OPTAIN

OPtimal strategies to retAIN and re-use water and nutrients in small agricultural catchments across different soil-climatic regions in Europe

Introduction to hydrological models

SWAP theory

Csilla Farkas

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 862756.

NIBIO
NORSK INSTITUTT FOR BIOØKONOMI

Why do we need process-based models?

Goal: To understand the naturally observed phenomena and be able to predict them

We do use models for

- developing scientific understanding of complex systems
- spatio-temporal extension of the knowledge gained
  (data from experiment/monitoring relationships can not be extrapolated in space/time)
- testing the reaction of the system to changing/unobservable conditions
- planning and decision-making

From natural curiosity to data-model fusion

natural curiosity

iSock

From natural curiosity to data-model fusion

natural curiosity

observation

qualitative information

From natural curiosity to data-model fusion

- Natural curiosity ➔ observations ➔ information

Measurements

monitoring

data collection

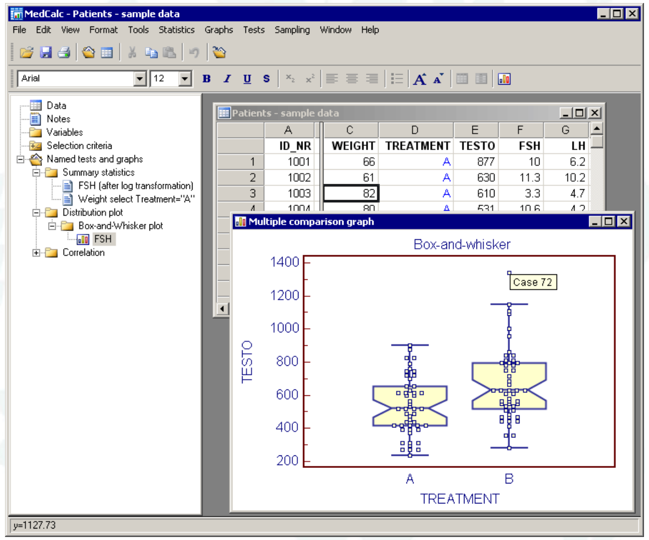
spatio-temporal databases

iSock

From natural curiosity to data-model fusion

- Natural curiosity ➔ observations ➔ information
- Measurements ➔ monitoring ➔ databases

Statistical analyses ➔ empirical models

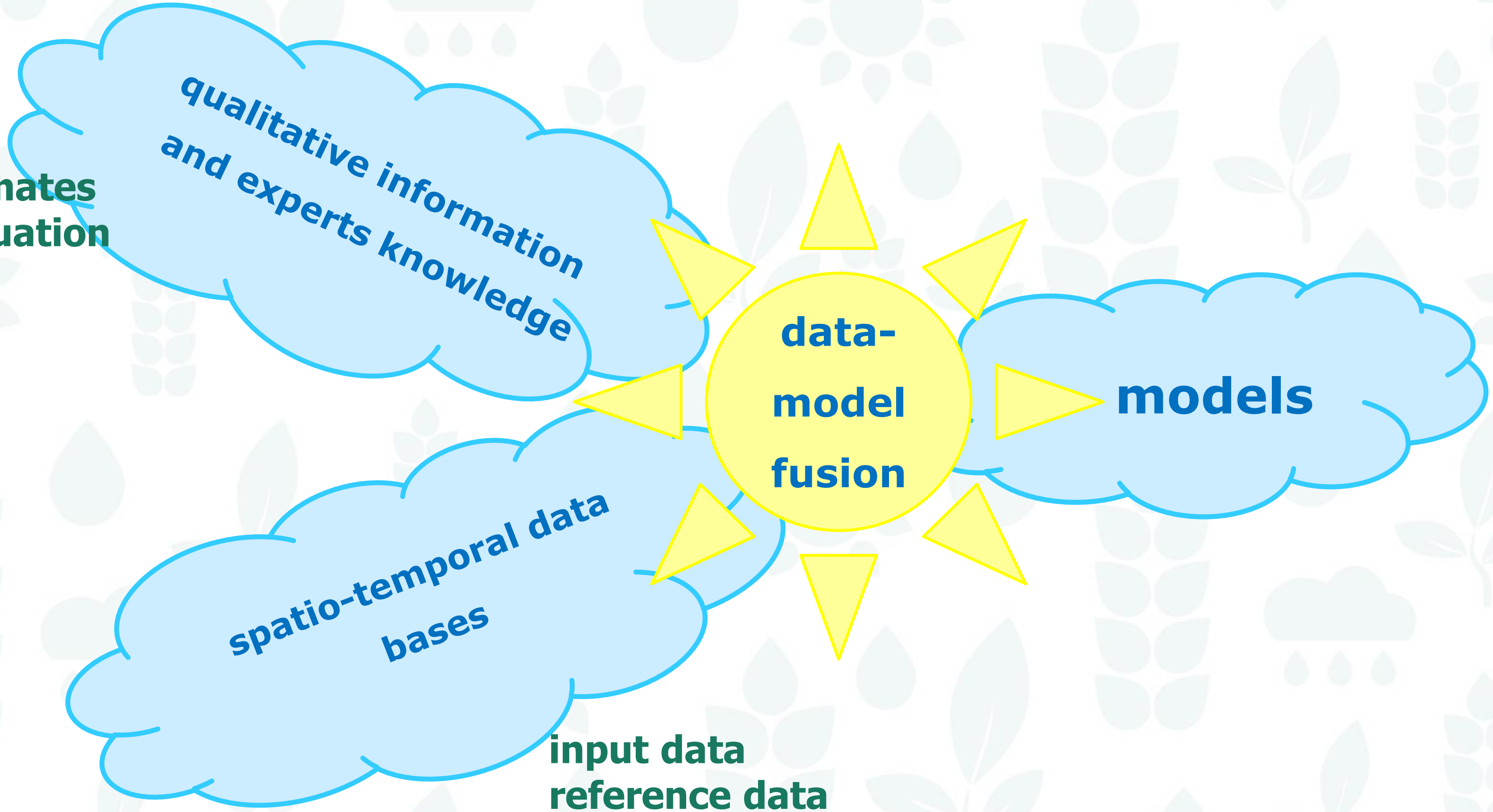


Physical laws/relationships ➔ process-based models

Models with finer spatio-temporal resolution

Data-model fusion – an advanced approach for studying complex systems

expert estimates
expert evaluation



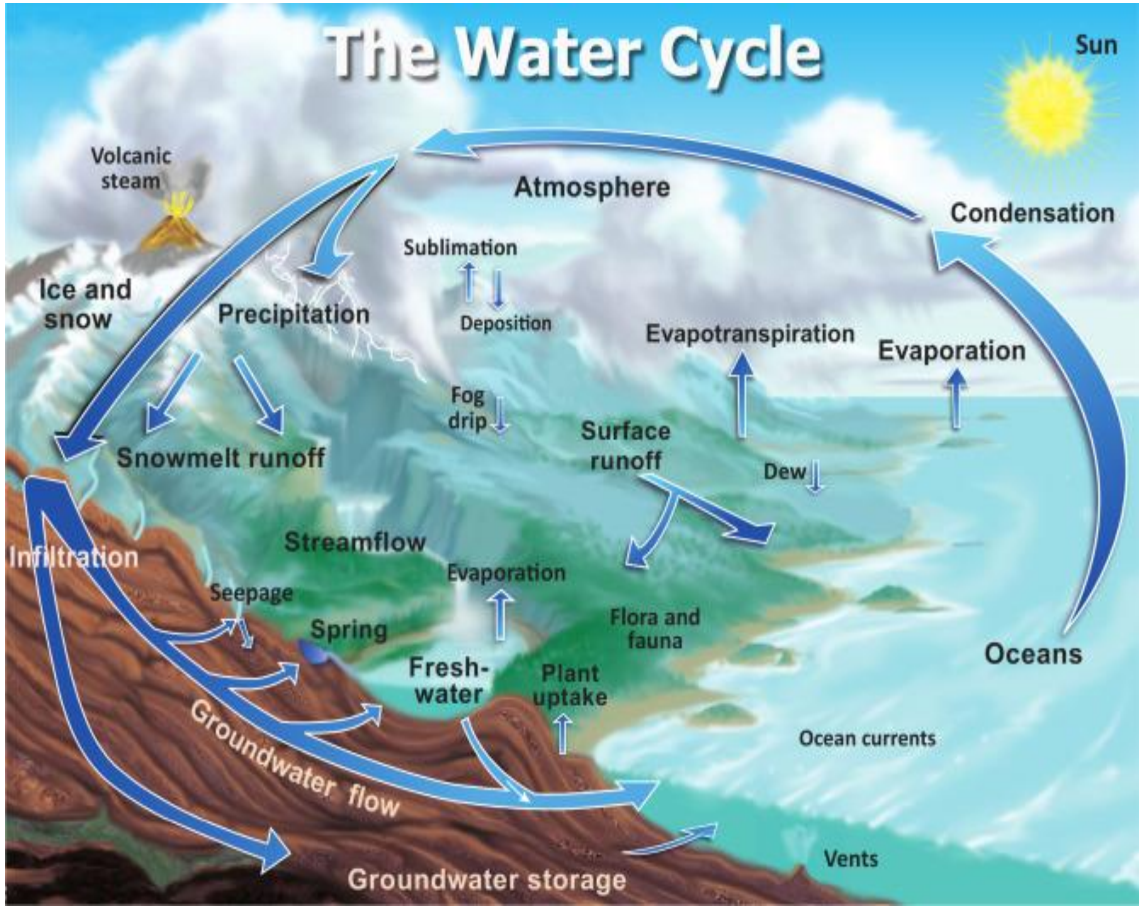
input data
reference data

Model
developers

„Modeller"

Modelling is TEAM work

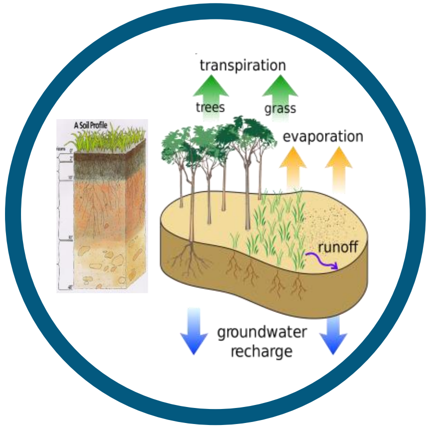
Hydrological modelling

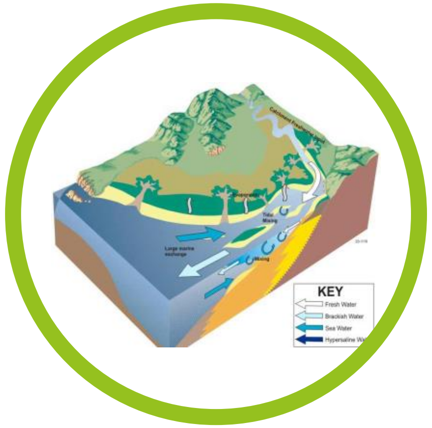


Hydrologic models

- simplified representation of a hydrological system
- aid in understanding, predicting, and managing water resources
- study both, flow and quality of water

Hydrological modelling





Global water cycle

Ground-water

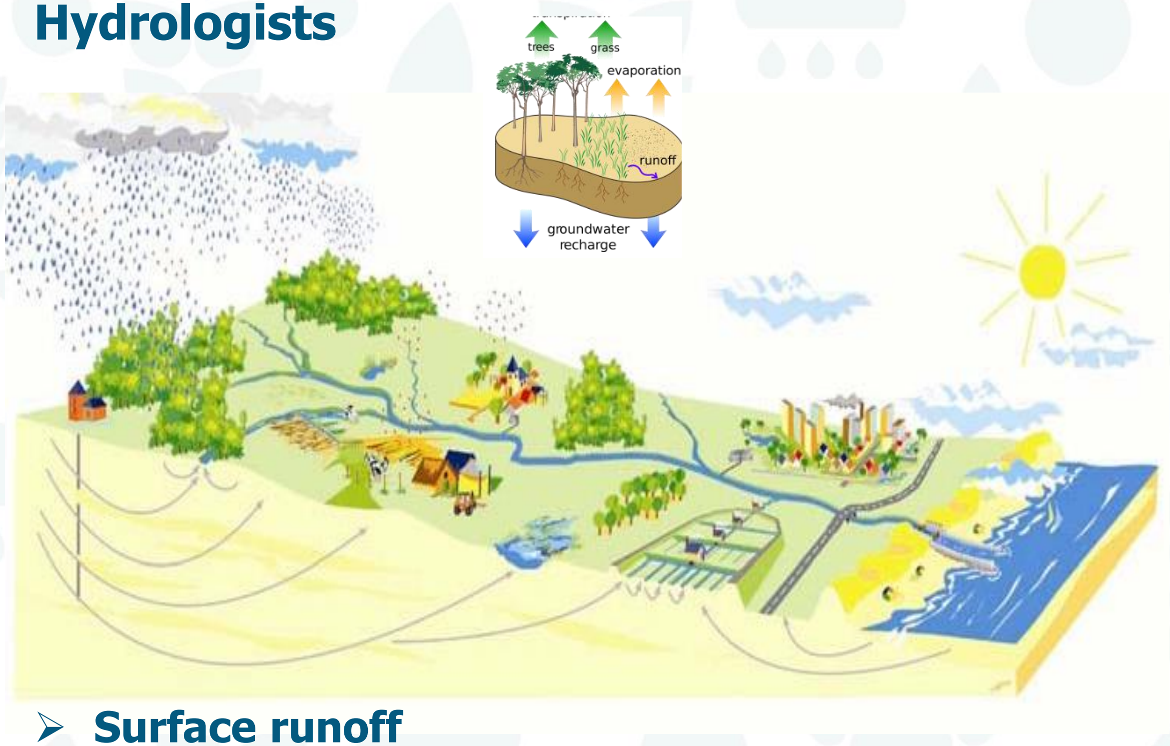
Surface water

Soil water

Estuary

Traditional understanding of hydraulic modelling

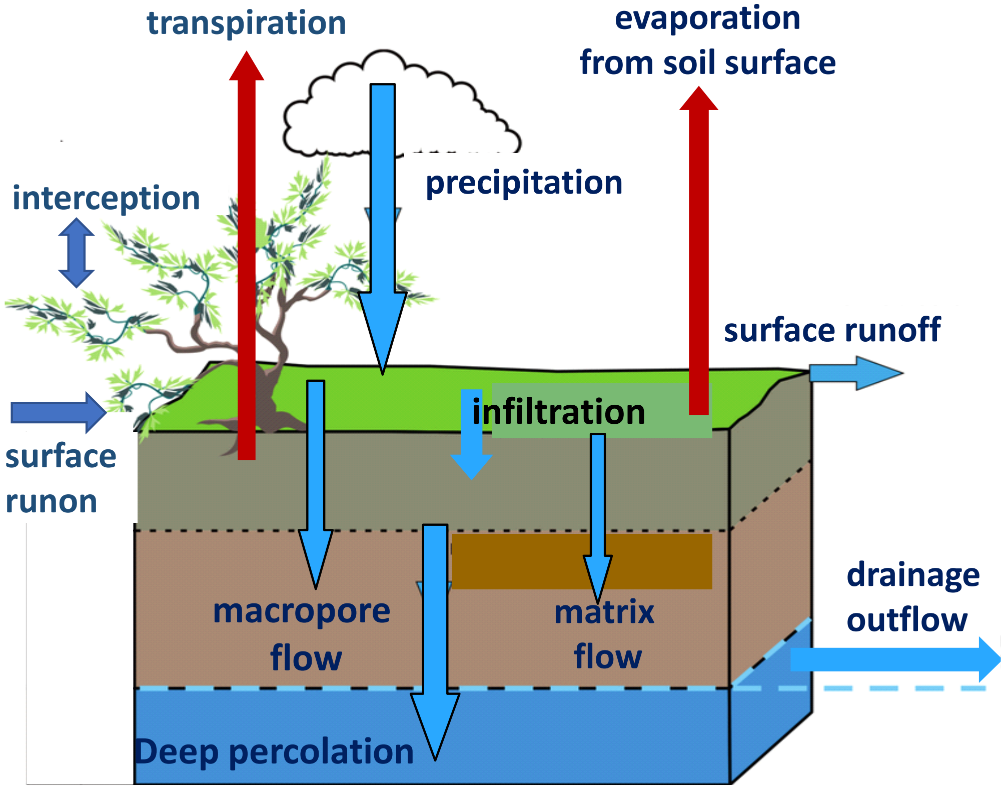
Hydrologists



- Surface runoff
- Subsurface runoff

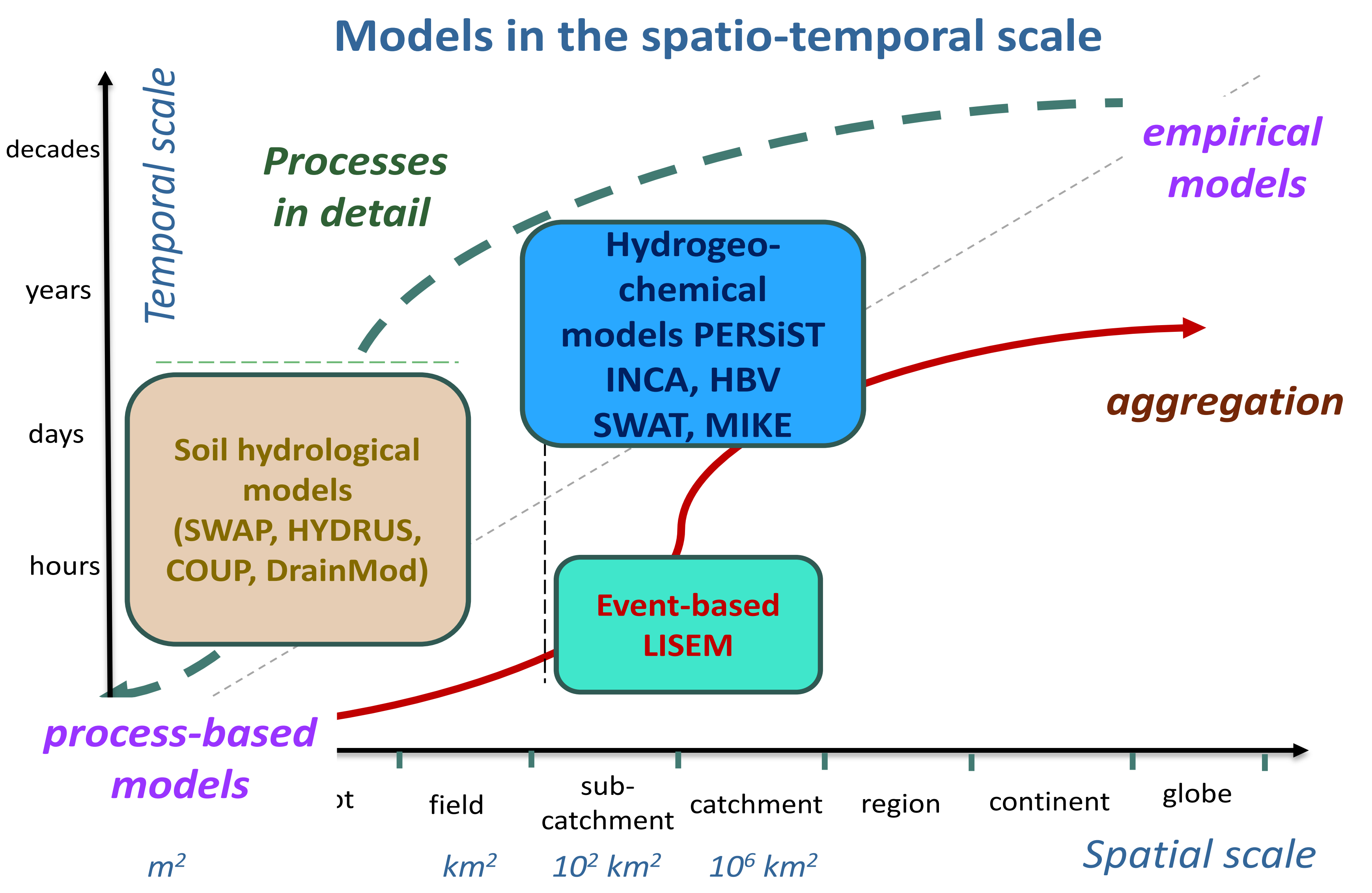
- Water quantity and quality at catchment outlet

Soil scientists



- Soil water content
- Drainage outflow

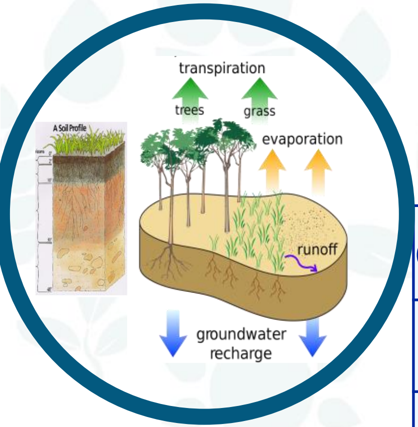
Hydrological models in the spatio-temporal scale

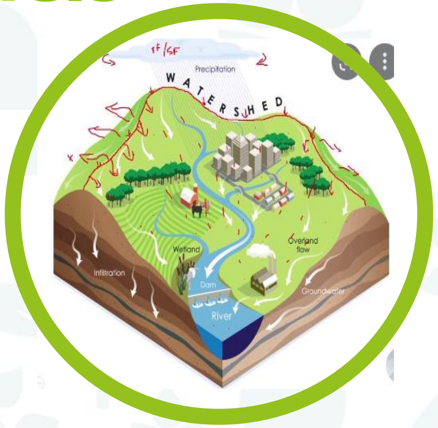


r: Clement et al., 2007

Source_ Clement et al., 2007

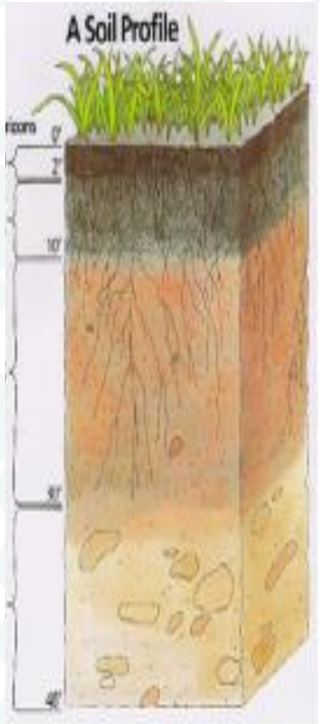
General comparison of different hydrological models





	DrainMod	SWAP	HBV	INCA	SWAT
Complete catchment model	No	No	Yes	Yes	Yes
Modest data requirements	Yes	No	Yes	Yes	No
High time resolution	Yes	Yes	Yes	Yes	Yes
Spatial distribution	No	No	Semi-distributed	Semi-distributed	Distributed
Process-based model	Yes	Yes	Partly	Mostly	Mostly
Calibration data required	Yes	Yes	Yes	Yes	Yes
Subsurface drainage included	Yes	Yes	No	Indirectly	
Heat flow simulation	Yes	Yes	No	Yes (very simple)	No
Instream processes	sNo	No	Yes	Yes	Yes

Processes in focus in different hydrological models



Model layer	Processes	DrainMod	Coup	HBV	INCA
Above ground vegetation zone	Precipitation	Driving	Driving	Driving	Driving
	Snow dynamics/snowmelt	Calculated	Calculated	Calculated	Calculated
	Interception	Indirectly	Calculated	Calculated	Indirectly
	Transpiration	Indirectly	Calculated	Calculated	Indirectly
Soil surface	Evaporation	Indirectly	Calculated	Calculated	Indirectly
	Surface runoff	Calculated	Calculated	Calculated	Calculated
	Infiltration	Calculated	Calculated	Indirectly	Indirectly
Unsaturated zone	Bypass/ macropore flow	NO	Calculated	Indirectly	NO
	Plant water uptake	Indirectly	Calculated	Indirectly	Indirectly
	Soil water redistribution	NO	Calculated	Calculated	NO
	Capillary rise	Calculated	Calculated	NO	NO
	Water flow in frozen soil	Indirectly	Calculated	Calculated	NO
	Lateral flow to stream	NO	NO	Calculated	Calculated
	Subsurface drainage flow	Indirectly	Calculated	NO	Indirectly
	Percolation to sat. zone	Calculated	Calculated	Calculated	Calculated
Saturated zone	Lateral inflow	Parameter	Parameter	NO	NO
	Capillary rise to unsat. zone	NO	Calculated	Calculated	NO
	Recharge to deep aquifer	NO	NO	NO	NO
	Base flow	Calculated	NO	Calculated	Calculated
CONFINING LAYER					
DEEP AQUIFER					

Model comparision - example

Comparison of three mathematical models simulating drainage outflow with respect ot their applicability to OPTIKORN goals

	SWAP	HYDRUS-1D	DRAINMOD-N
Drainage outflow calculation	🍀🍀	🍀	🍀🍀🍀
Soil water regime calculation	🍀🍀🍀	🍀🍀🍀	🍀🍀
Runoff calculation	🍀	🍀	🍀🍀
Calculation of evapotranspiration	E, TR and ET	E, TR and ET	ET = E+TR, no separation
N-loss calculation	🍀🍀	🍀	🍀🍀🍀
Autocalibration / Inverse solution	NO	Inverse solution BUT WITHOUT drainage only	Under development
Calibration against soil mositure content data	Not really successful experience for Norway except one site	Success using inverse solution for Skuterud	Not yet tested
Calibration agains drainage outflow	Not really successful experience for Norway	Not yet tested	Rather succesful
Calibration against runoff	Not really successful experience for Norway	Not yet tested	Not really succesful

Modell selection using Benchmark criteria

	KIWA	SWAT	DrainMod	HBV	INCA-P	Soil_NO COUP	AgriCat	?
Q1.1. How well does the model's output relate to the task?								
Q1.2. How well does the model's spatio-temporal resolution compare with the requirements of the task?								
Q1.3. How well the model has been tested under conditions in focus?								
Q1.4. How complicated is the model in relation to the task?								
Q1.5. How is the balance between the input data and data availability?								
Q1.8. How is the peer acceptance for the model with scientific theory?								
Q3.5. How is the model's flexibility for adaptation and improvements?								

Possible answers: Good; Adequate; Inadequate

Source: Farkas et al., 2010.

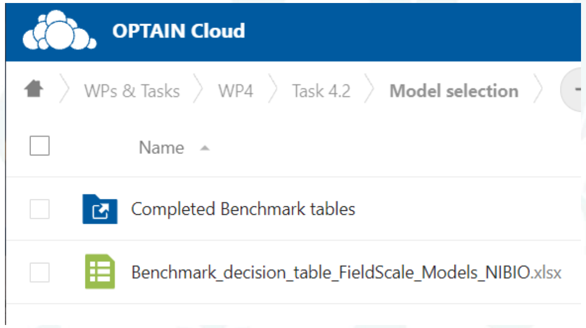
https://nc.ufz.de/apps/onlyoffice/s/KA9Cr2bbtALGMHr?fileId=117729538

OPTAIN

Task 4.2: Development of modelling protocols

Field-scale model selection

- ➢ Benchmark criteria in Excel workbook



Please, give your scores (0, 1 or 2) within the red frame only.
We appreciate any additional comments in columns M-P.

		SWAP	Hydrus	CropSys	DrainMod	CUP	Good (2)	Adequate (1)	Inadequate (0)	Items for taking decision
1.5	model's input data requirements and data availability?							if valid		most of the required model input data are available from monitoring and field observations, either from the management site or from othe applicable site close to it; however, some surrogate input data (e.g. results from other models, or data from other sites) must be used.
		2	2						if valid	majority of the required model input data are not available from monitoring and field observations from the management site (or from oth applicable site close to it)
1.6	How is the identifiability of the model parameters?						at least 1 item			all relevant model parameter values are well documented in scientific literature or can be estimated directly based on available data
										available data (corresponding to model output variables) will allow establishment of all relevant model parameter values via model calibra
								if valid		there seems to be enough data or documentation available to allow an adequate estimate of most of the relevant model parameter values directly or via model calibration)
		1	1						if valid	there are clearly not enough calibration data or other parameter documentation available to allow for an adequate establishment of many relevant model parameter values
1.7	How easily are the model results understood and interpreted?						if valid			non-specialist users are generally capable of understanding and interpreting the model output results
								if valid		assistance from research staff or modelling specialists is necessary to clarify ant interpret the model's output results
									at least 1 item	expert skills, long experience, and deep insight (e.g., those of a model developer) are needed to understand and interpret the model result
		2	2							much "tacit" (i.e., difficult-to-express) knowledge or intuition is involved in the interpretation of the model results.
1.8	How is the peer acceptance for the model and the model's consistency with scientific theory?						at least 2 items			the model has gained wide and international acceptance among the scientific community
										the model is widely used in many countries
										the whole model is based on well-established scientific theory
								at least 1 item		the model is used and gained peer-acceptance mostly locally/nationally
										most of the model components are based on well-established science
									at least 1 item	the model is based on speculative or immature scientific theory and/or assumptions
		2	2							the model is used only by few persons
	Total score	15	15	0	0	0				
	Number of "0" scores	0	0	0	0	0				

- ➢ Completed Benchmark tables (6 partners)
- ➢ Decision on model selection

COMMON MODEL SWAP

SWAP / HYDRUS | HYDRUS / SWAP | CROPSYS/ SWAP | SWAP | SWAP | HYDRUS / SWAP

boreal | continental | Pannonia

Models

well-known by the Team

no experience

OPTAIN

Model selection results – OPTAIN field-scale models

COMMON MODEL SWAP

SWAP / HYDRUS

HYDRUS / SWAP

boreal

CROPSYS/ SWAP

SWAP

SWAP

continental

HYDRUS / SWAP

Pannonia

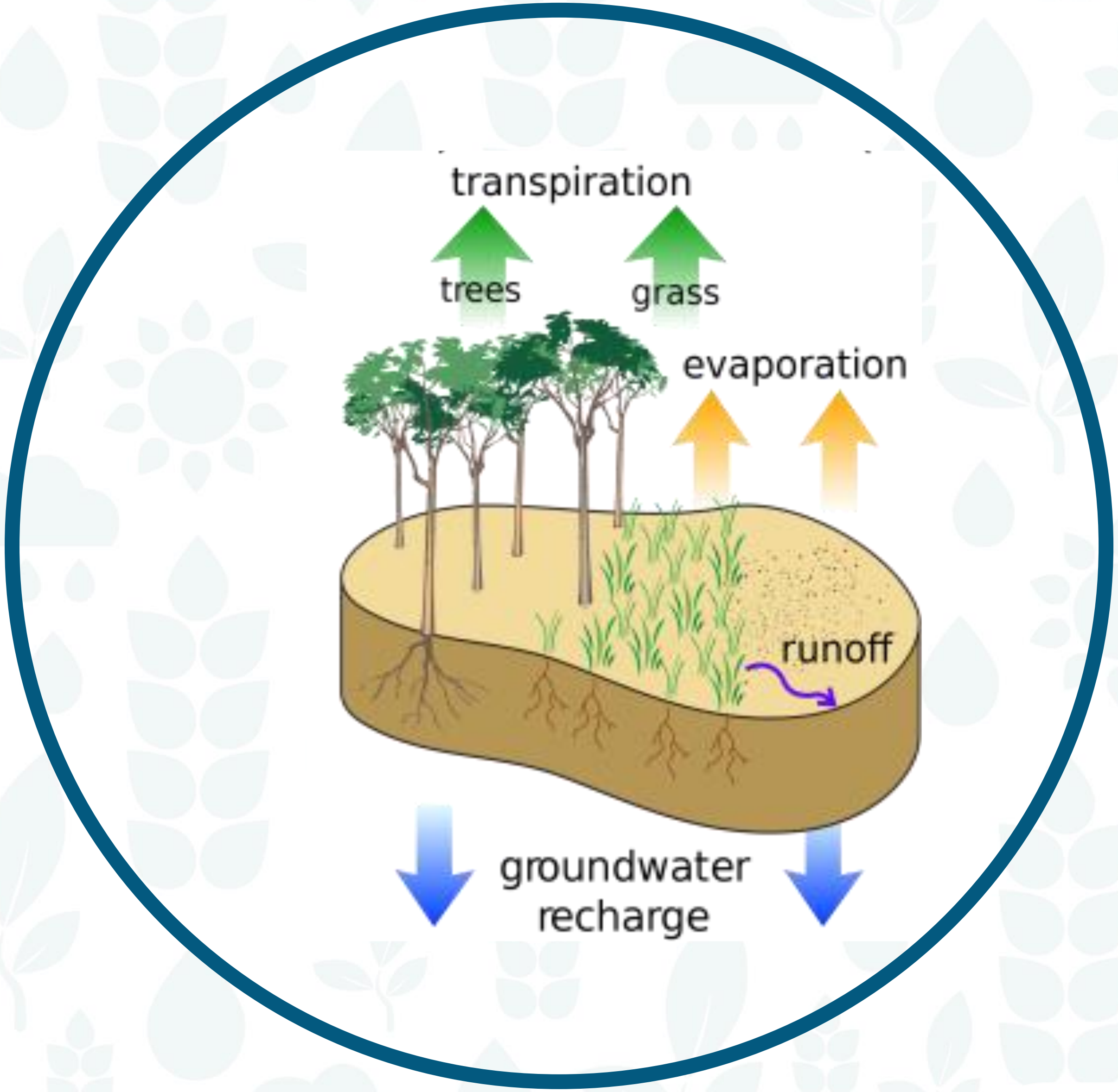
Models

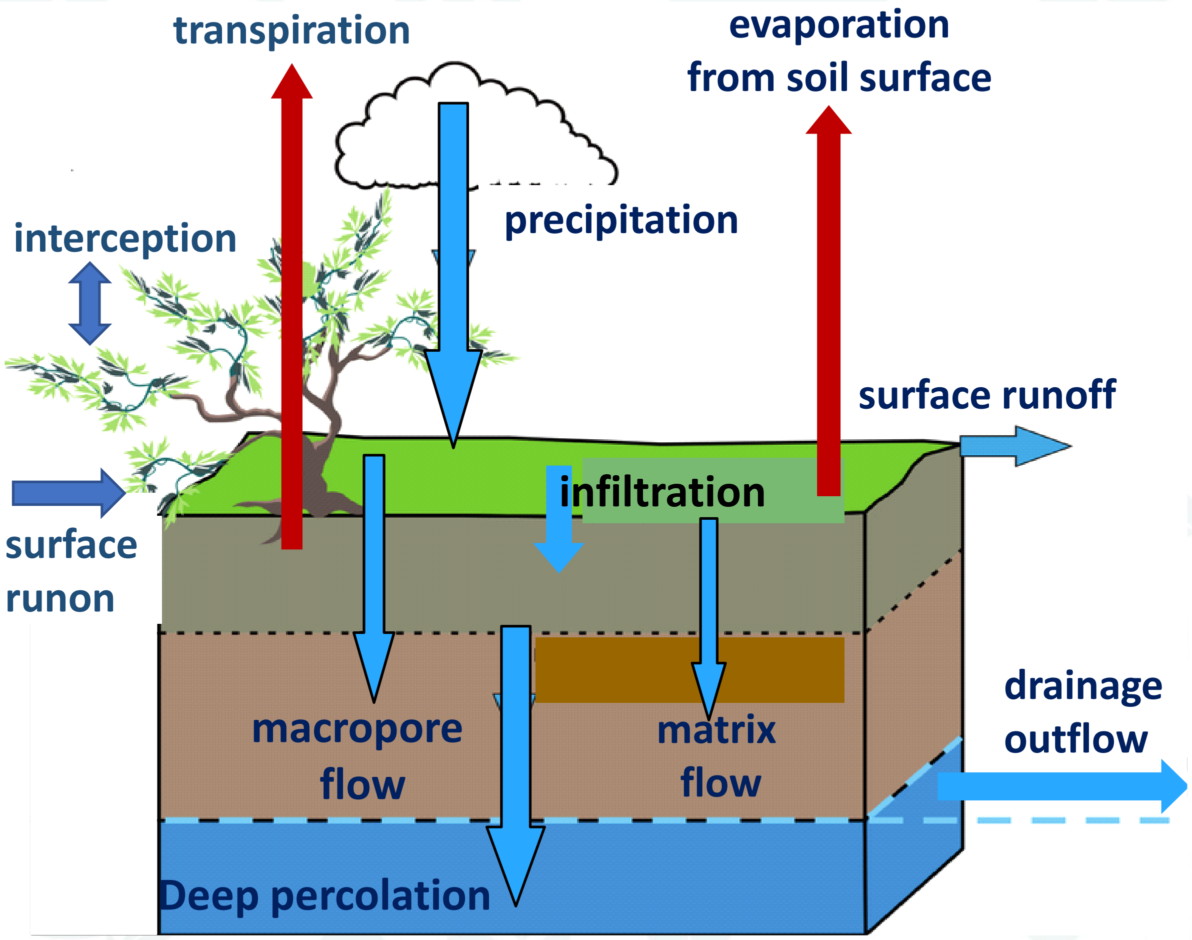
well-known by the Team
no experience

https://nc.ufz.de/apps/onlyoffice/s/KA9Cr2bbtALGMHr?fileId=123941147

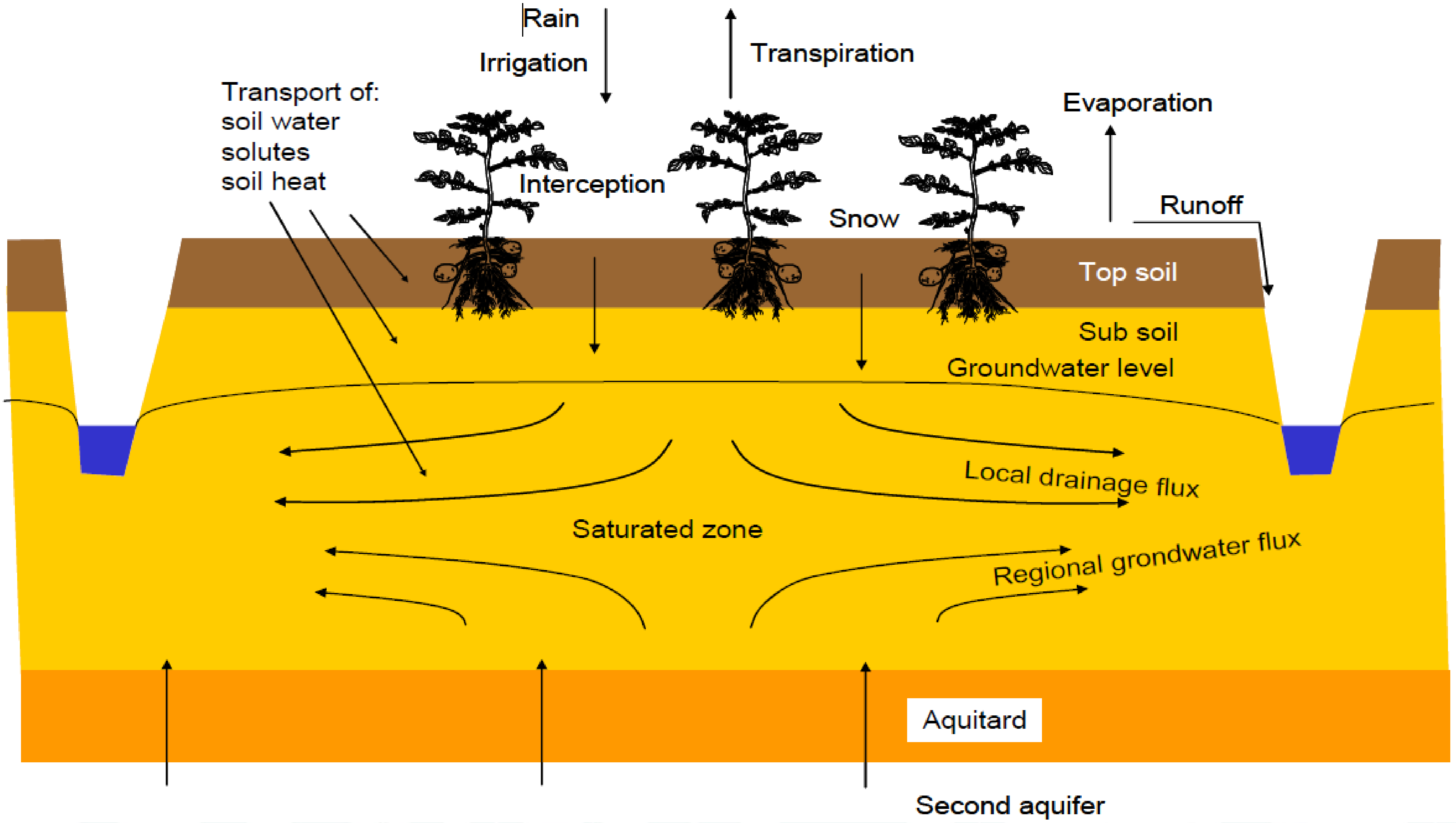
OPTAIN

The SWAP soil hydrological model



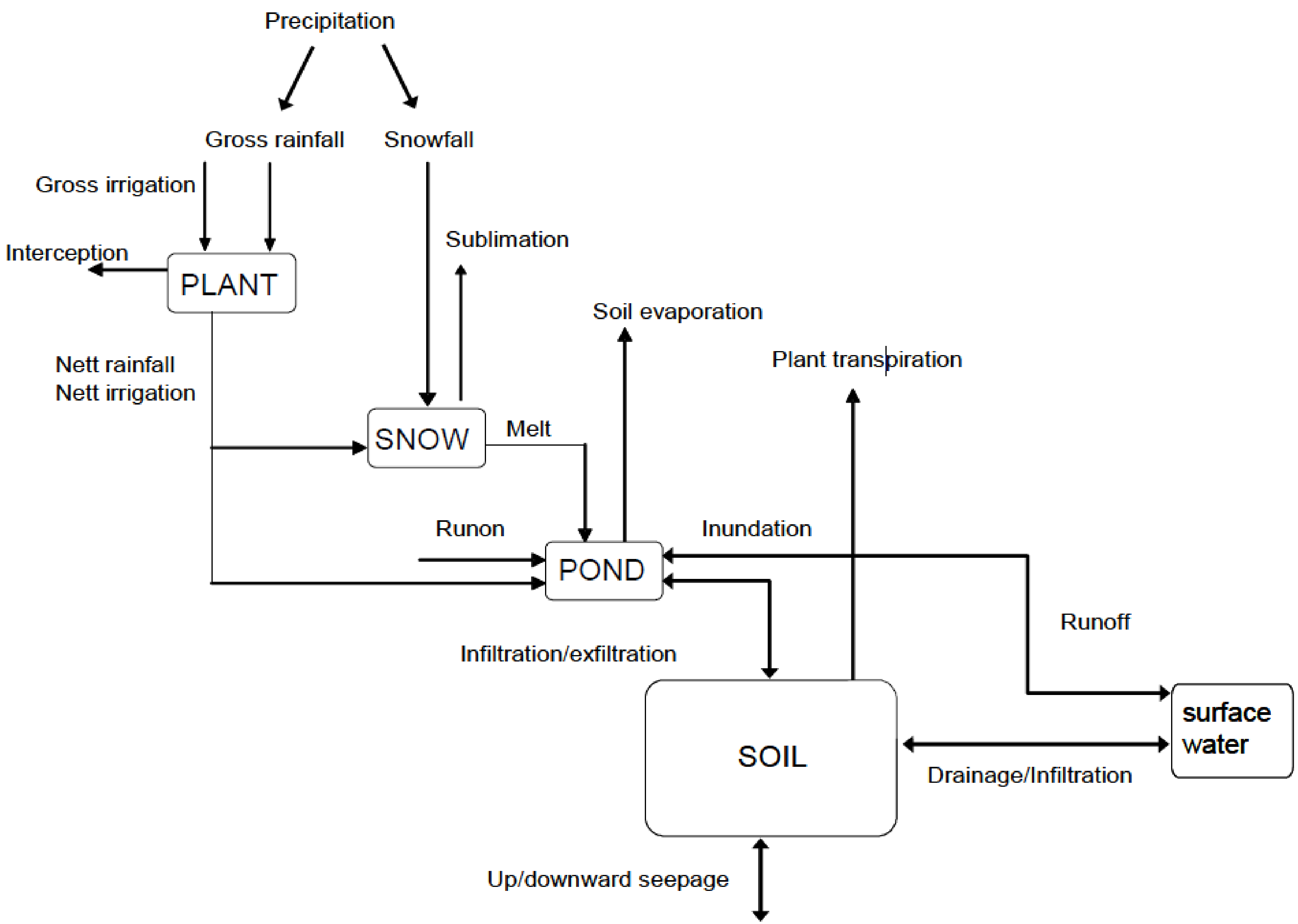


The SWAP model domain and processes



OPTAIN

The SWAP - water fluxes between the domains



The heart of the model – the Richard's equation

Darcy's law

$$q = -K(h)\frac{\partial(h+z)}{\partial z}$$

Continuity equation

$$\frac{\partial\theta}{\partial t} = -\frac{\partial q}{\partial z}$$

$$\frac{\partial\theta}{\partial t} = \frac{\partial\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]}{\partial z} \underbrace{- S_a(h) - S_d(h) - S_m(h)}_{\text{sink terms}}$$

Richard's equation (continued)

q - soil water flux density (cm d^{-1})

K(h) - hydraulic conductivity (cm d^{-1})

h - soil water pressure head (cm)

z - vertical coordinate (cm)

θ - volumetric water content (cm^3 cm^{-3})

t - time (d)

q and z are taken positive upward

Sink terms

S_a(h) - extraction rate by plant roots (cm^3 cm^{-3} d^{-1})

S_d(h) - extraction rate by drain (d^{-1})

S_m(h) - extraction rate by macro pores (d^{-1})

Solving the Richard's equation

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

Relationship between Θ, h and K

Θ - soil water content ($cm^3\ cm^{-3}$)

h - soil water pressure head (cm)

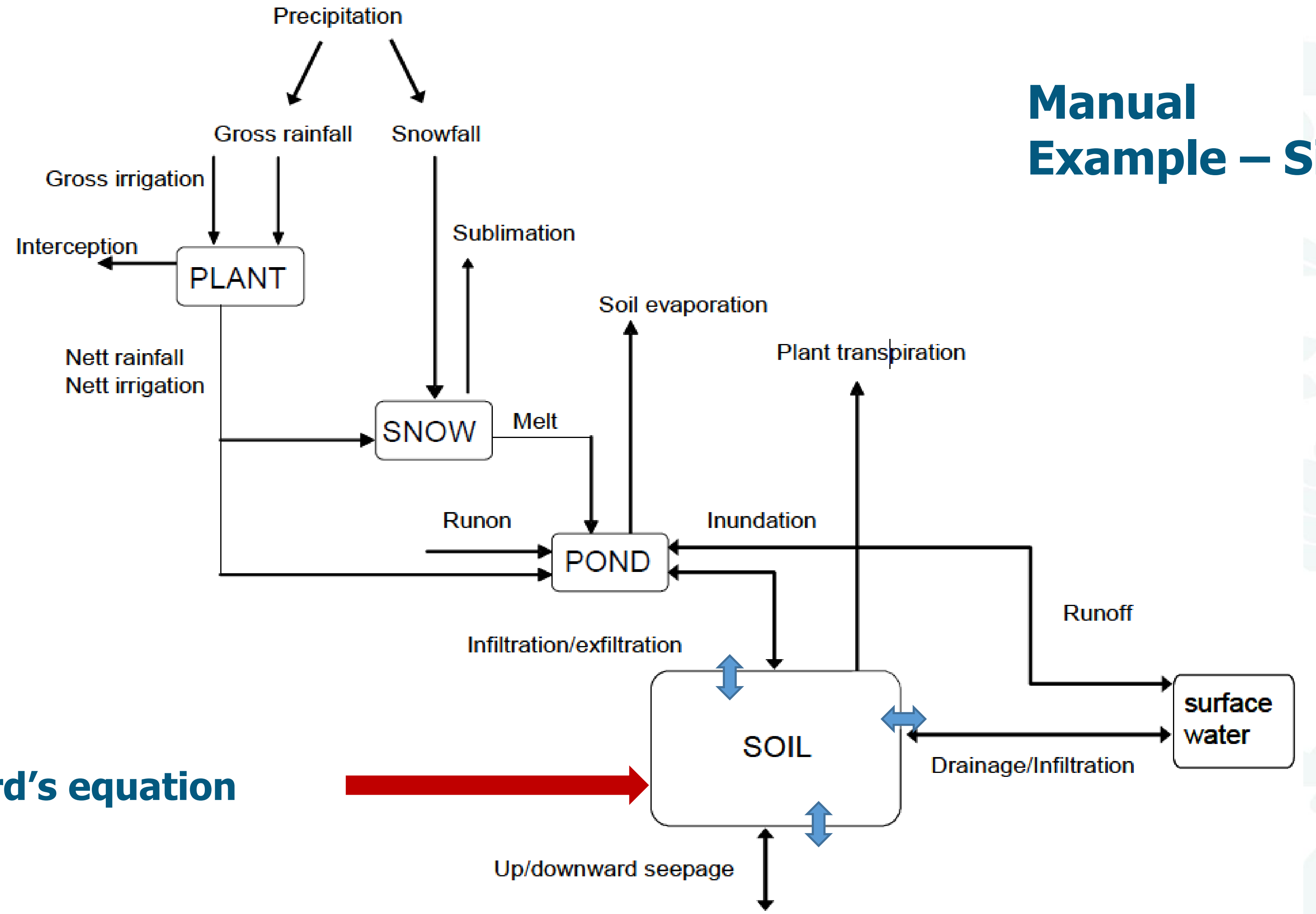
K - hydraulic conductivity ($cm\ d^{-1}$)

Soil hydraulic functions

- Soil water retention curve **Θ = f(h)**
- Soil hydraulic conductivity function

Θ = f(K) or **h = f(K)**

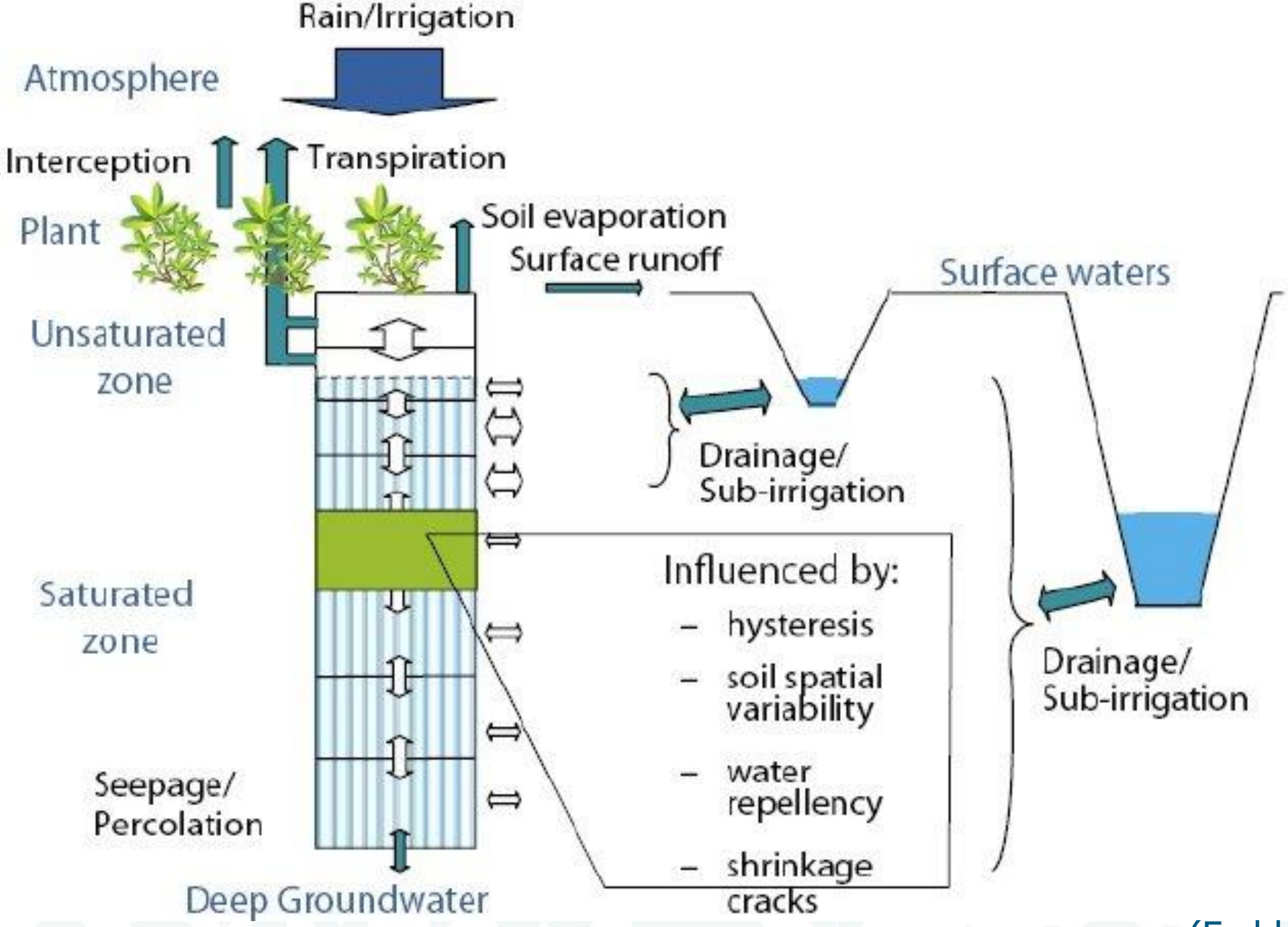
The SWAP - water fluxes between the domains



Manual
Example – Sinja

Richard's equation

SWAP-MODEL FOR MOVEMENT OF WATER, HEAT AND SOLUTES



(Feddes, 2007)

The OPTAIN SWAP Workshop

- Short introduction to hydrological modelling
- Short introduction of the SWAP model structure and theory
- Input and reference data requirement
- Tools for constructing met input data
- Processes, switches and parameters
- Reference data quality check
- Soft calibration tool
- Autocalibration tool

GOAL

- to have a finished project for each site
- gain knowledge and get tools for further soft- and hard calibration of the SWAP model

Thank you for your attention!

csilla.farkas@nibio.no

@H2020_OPTAIN

@H2020OPTAIN

WWW.OPTAIN.EU

OPTAIN