including leaching and water requirement for irrigating wheat to achieve optimal and potential yield.
- apply 20 cm of water as pre-irrigation for leaching purposes (day 30).
- 5 irrigation events are applied using furrow irrigation on the following dates: November 26 (day 96), December 16 (day 116) - January 5 (day 136), January 25 (day 156), and March 2 (day 190).

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Main Processes [X]

Heading:
Welcome to HYDRUS-1D

Simulate

- ☒ Water Flow
 - ☐ Vapor Flow
 - ☐ Snow Hydrology
- ☒ Solute Transport
 - ☐ Standard Solute Transport
 - ☒ Major Ion Chemistry
 - ☐ HP1 (PHREEQC)
- ☐ Heat Transport
- ☒ Root Water Uptake
- ☐ Root Growth
- ☐ CO2 Transport

☐ Inverse Solution ?

OK
Cancel
Next ...
Help

Geometry Information [X]

Length Units

- ☐ mm
- ☒ cm
- ☐ m

4 Number of Soil Materials

1 Number of Layers for Mass Balances

1 Decline from Vertical Axes (=1: vertical; =0: horizontal)

100 Depth of the Soil Profile [cm]

OK
Cancel
Previous ...
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Help

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Time Information

Time Units

- ☐ Seconds
- ☐ Minutes
- ☐ Hours
- ☒ Days
- ☐ Years

Time Discretization

Initial Time [day]: 0

Final Time [day]: 1

Initial Time Step [day]: 0.001

Minimum Time Step [day]: 1e-005

Maximum Time Step [day]: 5

Time-Variable Boundary Conditions

☐ Time-Variable Boundary Conditions

0 Number of Time-Variable Boundary Records (e.g., Precipitation)

☐ Repeat the same set of BC records n times: 1

☐ Daily Variations of Transpiration During Day Generated by HYDRUS

☐ Sinusoidal Variations of Precipitation Generated by HYDRUS

Meteorological Data

☐ Meteorological Data

0 Number of Meteorological Records (e.g., Radiation)

- ☒ Penman-Montheith Equation
- ☐ Hargreaves Formula
- ☐ Energy Balance Boundary Condition
- ☐ Daily Variations of Meteo Data During Day Generated by HYDRUS

OK Cancel Previous ... Next ... Help

Print Information

Print Options

☒ I-Level Information

Every n time steps: 1

☐ Print at Regular Time Interval

Time Interval [day]: 1

☒ Screen Output

☒ Print Fluxes (instead of Temp) for Observation Nodes

☒ Hit Enter at End?

Print Times

Number of Print Times: 12

Select Print Times ...

OK Cancel Previous ... Next ... Help

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Time Information

Time Units

- ☐ Seconds
- ☐ Minutes
- ☐ Hours
- ☒ Days
- ☐ Years

Time Discretization

Initial Time [day]: 0

Final Time [day]: 1

Initial Time Step [day]: 0.001

Minimum Time Step [day]: 1e-005

Maximum Time Step [day]: 5

Time-Variable Boundary Conditions

☐ Time-Variable Boundary Conditions

0 Number of Time-Variable Boundary Records (e.g., Precipitation)

☐ Repeat the same set of BC records n times: 1

☐ Daily Variations of Transpiration During Day Generated by HYDRUS

☐ Sinusoidal Variations of Precipitation Generated by HYDRUS

Meteorological Data

☐ Meteorological Data

0 Number of Meteorological Records (e.g., Radiation)

- ☒ Penman-Montheith Equation
- ☐ Hargreaves Formula
- ☐ Energy Balance Boundary Condition
- ☐ Daily Variations of Meteo Data During Day Generated by HYDRUS

OK

Cancel

Previous ...

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Print Information

Print Options

☒ I-Level Information

Every n time steps: 1

☐ Print at Regular Time Interval

Time Interval [day]: 1

☒ Screen Output

☒ Print Fluxes (instead of Temp) for Observation Nodes

☒ Hit Enter at End?

Print Times

Number of Print Times: 12

Select Print Times ...

OK

Cancel

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Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Print-Times

	1	2	3	4
Print Times [day]	6.77778	13.5556	20.3333	27.1111

◀ ▶

Default (log) Default OK Cancel

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil

Iteration Criteria

Iteration Criteria

10 Maximum Number of Iterations

0.001 Water Content Tolerance

1 Pressure Head Tolerance [cm]

Time Step Control

3 Lower Optimal Iteration Range

7 Upper Optimal Iteration Range

1.3 Lower Time Step Multiplication Factor

0.7 Upper Time Step Multiplication Factor

Internal Interpolation Tables

1e-006 Lower Limit of the Tension Interval [cm]

10000 Upper Limit of the Tension Interval [cm]

OK

Cancel

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Soil Hydraulic Model

Hydraulic Model

Single Porosity Models

☒ van Genuchten - Mualem

☐ With Air-Entry Value of -2 cm

☐ Modified van Genuchten

☐ Brooks-Corey

☐ Kosugi (log-normal)

Dual-Porosity/Dual-Permeability Models

☐ Dual-porosity (Durner, dual van Genuchten - Mualem)

☐ Dual-porosity (mobile-immobile, water c. mass transfer)

☐ Dual-porosity (mobile-immobile, head mass transfer)

== Models below are recommended only for experienced users ==

☐ Dual-permeability (Kinematic wave equation)

☐ Dual-permeability (Gerke and van Genuchten, 1993)

☐ Look-up Tables

Hysteresis

☒ No hysteresis

☐ Hysteresis in retention curve

☐ Hysteresis in retention curve and conductivity

☐ Hysteresis in retention curve (no pumping, Bob Lenhard)

☐ Initially drying curve

☐ Initially wetting curve

OK

Cancel

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Example 1: HYDRUS 1D

Water flow and solute transport into a Fo

n	α	θ_s	θ_r	K_s	SAR	sand	silt	Clay	pH	EC	Depth	
	cm ⁻¹	cm ³ /cm ³		cm/day		%				ds/m	cm	
1.3065	0.0073	0.417	0.116	5.835	13.6	40	37	23	7.7	21.5	0-13	Nim2-9
1.3484	0.0049	0.426	0.120	4.395	8.7	40	57	3	7.8	7.8	13-28	
1.3105	0.00702	0.417	0.116	5.630	10.4	40	39	21	7.8	7.4	28-64	
1.3105	0.00702	0.417	0.116	6.1	11.6	66	26	8	7.9	6.6	61-90	

Water Flow Parameters

Mat	Qr [-]	Qs [-]	Alpha [1/cm]	n [-]	Ks [cm/day]	I [-]
1	0.11628	0.417347	0.007338	1.30657	5.835	0.5
2	0.120837	0.426867	0.004993	1.34848	4.39529	0.5
3	0.116604	0.417571	0.007024	1.31053	5.835	0.5
4	0.116604	0.417571	0.007024	1.31053	6.11	0.5

Soil Catalog Neural Network Prediction ☐ Temperature Dependence

OK

Cancel

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Rosetta Lite v. 1.1 (June 2003)

Select Model

- ☐ Textural classes
 ☐ SSCBD+ water content at 33 kPa (TH33)
 ☒ % Sand, Silt and Clay (SSC)
 ☐ Same + water content at 1500 kPa (TH1500)
 ☐ %Sand, Silt, Clay and Bulk Density (BD)

Input

Textural Class: Unknown
 Sand [%]: 40
 Silt [%]: 37
 Clay [%]: 23
 BD [gr/cm³]: 1.5
 TH33 [cm³/cm³]:
 TH1500 [cm³/cm³]:

Output

Theta r [cm³/cm³]: 0.0676
 Theta s [cm³/cm³]: 0.4113
 Alpha [1/cm]: 0.0113
 n [-]: 1.4631
 Ks [cm/day]: 7.75

Help!

Predict

Accept

Cancel

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Water Flow Boundary Conditions [X]

Upper Boundary Condition

- ☐ Constant Water Content
- ☐ Constant Flux
- ☒ Atmospheric BC with Surface Layer
- ☐ Atmospheric BC with Surface Run Off
- ☐ Variable Pressure Head
- ☐ Variable Pressure Head/Flux
- ☐ Triggered Irrigation

Lower Boundary Condition

- ☐ Constant Water Content
- ☐ Constant Flux
- ☐ Variable Pressure Head
- ☐ Variable Flux
- ☒ Free Drainage
- ☐ Deep Drainage
- ☐ Seepage Face; $h =$
- ☐ Horizontal Drains

Initial Condition

- ☐ In Pressure Heads
- ☒ In Water Contents

Atmospheric BC

- ☒ Input PET and LAI
- Extinction Coeff.
- ☐ Interception

Max h at Soil Surface

OK
Cancel
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Solute Transport [X]

Time Weighting Scheme

- ☐ Explicit Scheme
- ☒ Crank-Nicholson Scheme
- ☐ Implicit Scheme

Space Weighting Scheme

- ☒ Galerkin Finite Elements
- ☐ Upstream Weighting FE
- ☐ GFE with Artificial Dispersion
- ☐ Eulerian-Lagrangian Approach

Mass Units:

☒ Use Tortuosity Factor Stability Criterion:

Composition

- Number of Solution Concentration Combinations
- Number of Adsorbed Concentration Combinations
- Number of Precipitated Concentration Combinations

OK
Cancel
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Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

layer	Ca ²⁺	Mg ²⁺	Na ⁺	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻	HCO ₃ ⁻
	Meq/l						
Soil layer 1	170	17	125	150	0.8	0.5	2.16
Soil layer 2	54	5.4	45	54	0.8	0.5	1.68
Soil layer 3	41	4.1	47	56.4	1	1	2.04
Soil layer 4	30	3.8	45	50.4	0.5	0.5	1.54
Irrigation Water	1.8	4.1	6.69	0.17	3.41	5.5	3.02
Rain	0.01	0.01	0.01	0.01	0	0	0.04

Solute Composition

Solution Composition [meq/L]

Sol	Ca	Mg	Na	K	Alk	SO4	Cl	Tracer
1	170	17	125	0.1	2.66	0.8	150	1E+030
2	54	5.4	45	0.1	2.18	0.8	54	1E+030

Solute Composition

Solution Composition [meq/L]

Sol	Ca	Mg	Na	K	Alk	SO4	Cl	Tracer
3	41	4.1	47	0.2	2.05	1	56.4	1E+030
4	30	3.8	45	0.2	3.52	0.5	50.4	1E+030
5	1.8	4.1	6.69	0.17	3.41	5.5	3.02	1E+030
6	0.01	0.01	0.01	0.01	0	0	0.04	0

Adsorption Concentrations [meq/kg]

Ads	Ca	Mg	Na	K
1	0	0	0	0

Precipitated Concentrations [meq/kg]

Prec	Calcite	Gypsum	Dolomite	HydroMg	Nesqoh	Sepiolite
1	0	0	0	0	0	0

OK

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Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Chemical Parameters

☐ Kinetic Precipitation/Dissolution

☐ Silica in Solution (pH dependency)

Critical Ionic Strength (Debye- Huckel * Pitzer equations)

Maximum Number of Iterations

☐ Conductivity Reduction due to Chemistry

OK
Cancel
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Solute Transport and Reaction Parameters - Solute 1

Mat	bulk.d.	Dw	Disper	CEC	Calc. SA
1	1.45	2	10	0	0
2	1.5	2	10	0	0
3	1.5	2	10	0	0
4	1.5	2	10	0	0

OK Cancel Previous ... Next ... Help

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Solute Transport Boundary Conditions

Upper Boundary Condition

- ☐ Concentration BC
- ☒ Concentration Flux BC
- ☐ Stagnant BC for Volatile Solutes

Lower Boundary Condition

- ☐ Concentration BC
- ☐ Concentration Flux BC
- ☒ Zero Concentration Gradient

Initial Conditions

- ☒ In Liquid Phase Concentrations [Mass_solute/Volume_water]
- ☐ In Total Concentrations [Mass_solute/Volume_soil]
- ☐ Nonequilibrium phase is initially at equilibrium with equilibrium phase

OK

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Root Water and Solute Uptake Model

Root Water Uptake Model

Water Uptake Reduction Model

- ☒ Feddes
- ☐ S-Shape

Solute Stress Model

- ☐ No Solute Stress
- ☐ Additive Model
- ☒ Multiplicative Model
 - ☒ Threshold Model
 - ☐ S-Shape

1 Critical Stress Index for Water Uptake

OK

Cancel

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Root Solute Uptake Model

Maximum Allowed Concentration
for Passive Root Solute Uptake

Sol. No.	cRoot
1	6

☐ Active Solute Uptake

1 Solute with Active Uptake

0 Potential Solute Uptake Rate

0.5 Michaelis-Menten Constant

0 Minimum Concentration for Uptake

1 Critical Stress Index for Active
Solute Uptake

☐ Reduced Potential Solute Uptake
due to Reduced Water Uptake

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Root Water Uptake Parameters [X]

Feddes' Parameters

P0 [cm]

P0pt [cm]

P2H [cm]

P2L [cm]

P3 [cm]

r2H [cm/day]

r2L [cm/day]

Database

OK

Cancel

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Root Water Uptake Parameters [X]

Threshold Model

Threshold [cm]:

Slope [1/cm]:

Conversion to pressure/
osmotic head:

	Osm. Coeff.
1	1

Database

OK

Cancel

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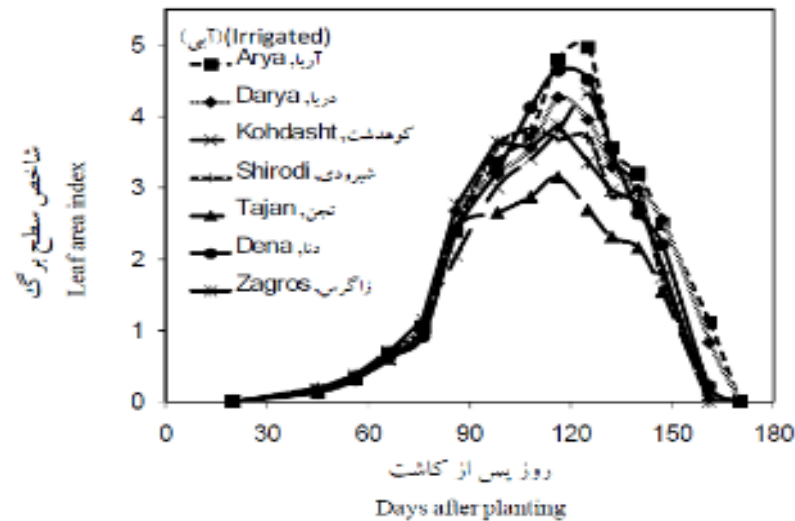
Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

Time Variable Boundary Conditions

	Time [day]	Precip. [cm/day]	potET [cm/day]	hCritA [cm]	LAI	cTop	cBot
1	1	0	0.32	100000	0	0	0
2	2	0	0.33	100000	0	0	0
3	3	0.1	0.37	100000	0	6	0
4	4	0.43	0.37	100000	0	6	0
5	5	0.011	0.36	100000	0	6	0
6	6	0.003	0.36	100000	0	6	0
21	21	0.081	0.33	100000	0	6	0
22	22	0.041	0.32	100000	0	6	0
23	23	0.21	0.29	100000	0	6	0
24	24	0.141	0.26	100000	0	6	0
25	25	0.371	0.29	100000	0	6	0
26	26	0.982	0.31	100000	0	6	0
27	27	0	0.3	100000	0	0	0
28	28	0.03	0.34	100000	0	6	0
29	29	0.31	0.34	100000	0	6	0
30	30	20.93	0.27	100000	0	5	0
31	31	0.86	0.29	100000	0	6	0
32	32	0.63	0.26	100000	0	6	0
33	33	0.87	0.28	100000	0	6	0
34	34	0	0.28	100000	0	0	0

- 20 cm of water as pre-irrigation for leaching purposes (day 30).
- 5 irrigation events
- (day 96), (day 116), (day 136),
- (day 156), (day 190).



ETo Calculator

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

HYDRUS-1D guide

Do you want to run PROFILE application ?

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Cancel

OK

Soil Profile Summary

	z [cm]	theta	Root [1/cm]	nConc	nAds	nPrec	Mat
1	0	0.2	0	1	1	1	1
2	1	0.2	0.0833333	1	1	1	1
3	2	0.2	0.166667	1	1	1	1
4	3	0.2	0.25	1	1	1	1
5	4	0.2	0.333333	1	1	1	1
6	5	0.2	0.416667	1	1	1	1
7	6	0.2	0.5	1	1	1	1
8	7	0.2	0.583333	1	1	1	1
9	8	0.2	0.666667	1	1	1	1
10	9	0.2	0.75	1	1	1	1
11	10	0.2	0.833333	1	1	1	1
12	11	0.2	0.916667	1	1	1	1
13	12	0.2	1	1	1	1	1
14	13	0.2	1	1	1	1	2
15	14	0.2	0.916667	1	1	1	2

Set to Default Values

Set Initial Conditions Equal to Field Capacity

OK

Cancel

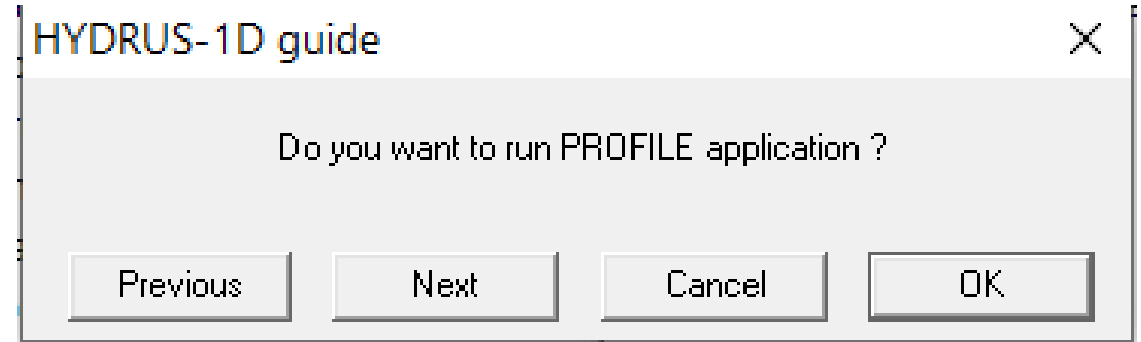
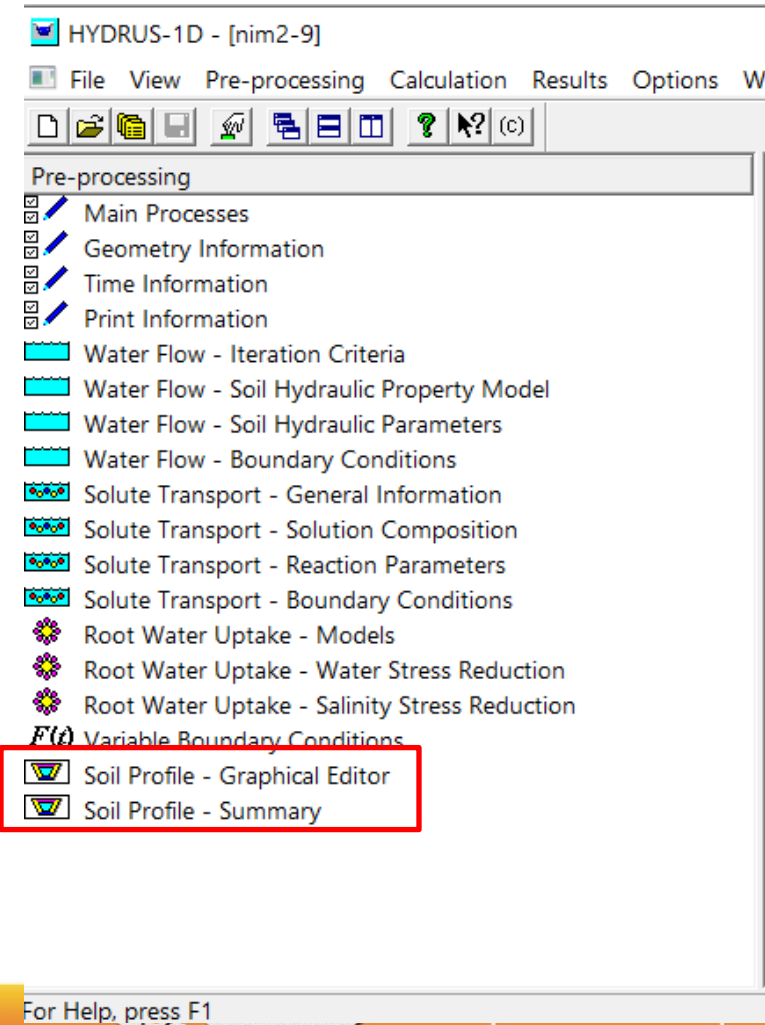
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Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile



Soil Profile – Graphical Editor

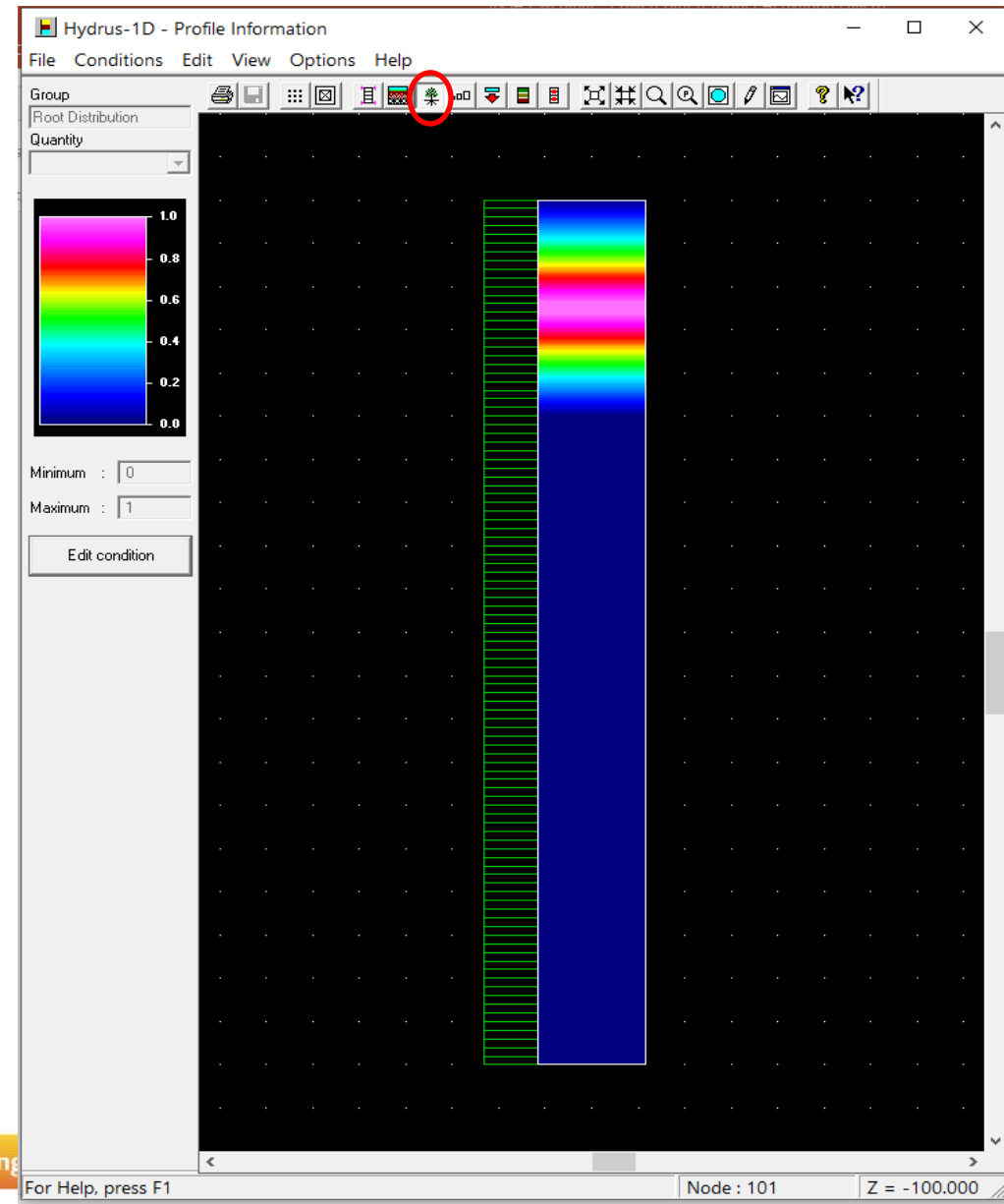
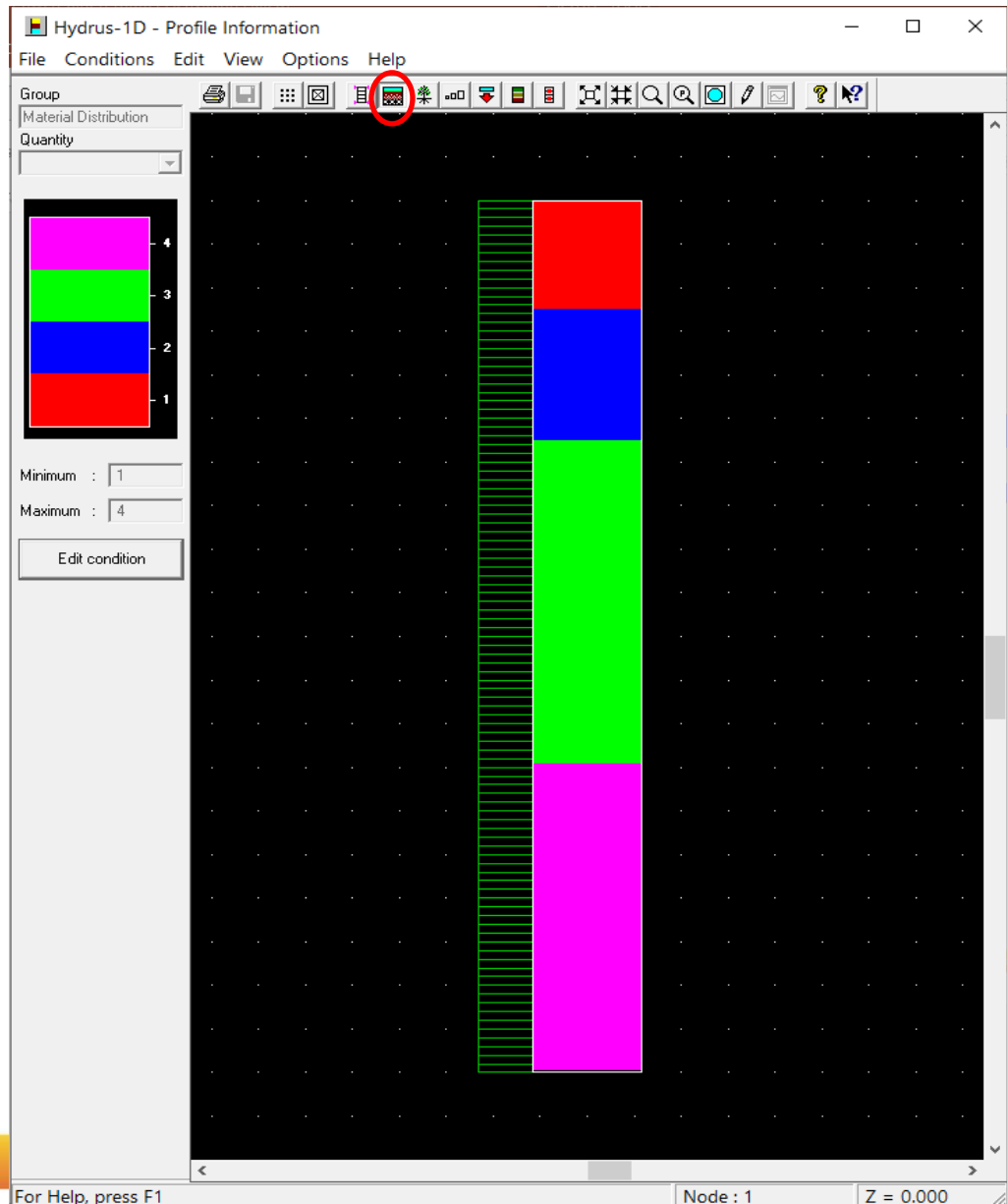
Menu: Conditions->Initial Conditions->water content, or press the Red Arrow() on the Toolbar (top to bottom=0.2)

Menu: Conditions -> Observation Points

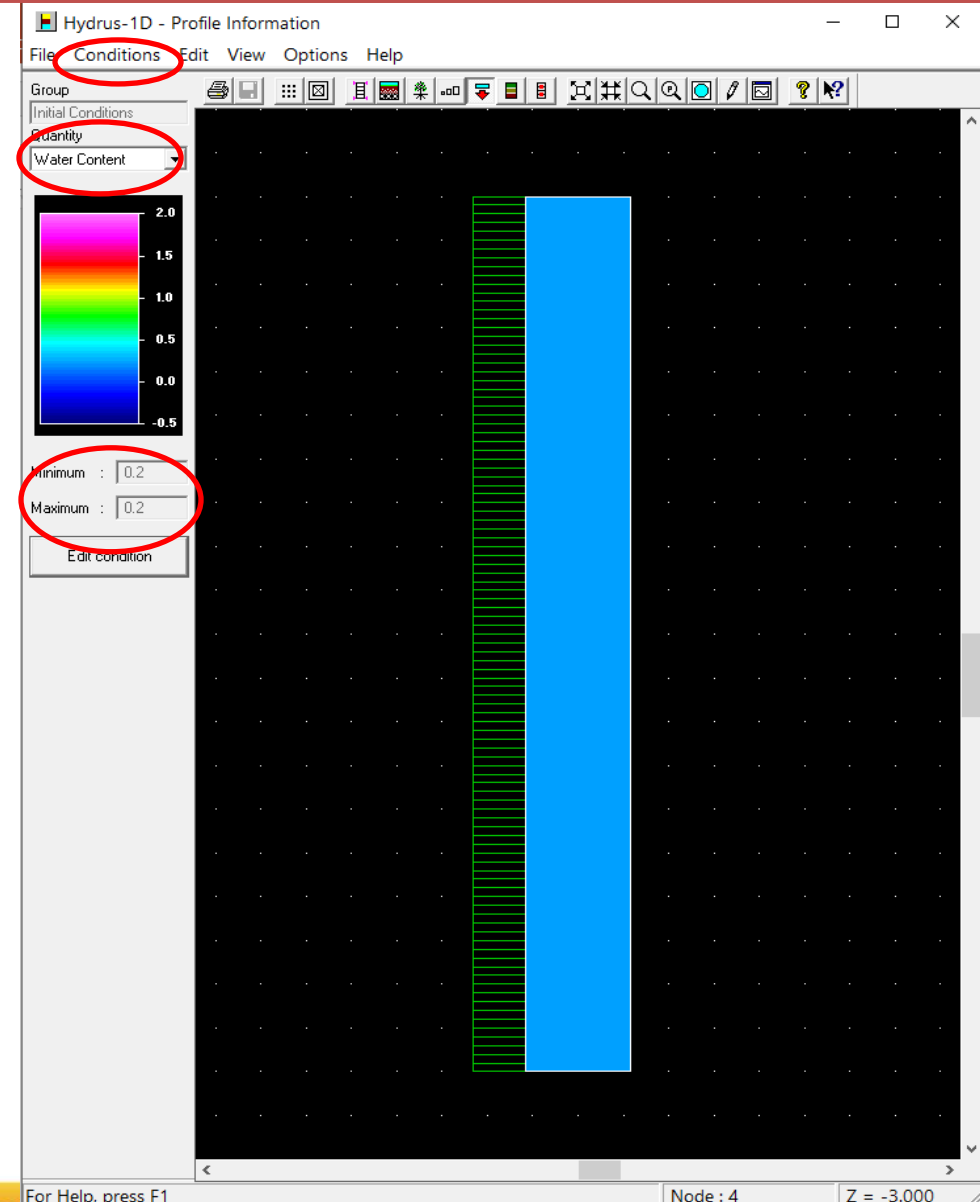
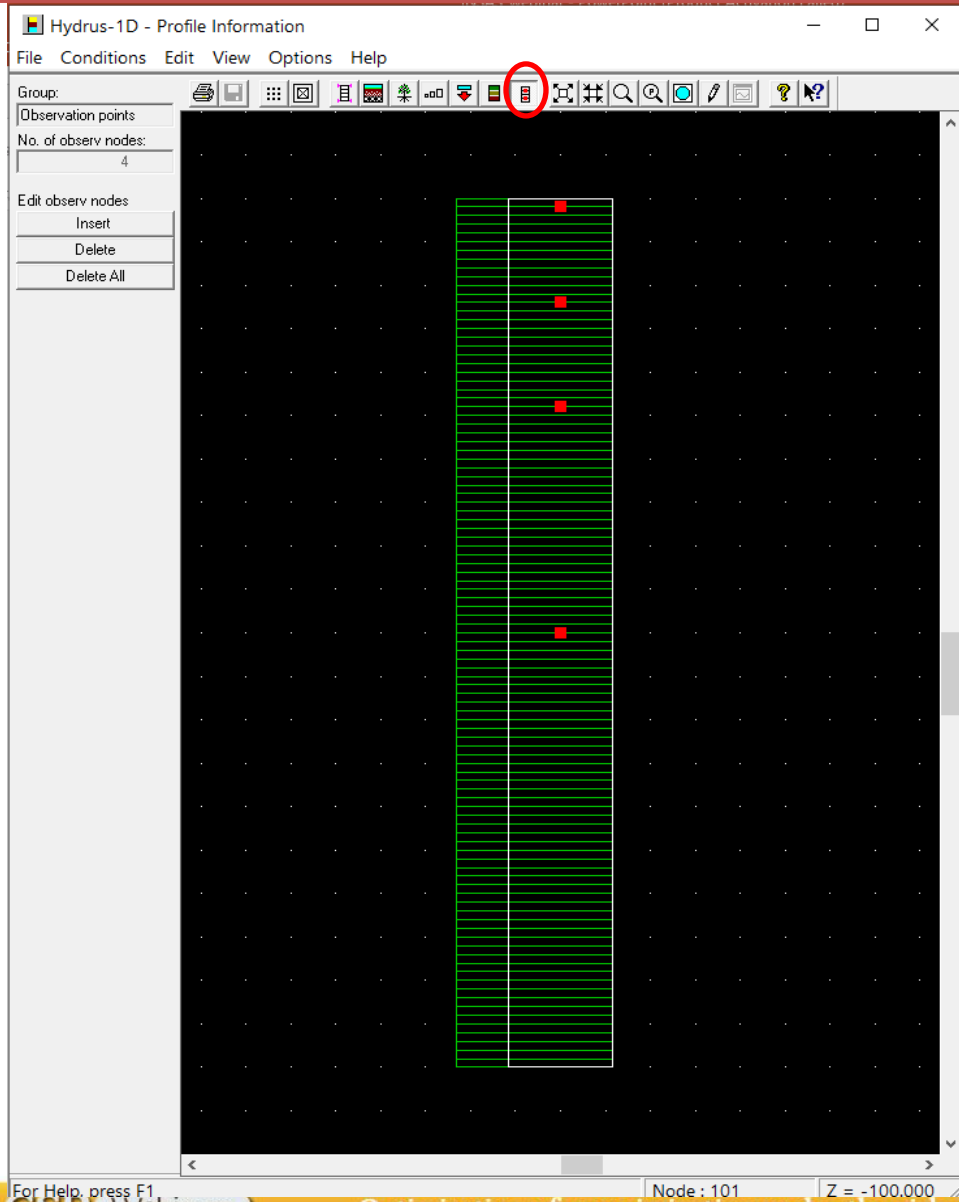
Button "Insert", Insert nodes at 2, 13, 25, and 51 cm



Example 1: HYDRUS 1D



Example 1: HYDRUS 1D



For Help, press F1

For Help, press F1

Node : 4

Z = -3.000

Example 1: HYDRUS 1D

Water flow and solute transport into a Four-Layered Soil Profile

HYDRUS-1D guide

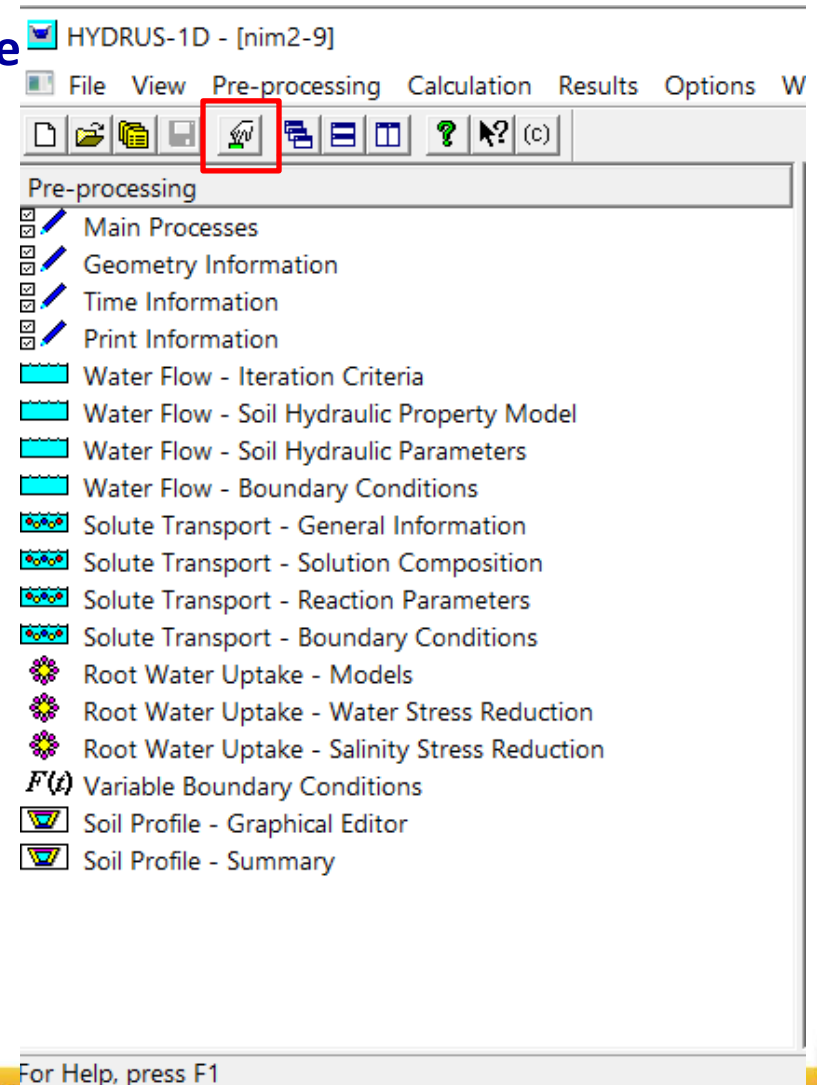
Do you want to run HYDRUS-1D application ?

Previous

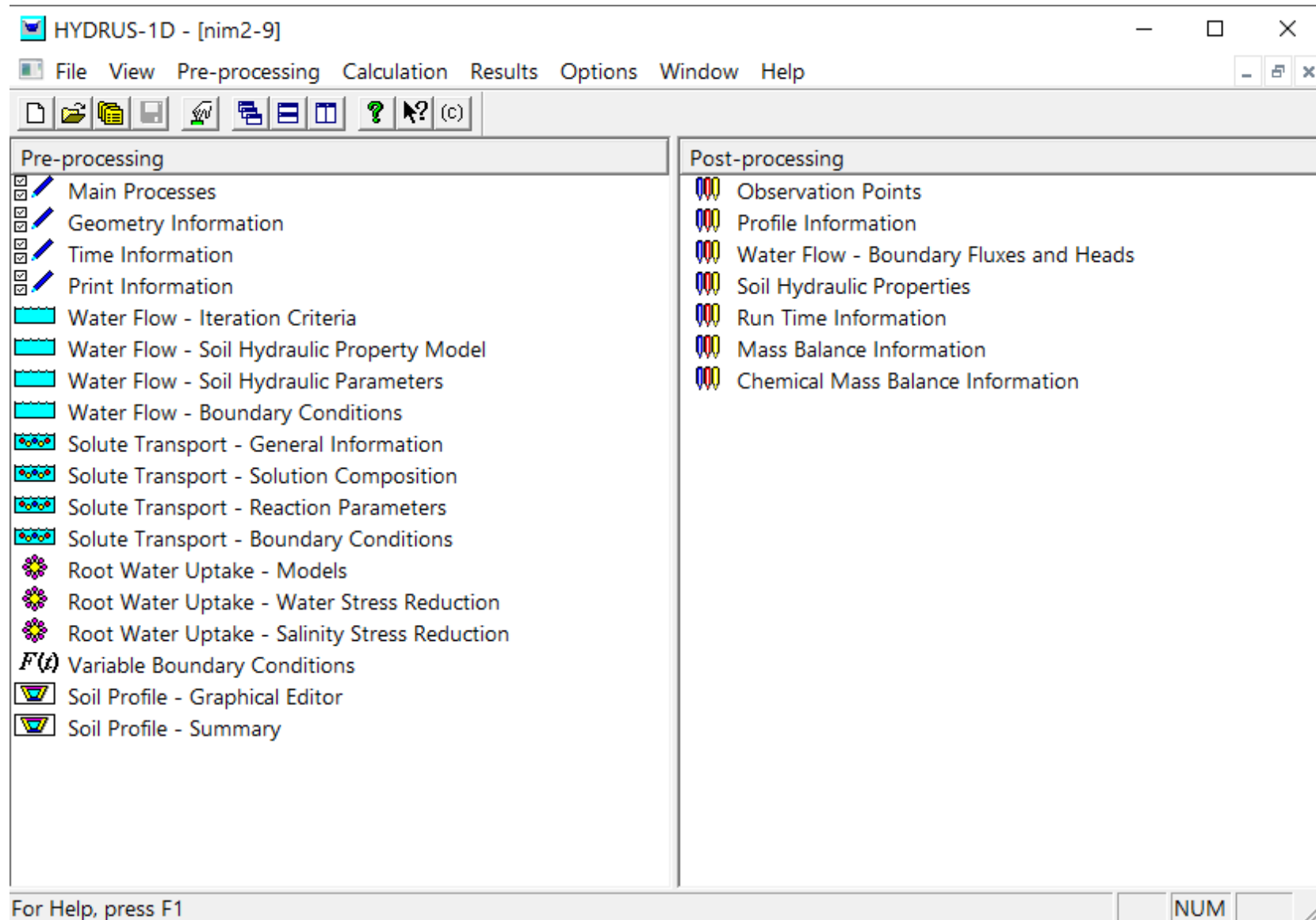
Next

Cancel

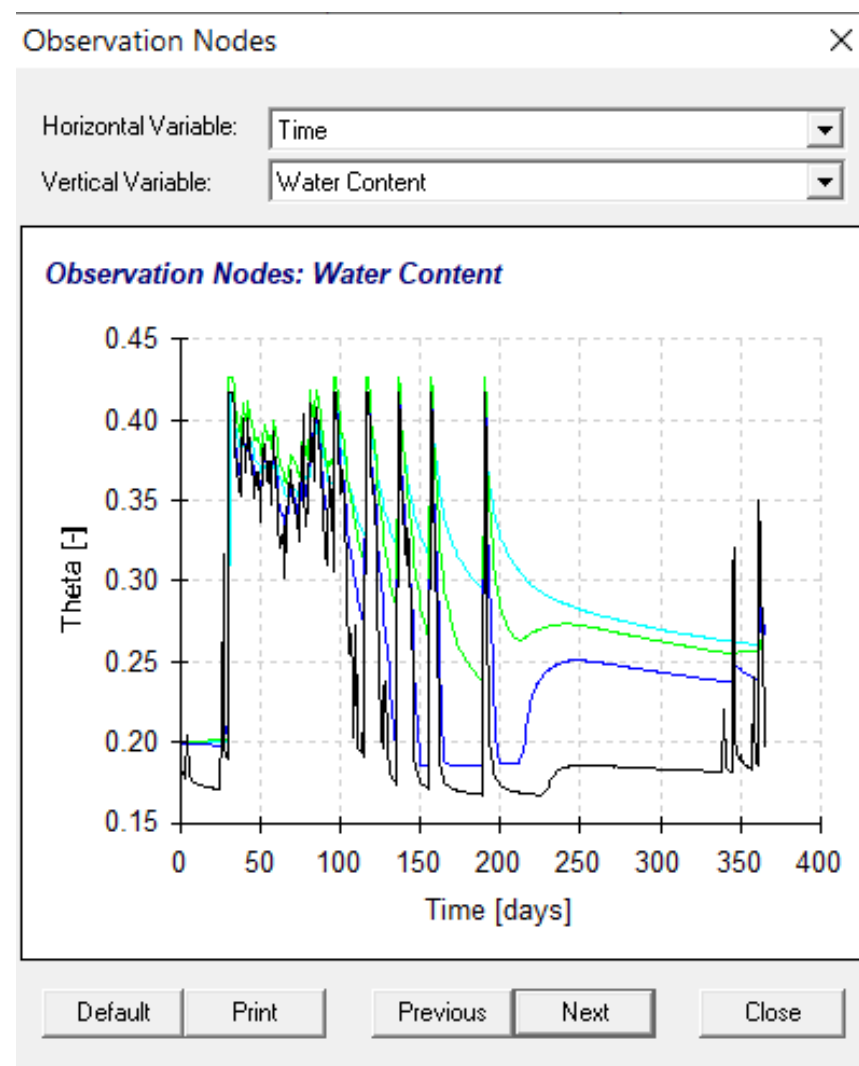
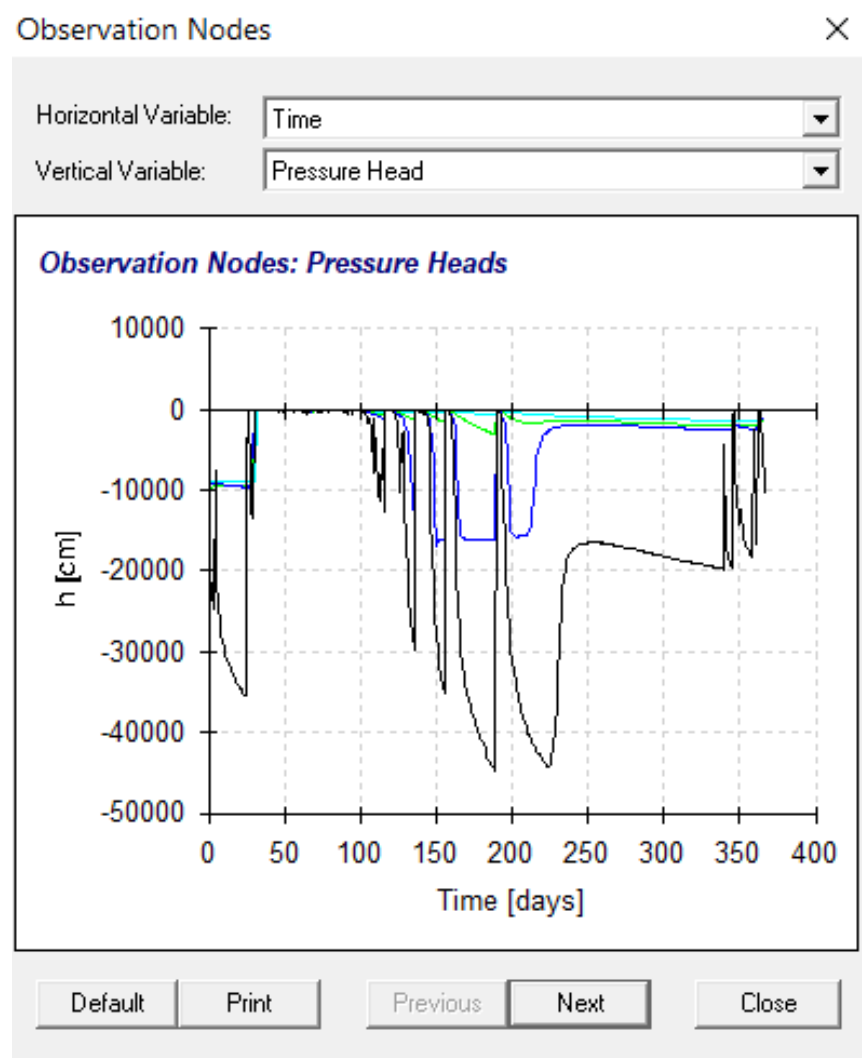
OK



Example 1: HYDRUS 1D



Example 1: HYDRUS 1D

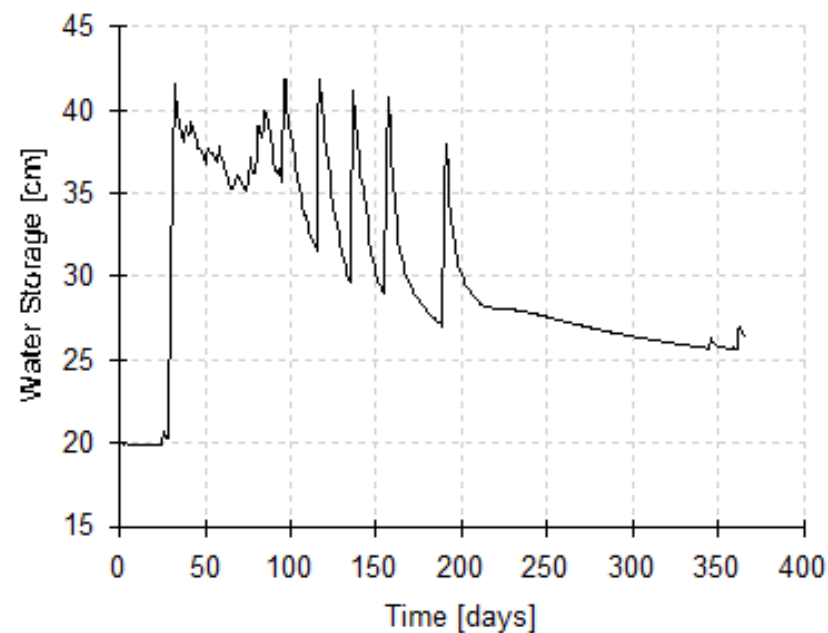


Example 1: HYDRUS 1D

Boundary Water Fluxes and Pressure Heads

Horizontal Variable: Time
Vertical Variable: Soil Water Storage

Soil Water Storage



Default

Print

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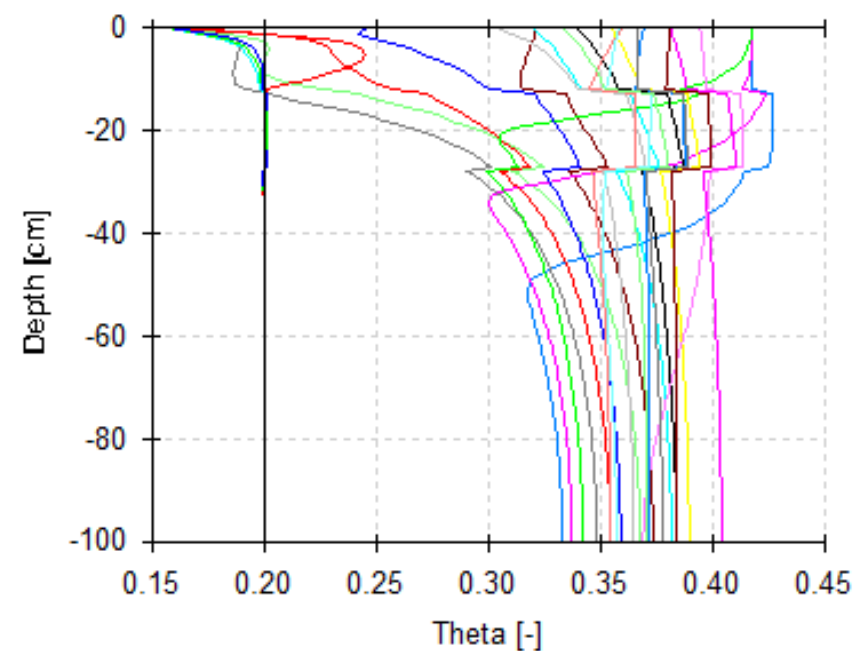
Next

Close

Basic Profile Information

Horizontal Variable: Profile Information: Water Content
Vertical Variable: Depth

Profile Information: Water Content



Default

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Food and Agriculture
Organization of the
United Nations

Thank you for your attention



International Network of
Salt-Affected Soils

Optimization of crop irrigation under the risk of salinization
using agrohydrological tools

22 October – 29 October – 12 November 2024



Meisam.rezaei1@gmail.com; Skype: [Meisam.rezaei1](#)



موسسه تحقیقات خاک و آب