Potsdam Institute for Climate Impact Research

Eco-hydrological modeling

Fred F. Hattermann

Leibniz Association

Types of hydrological models

1 Physical representation of processes

Physically-based

- Processes based on physical equations, high data and computation demand
- Grid

Process-oriented

- Processes based on physical and empirical equations, medium data and computation demand
- HRUs (hydrological response units)

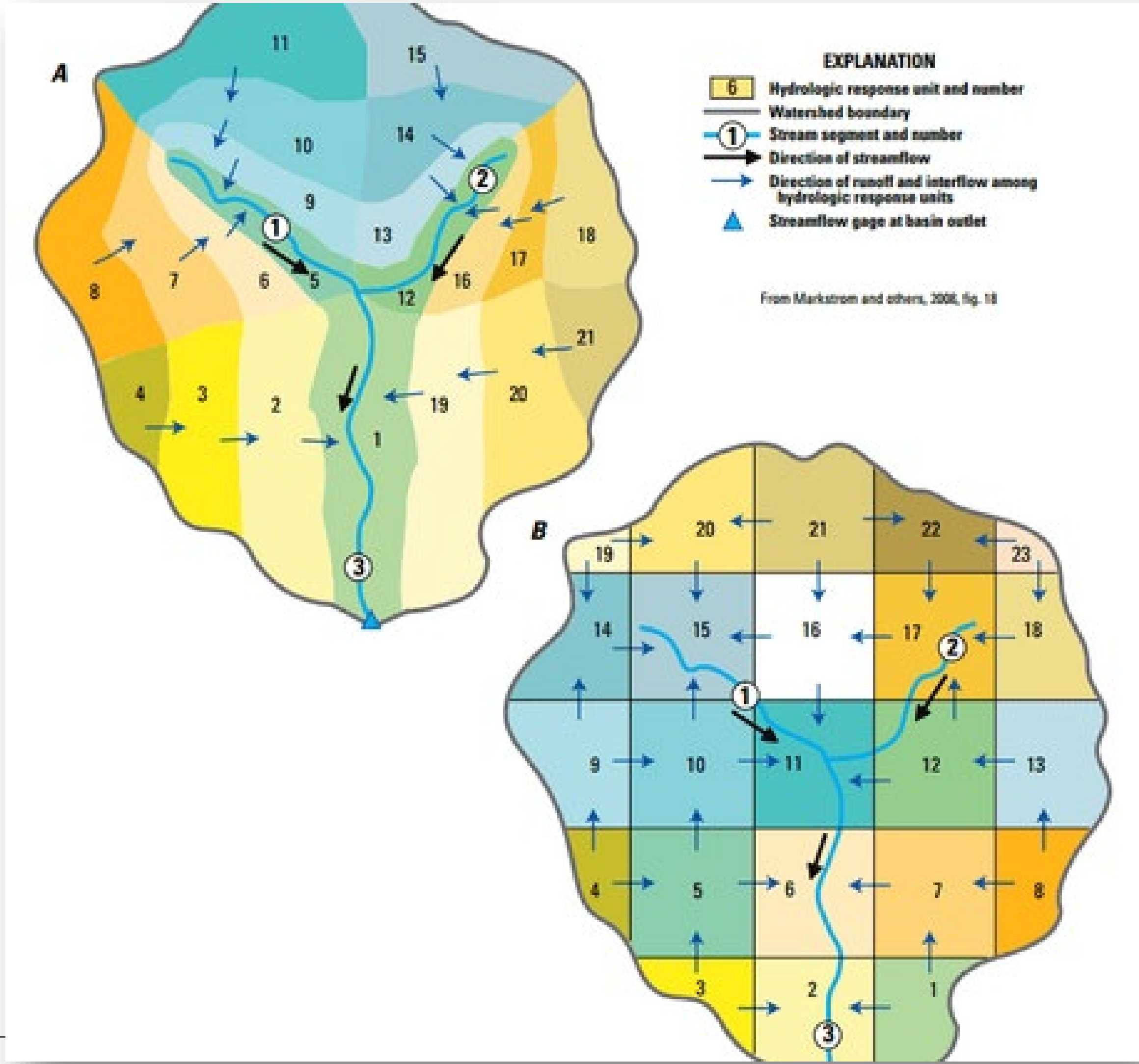
Empirical-statistical models

- Based on empirical equations
- Lumped

Types of hydrological models

1 Spatial disaggregation

Hydrological response units



Grid cells

Potsdam Institute for Climate Impact Research

PIK

SWIM

Soil and Water Integrated Model

Introduction

Model structure

Stefan Liersch

2021

Leibniz Association

SWIM

Soil and **W**ater **I**ntegrated **M**odel

Eco-hydrological model designed to

- Simulate processes at the catchment scale
- Simulation of water and nutrient fluxes
- Assess the impacts of
  - Climate change
  - Changed water resources management

Continuous development (5-10 developers)

- Adapted to new requirements
- Major developments over recent years to address water resources management (reservoirs, irrigation, water allocation...)

Modelling approach

Catchment-scale eco-hydrological model

Process-based

- Physical equations: evapotranspiration, percolation...
- Empirical approaches: curve number-based infiltration...
- Daily time step

Spatially semi-distributed

- Hydrological Response Units (HRUs)
- HRUs are laterally not connected

Mesoscale applications (>1000 km²)

SWIM Soil and Water Integrated Model

based on

SWAT Soil & Water Assessment Tool

Version 1993

&

MATSALU

Eco-hydrological model

Natural processes

Weather / climate (input)

- Precipitation (rain & snow)
- Temperature, solar radiation, rel. humidity

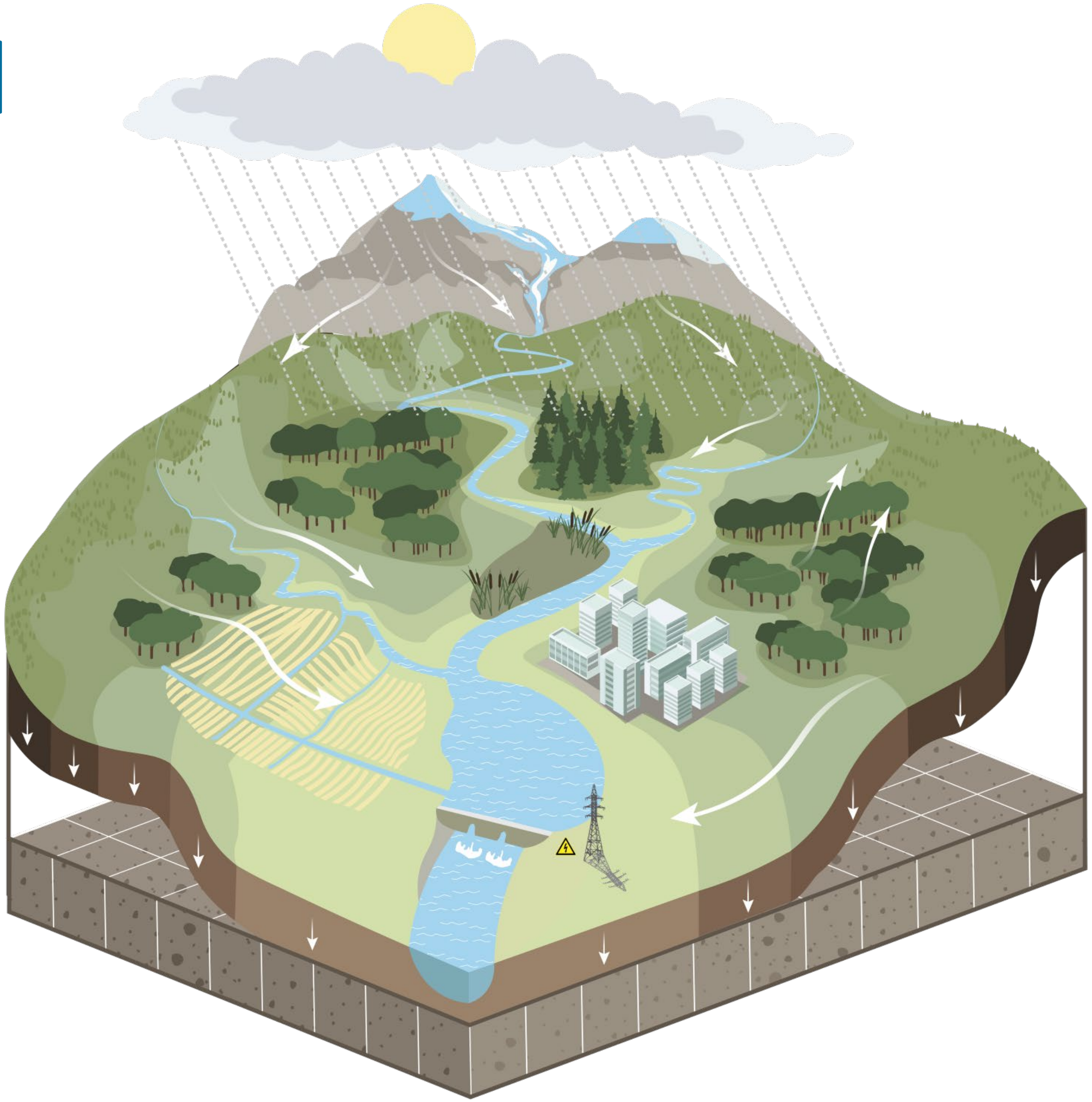
Hydrology

- Infiltration
- Runoff: surface, sub-surface, groundwater
- River discharge
- Evapotranspiration

Vegetation

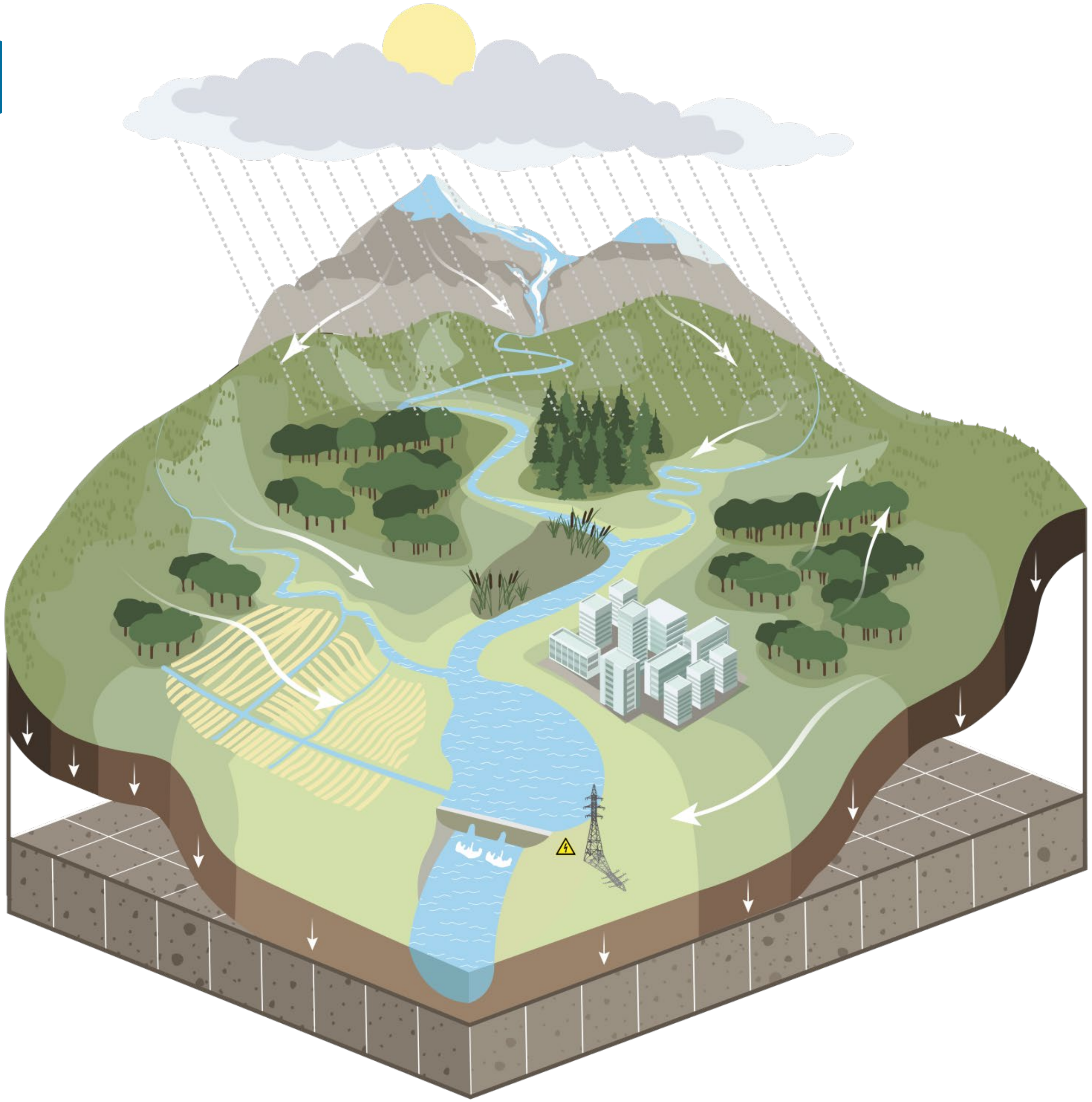
- Natural: forests, grasslands, savannah...
- Managed crops

Glaciers



Eco-hydrological model

Water and land management



Crop management

- Crop rotations
- Fertilization

Irrigation

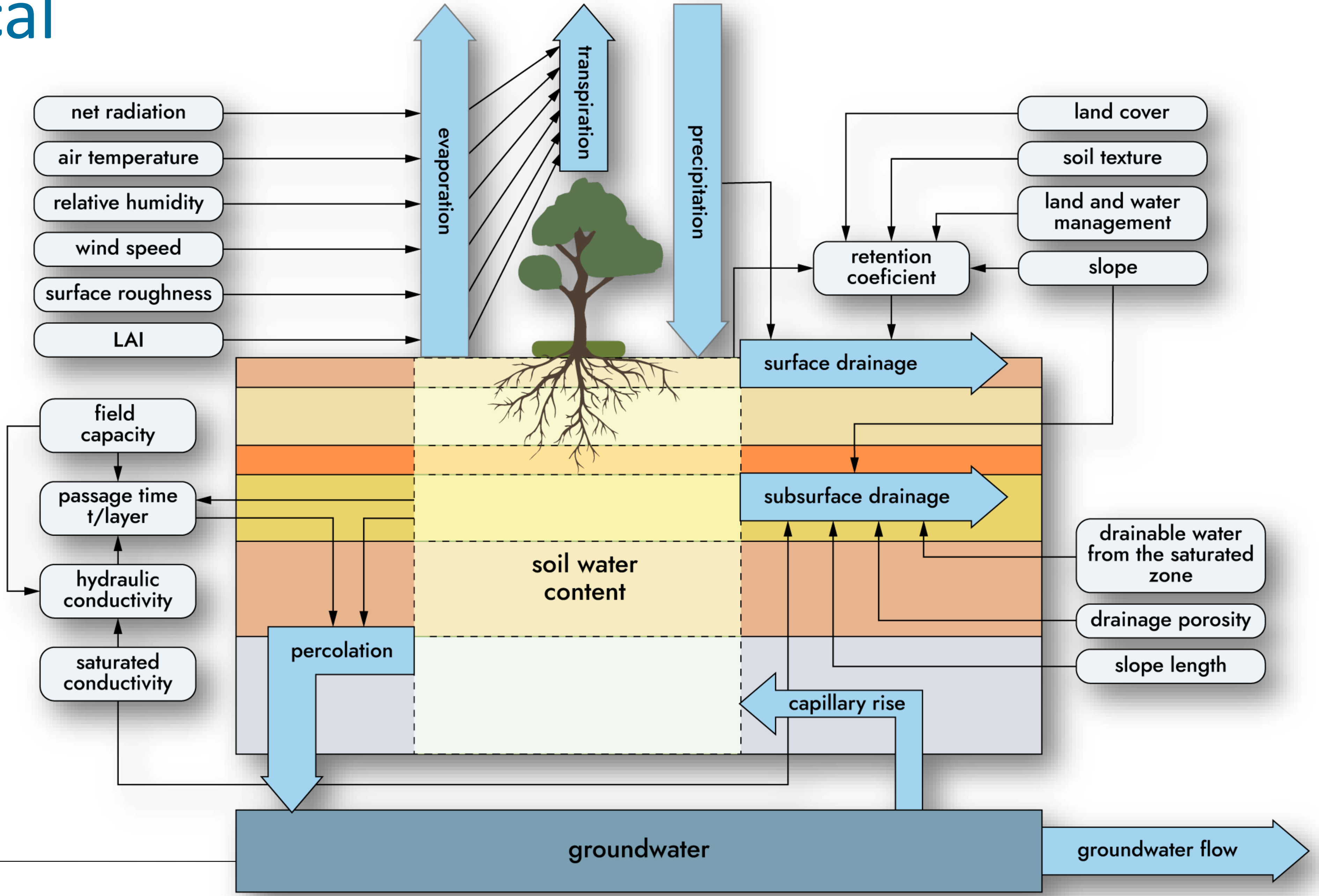
- Crop water demand / deficits
- Water use efficiency

Water allocation

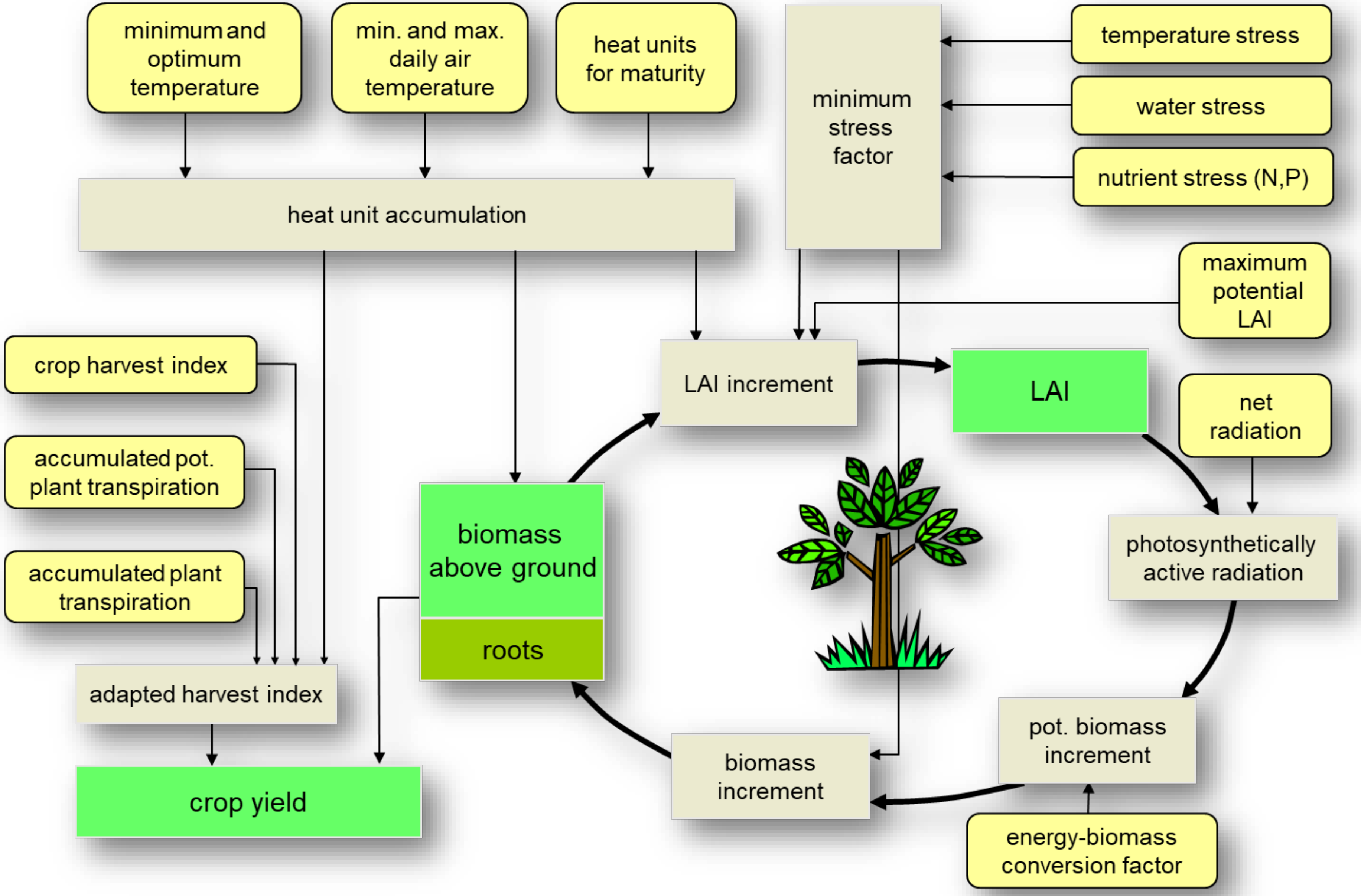
Reservoirs

- Hydropower
- Flood protection
- Water supply

Hydrological processes



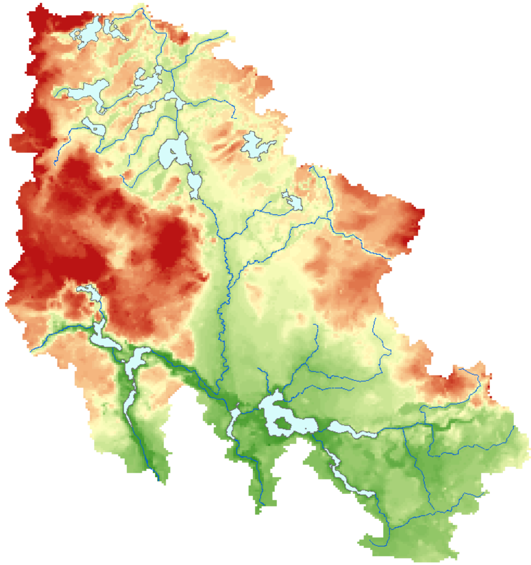
Plant processes

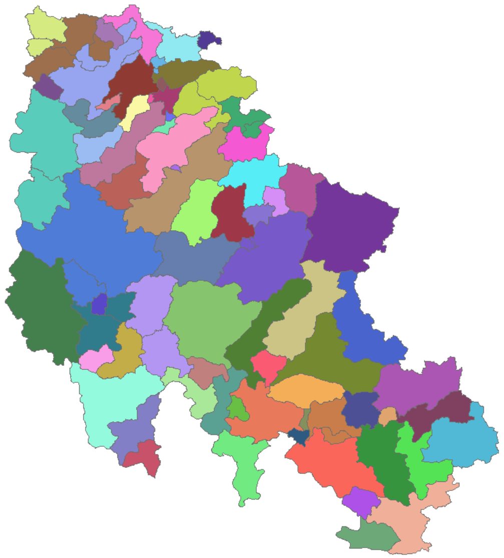


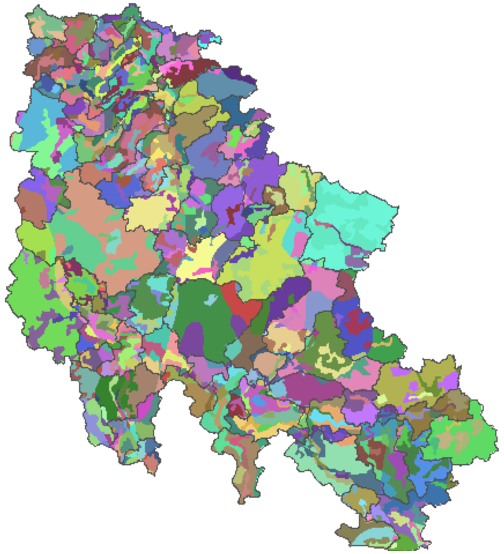
Spatial disaggregation in SWIM

3 levels

Basin → **Sub-basins/** → **Hydrotopes** **(HRUs)**







Routing in river (water, N, P, sediments) ← Aggregation of lateral flows ← Water, N, P cycles vegetation growth

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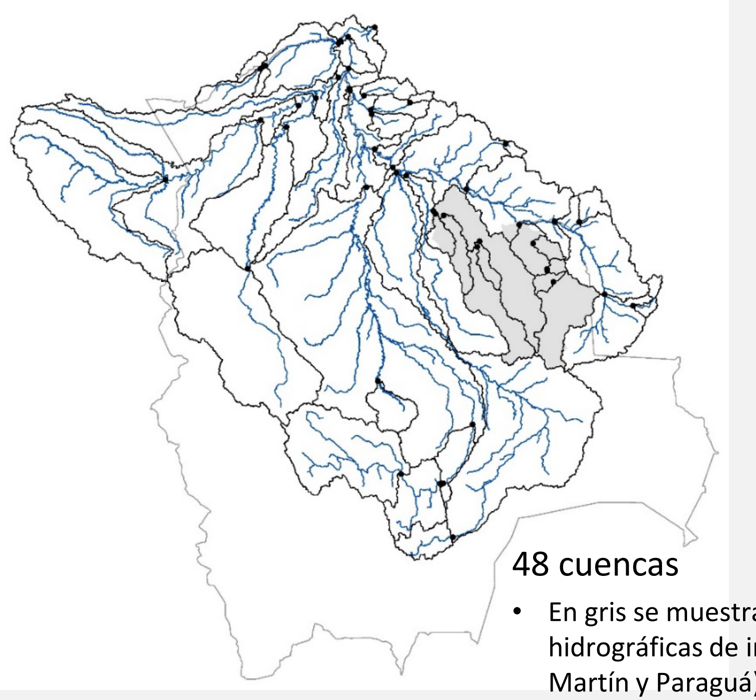
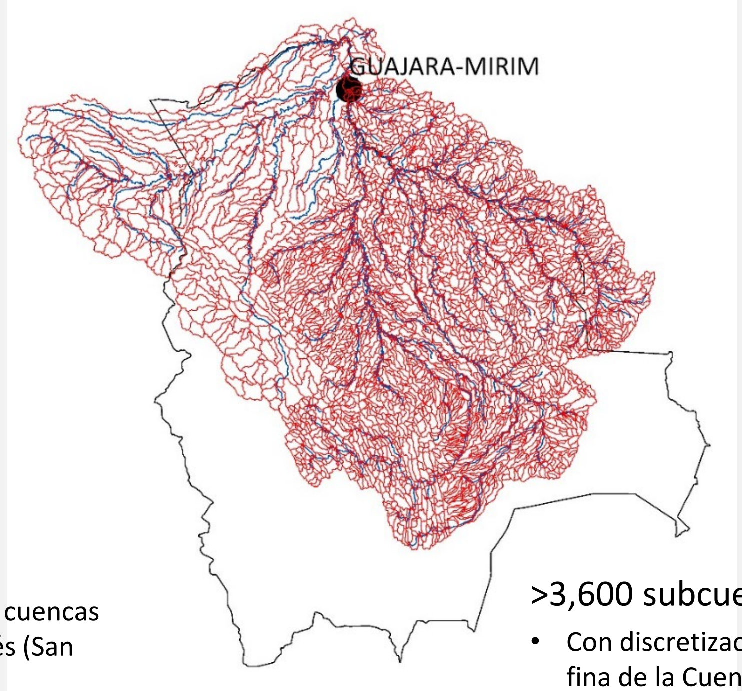
SWIM - desagregación espacial (ejemplo de la cuenca del Amazonas boliviano)

Escala de cuenca → Escala de subcuencas → Escala de hidrotopos



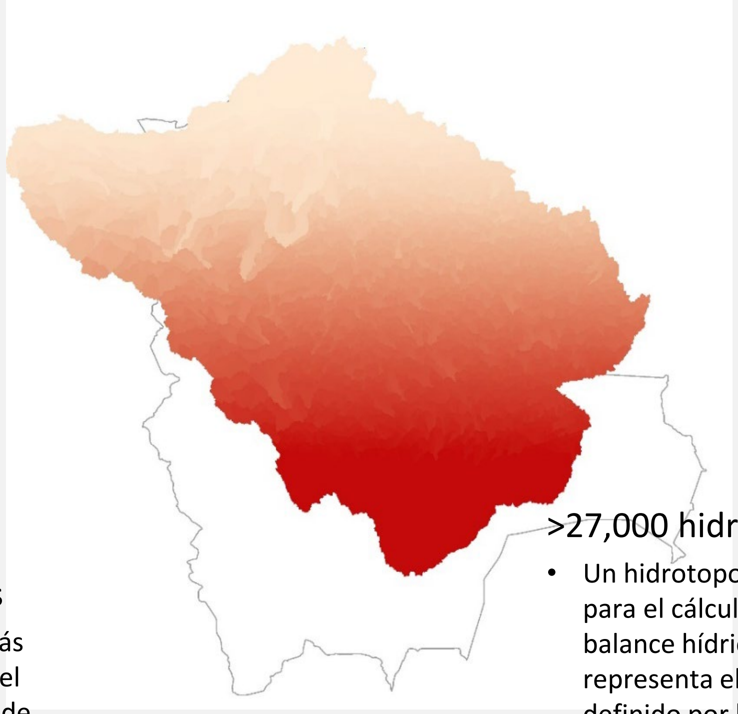
48 cuencas

- En gris se muestra las cuencas hidrográficas de interés (San Martín y Paraguá).
- Las estaciones de aforo en las regiones de estudio son hipotéticas



>3,600 subcuencas

- Con discretización más fina de la Cuenca en el área de aguas arriba de la estación hidrológica de Guajara-Mirim



>27,000 hidrotopos

- Un hidrotopo es la base para el cálculo del balance hídrico y representa el área definido por la combinación única de uso de suelo y tipo de suelo

Ciclo hidrológico, dinámica de la vegetación → Agregación de los componentes del balance hídrico → Enrutamiento de flujo en la red de drenaje

Spatial data

GIS layers

Elevation, slope (DEM)

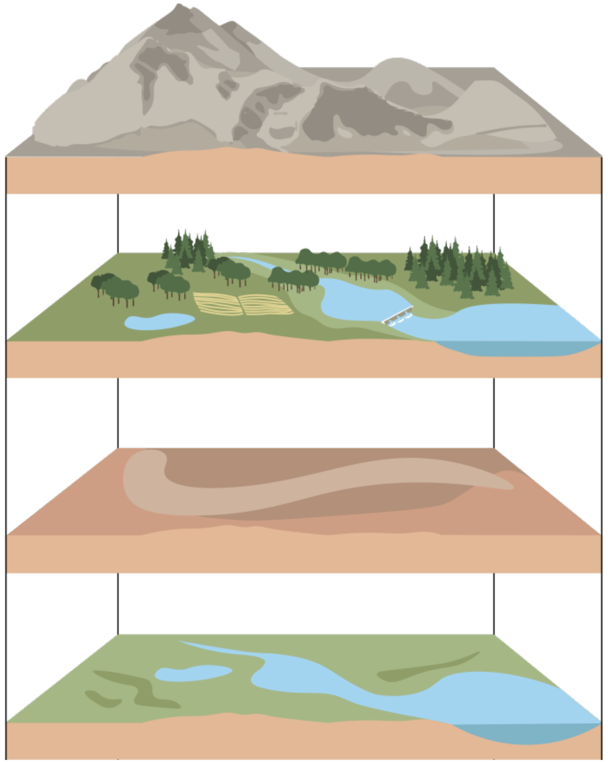
Land use / cover (LULC)

Natural, managed

Soils

Other

Reservoirs, irrigation, wetlands, glaciers, elevation

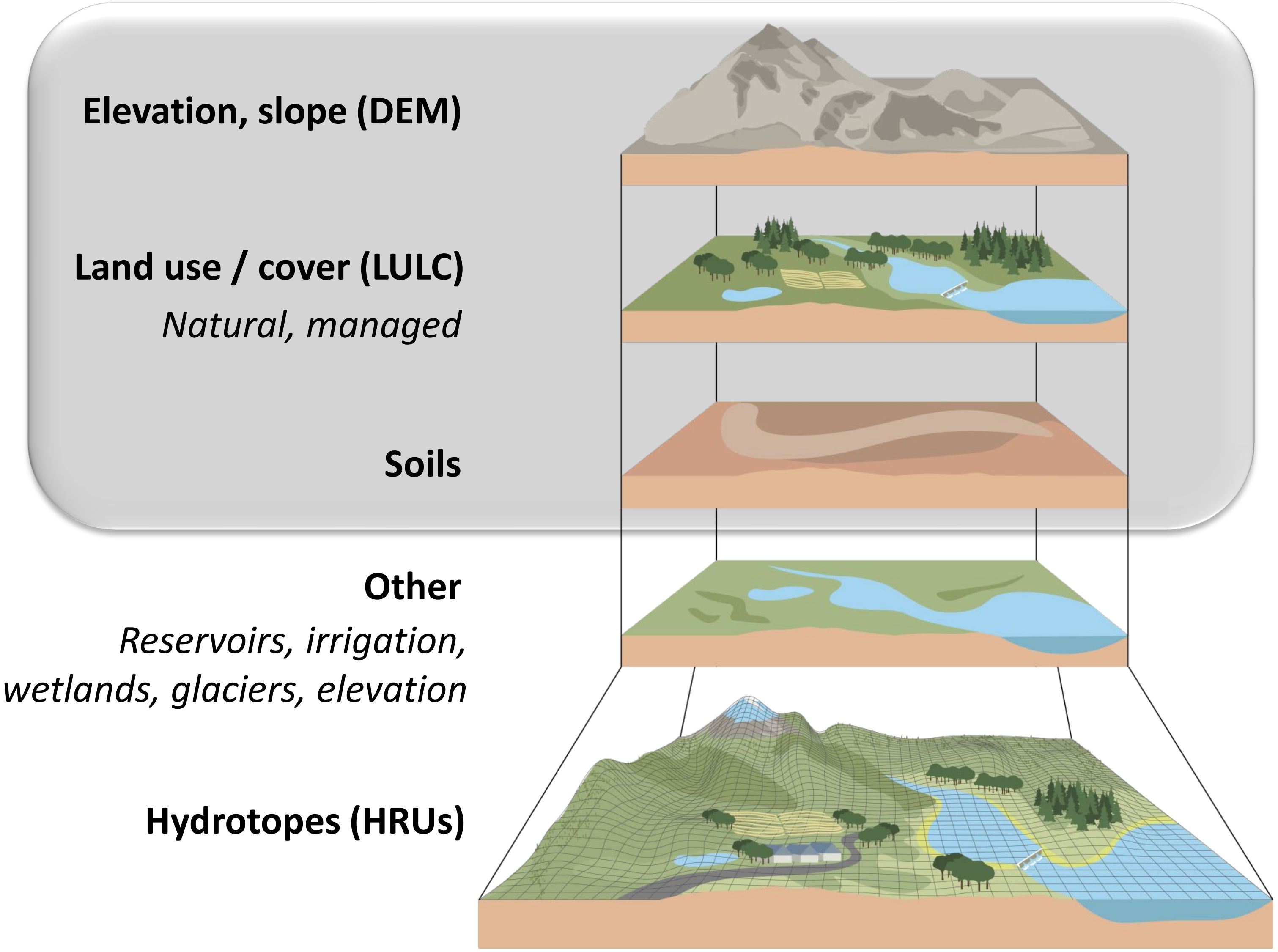


Spatial data

Basic GIS layers

Overlay in GIS

- HRUs
  Hydrological Response Units
- SWIM input file: ***.str**



Spatial data

Optional GIS layers

Overlay in GIS

- HRUs
  Hydrological Response Units
- SWIM input file: ***.str**

Optional layers

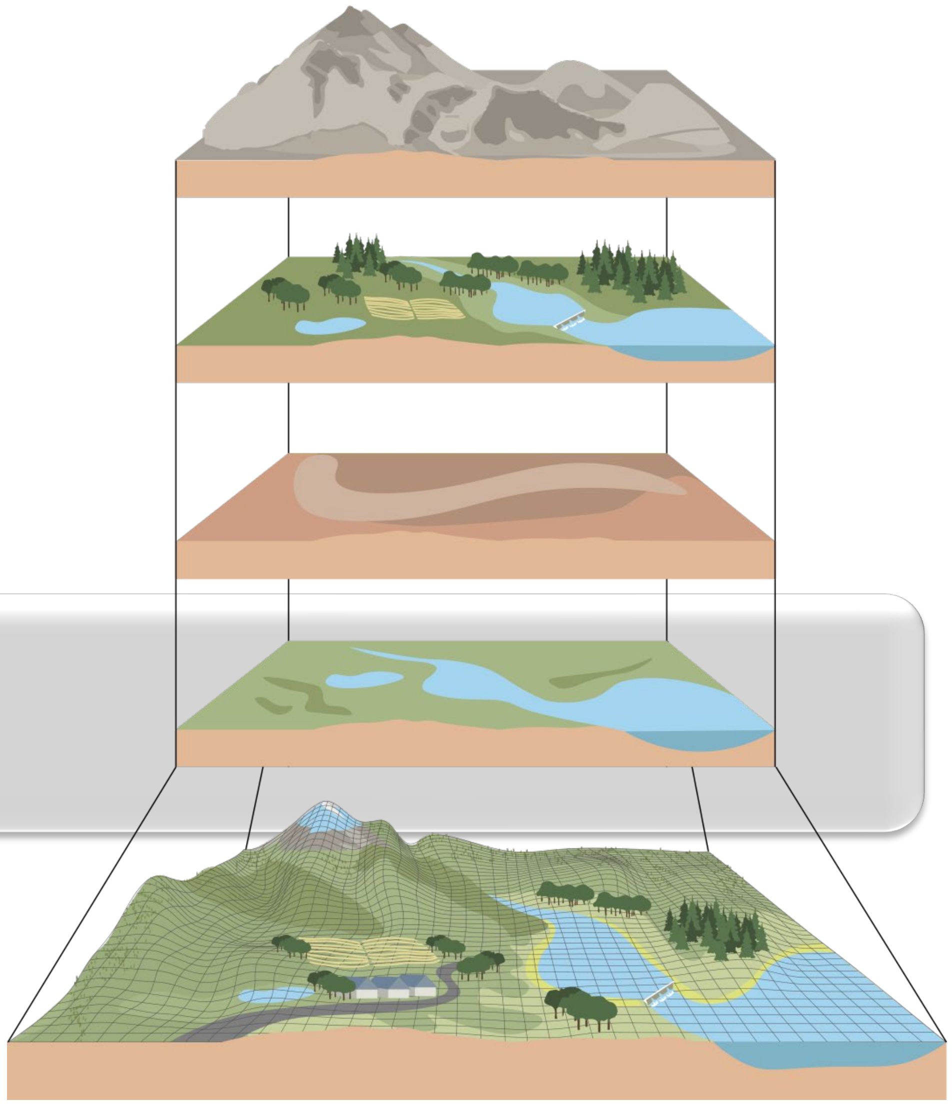
Elevation, slope (DEM)

Land use / cover (LULC)
Natural, managed

Soils

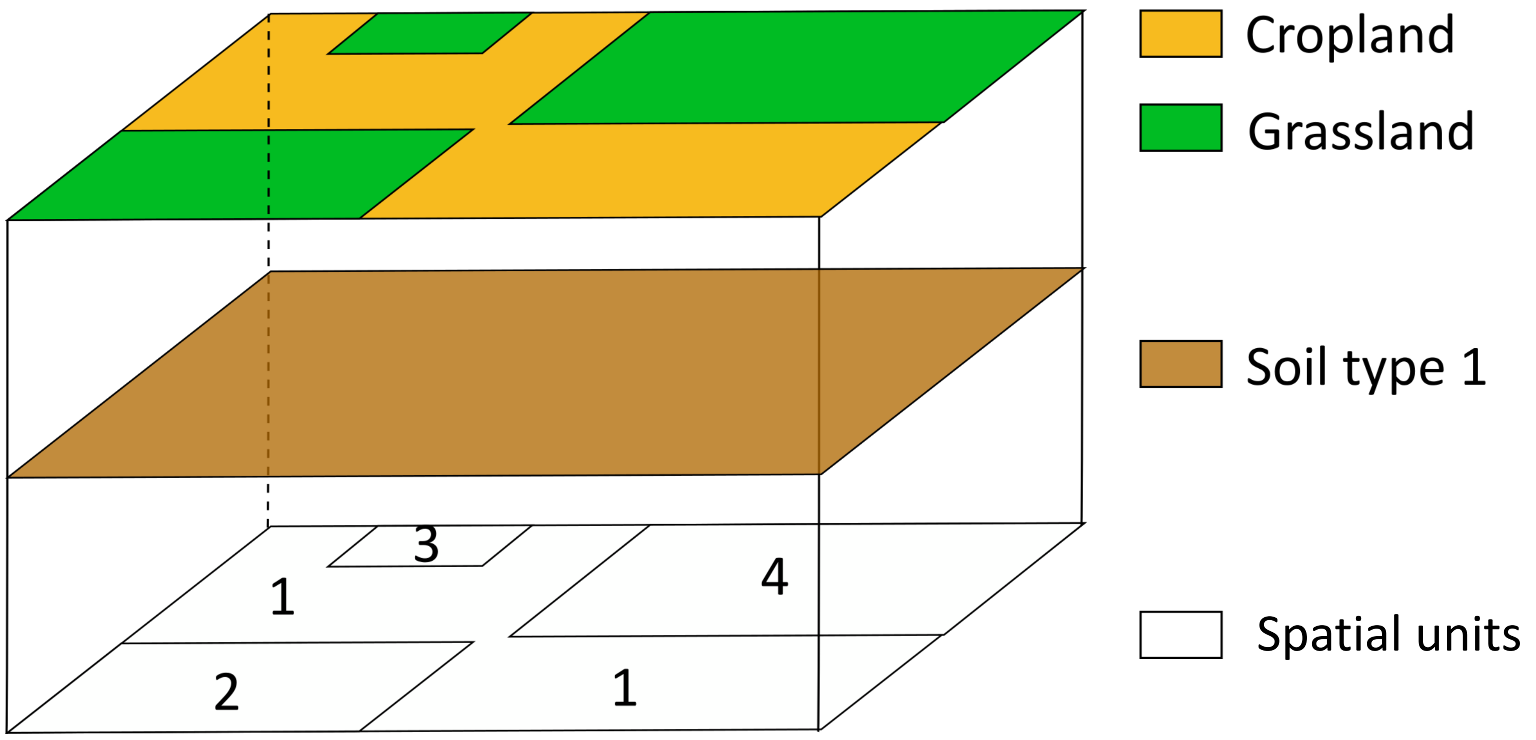
Other
Reservoirs, irrigation, wetlands, glaciers, elevation

Hydrotopes (HRUs)



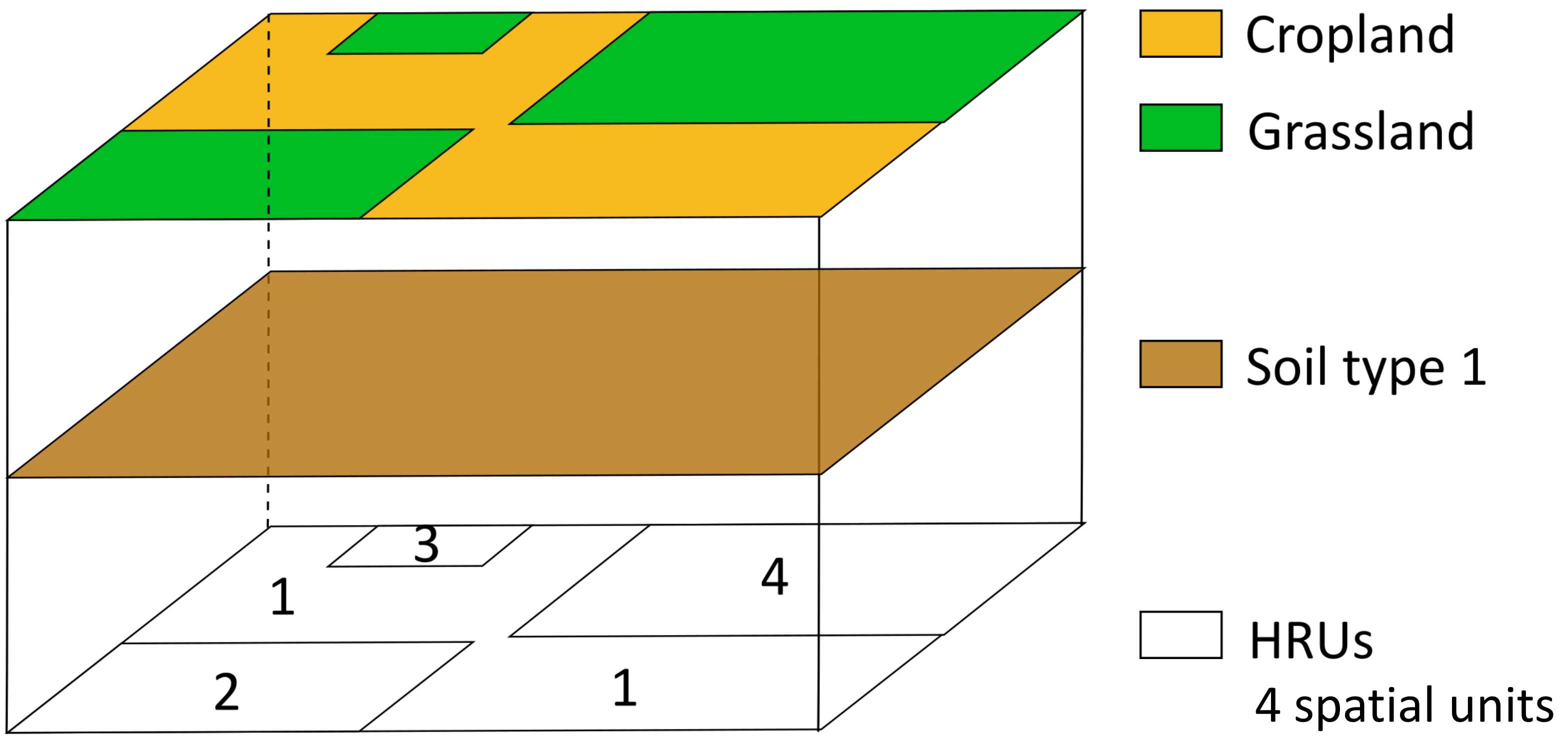
HRU

Hydrolocigal Response Unit



HRU

Hydrolocigal Response Unit

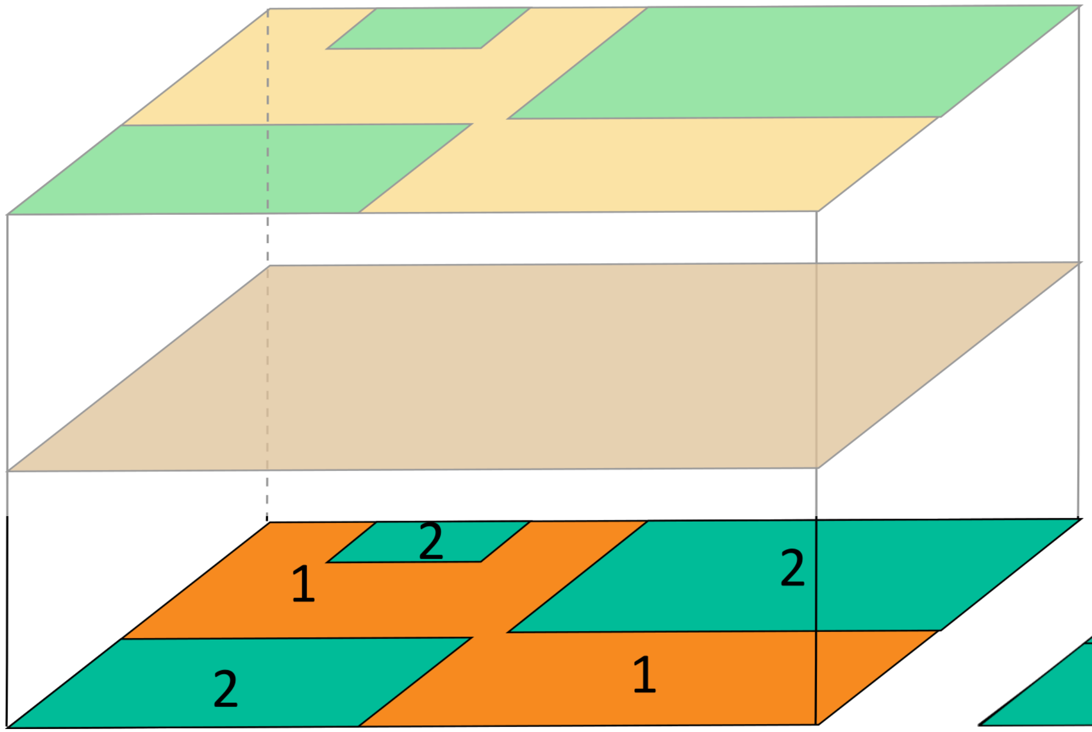


4 lines in ***.str** file

SUB	LU	SOIL	...	AREA
1	5	1		40000
1	8	1		10000
1	8	1		22000
1	8	1		28000

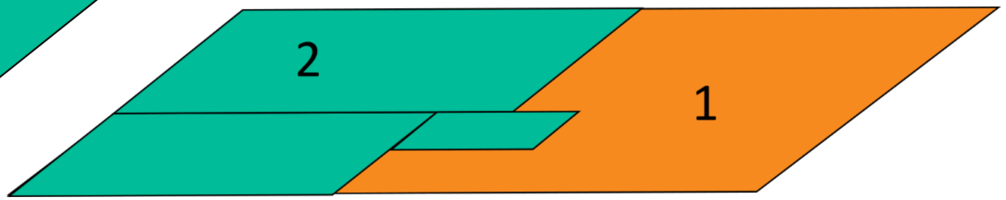
HRU, Lumping units with same properties

Computationally efficient



2 lines in ***.str** file

SUB	LU	SOIL	...	AREA
1	5	1		40000
1	8	1		60000



Spatial units lumped together
HRU 1 = 40% of sub-basin area
HRU 2 = 60% of sub-basin area

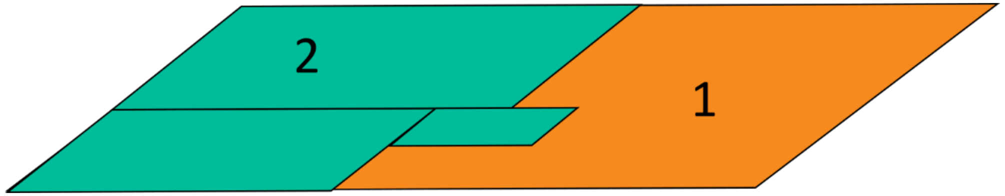
HRU

Hydrolocigal Response Unit

Smallest unit / entity within a sub-basin

Lumped product

- Laterally not connected
- Area-weighted products...
- Routing at the sub-basin level



$$\mathbf{Q_{sub}} = Q_{HRU1} * 0.4 + Q_{HRU2} * 0.6$$

0.4 and 0.6 = fraction of HRU area in sub-basin

The model itself

Is simply a...

Data processor

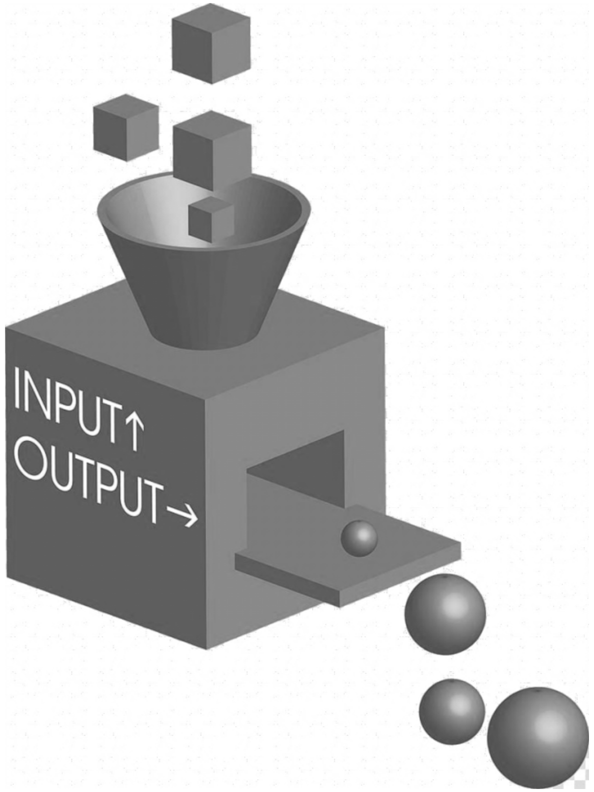
- Reading input → producing output

Input

- ASCII text files (readible / editable in a text editor)
- Produced during GIS (and other) pre-processing
- Representing spatio-temporal data

Output

- ASCII text files (readible / editable in a text editor)
- Time series
- GIS reclassification files at HRU level

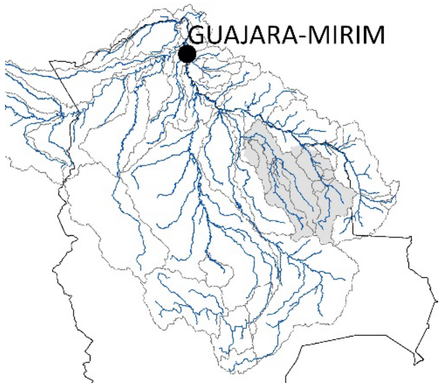


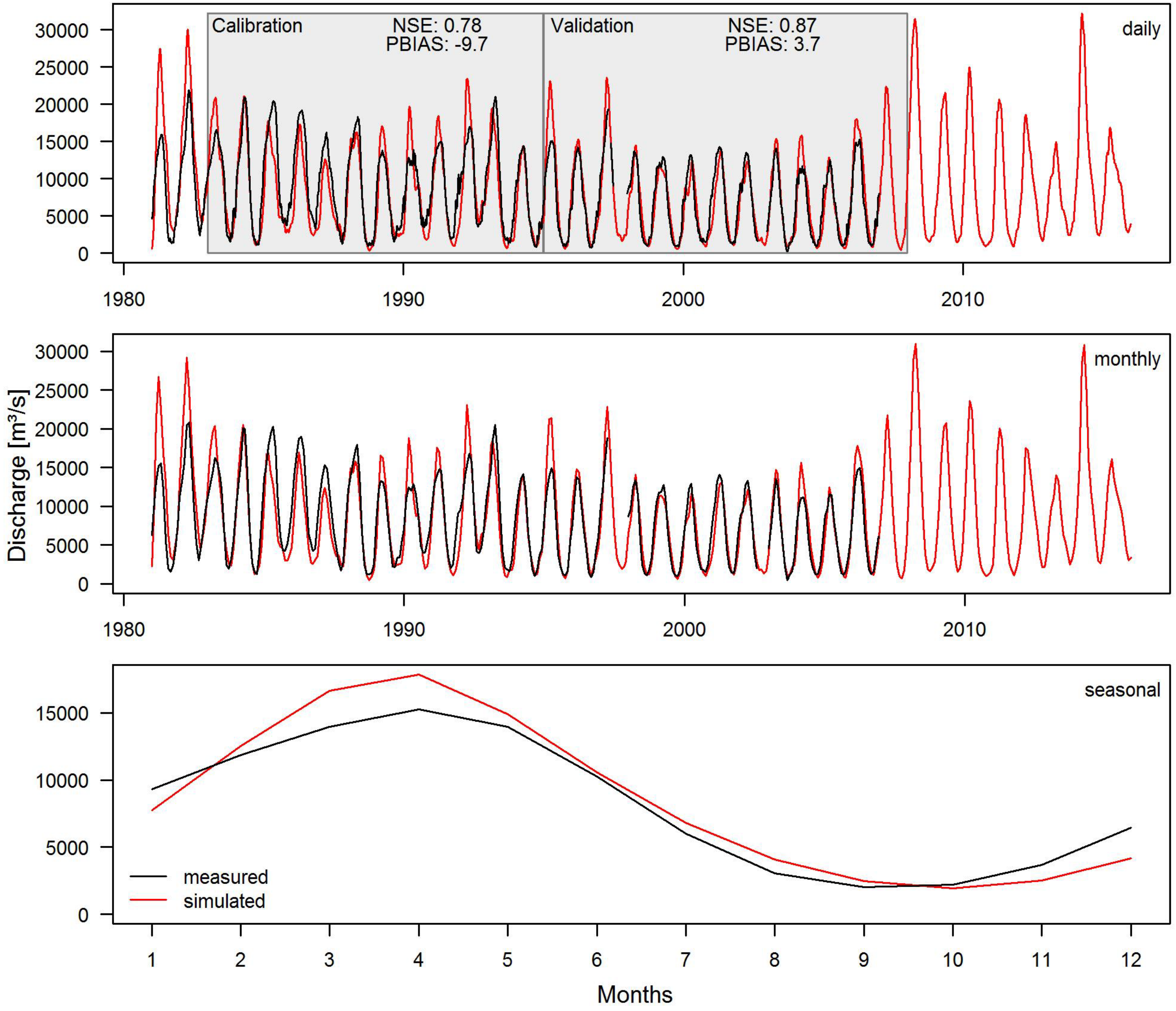
https://p7.hiclipart.com/

Discharge, observed vs. simulated

Guajara-Mirim

Average daily Q



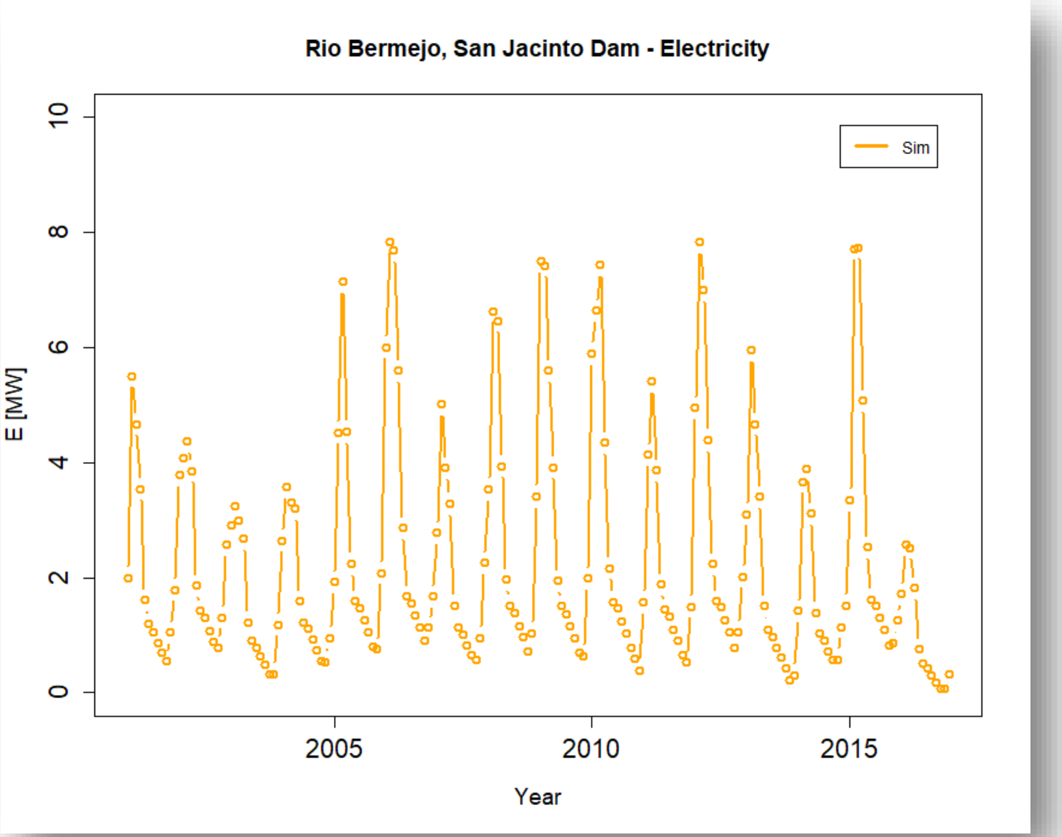


Hydropower potential

SSP126, ISIMIP3b, 8 GCMs

San Jacinto Dam

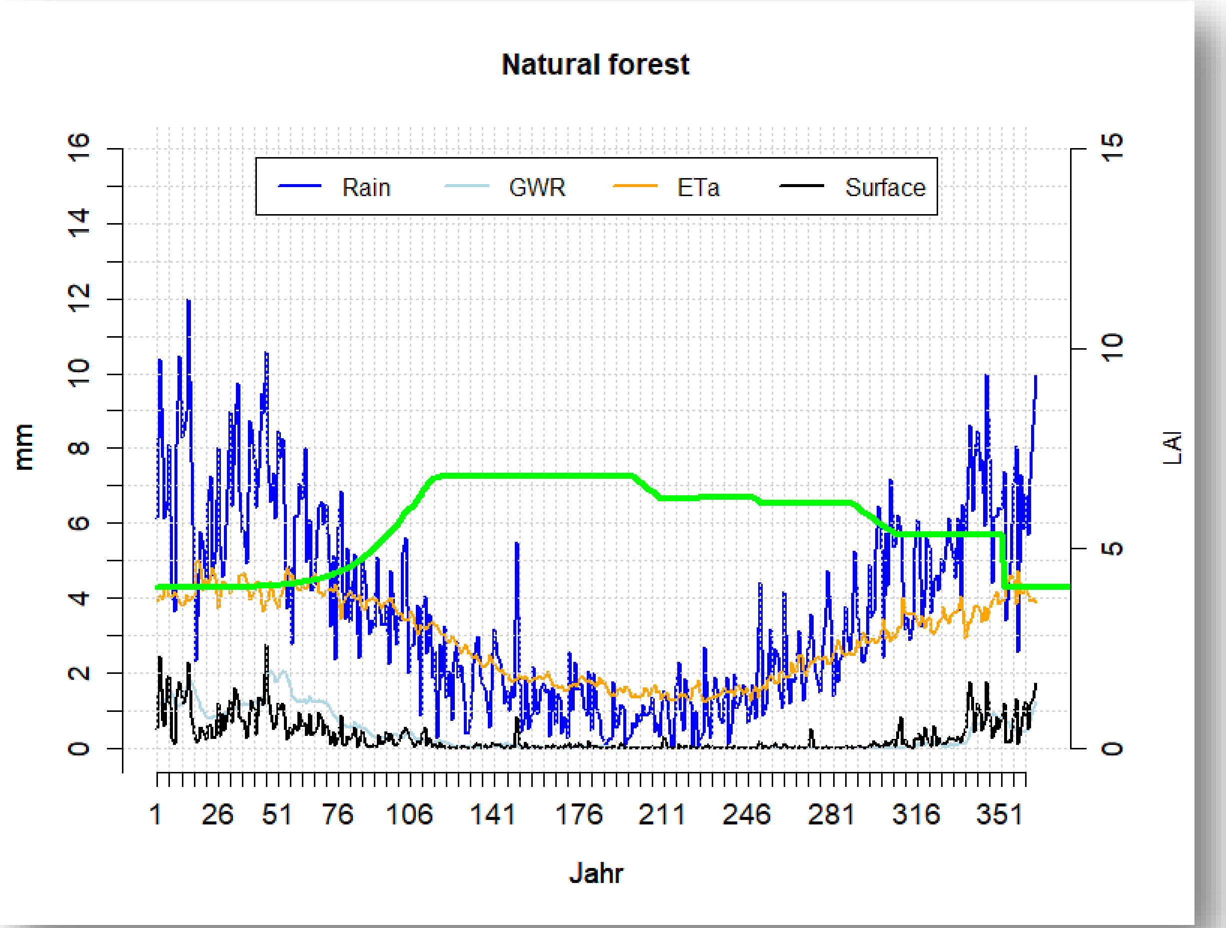
- Rio Bermejo
- Tarija



Some HRU output

Bagré irrigation site, WFDE5

- Precipitation
- Water stress
- Irrigation
- Leaf area index
- Percolation
- Biomass
- Root depth
- ...



Spatial output

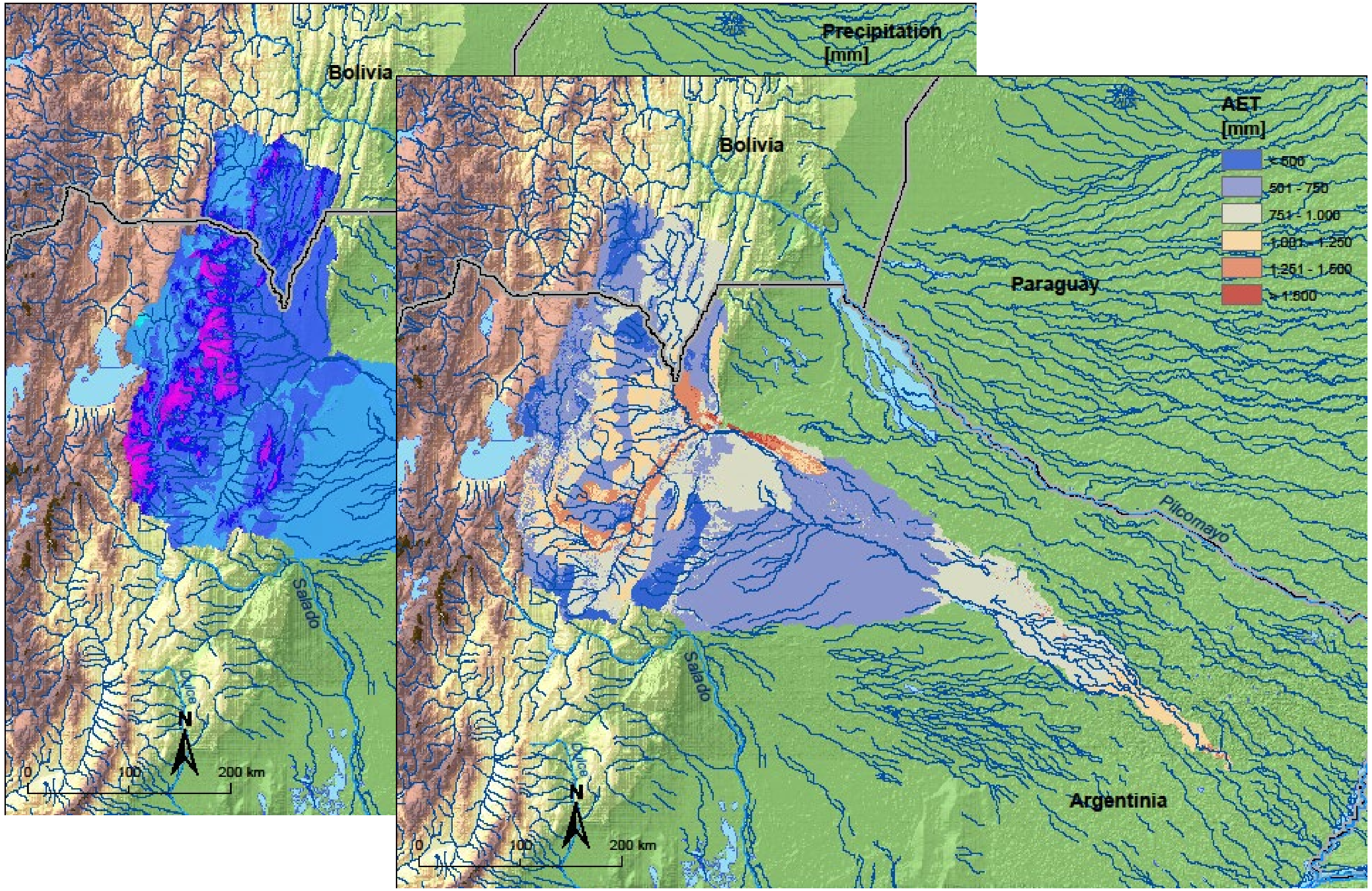
Tarija, ISIMIP3b

ETa change (example)

- Reference: 1984-2014

Spatial output

- Precipitation
- ETp, ETa
- Surface Q
- GW recharge
- Soil water index



SWIM code

Fortran programming language

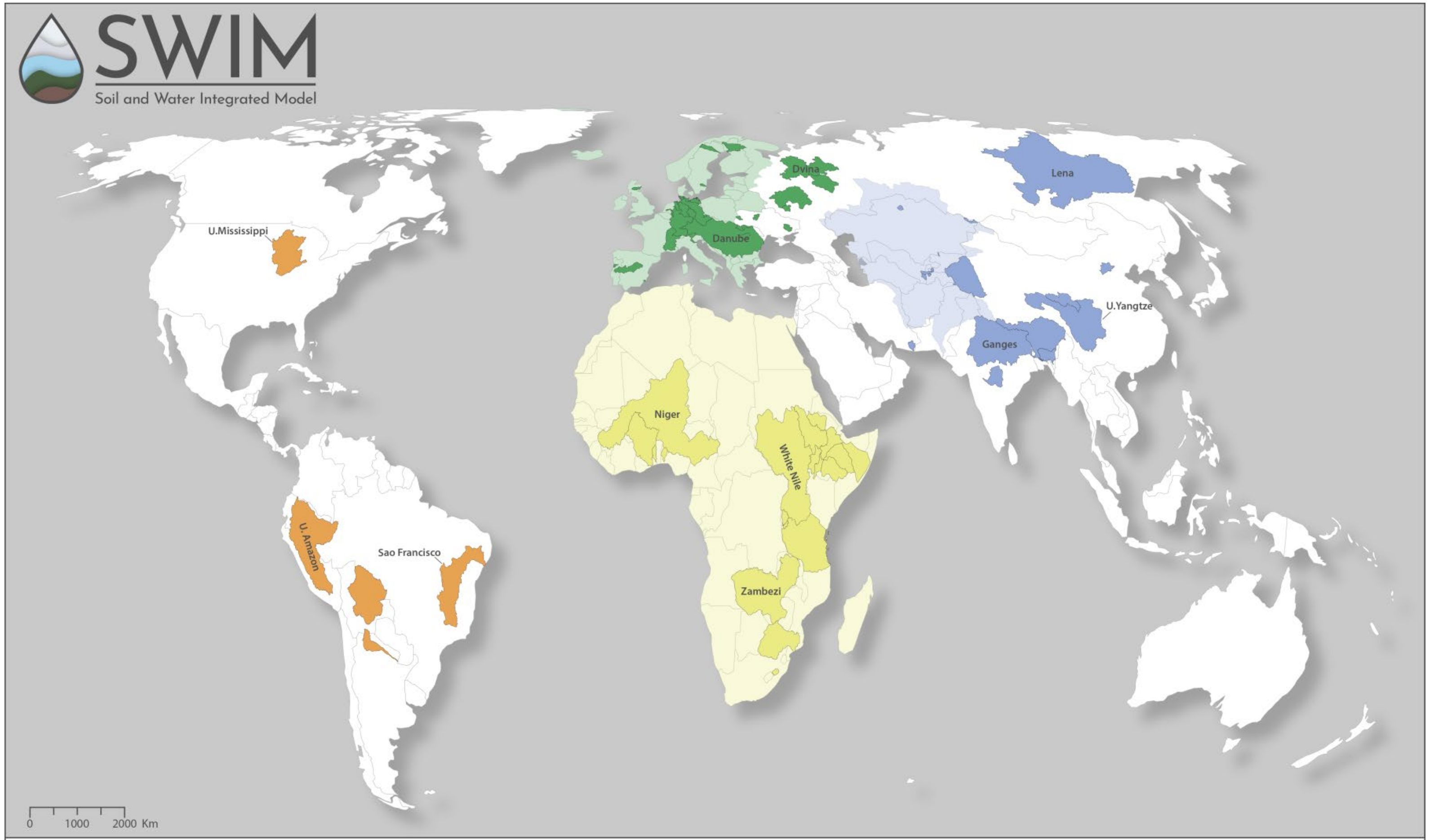
Redesign of SWIM code

- Conversion of the code into a modular struture (Fortran 90 / 95)
- Fully open source some time in 2022

Simulation (execution) time

- Mainly depending on number of HRUs
- Volta model (~9800 HRUs): 140 years ~3 hours or ~1 min / year

Worldwide applications



Europe

- 1.1. Tagus
- 1.2. Rhine
- 1.3. Lule
- 1.4. Rhine
- 1.5. Eman
- 1.6. Adige
- 1.7. Tay
- 1.8. Upper Tisza
- 1.9. Upper Prut
- 1.10. U. W. Bug
- 1.11. Samara
- 1.12. Teteriv
- 1.13. Danube
- 1.14. Dvina
- 1.15. Elbe
- 1.16. Weser
- 1.17. Oka
- 1.18. Rhone
- 1.19. Jizera
- 1.20. Saale
- 1.21. Tyligul
- 1.22. Vistula lag.
- 1.23. Mures
- 1.24. Warnow
- 1.25. Trave
- 1.26. Eider
- 1.27. Maas
- 1.28. Ems
- 1.29. Tagus
- 1.30. Sosna
- 1.31. Vyatka
- 1.32. Mar Menor
- 1.33. Ria de Aveiro

Africa

- 2.1. Blue Nile
- 2.2. Tanzania
- 2.3. Zambezi
- 2.4. Niger
- 2.5. Limpopo
- 2.6. White Nile
- 2.7. Mono
- 2.8. Volta
- 2.9. Awash
- 2.10. Omo
- 2.11. Shebelle
- 2.12. Sobat
- 2.13. Ogun
- 2.14. Genale
- 2.15. Thukela

America

- 3.1. U. Amazon
- 3.2. Sao Francisco
- 3.3. Mamore
- 3.4. Bermejo
- 3.5. U. Mississippi

Asia

- 4.1. Lena
- 4.2. U. Yangtze
- 4.3. Ganges
- 4.4. U. Yellow
- 4.5. Aspara
- 4.6. Isfara
- 4.7. Guanting
- 4.8. Upper Tarim
- 4.9. Tailan
- 4.10. Aksu
- 4.11. Yarkan
- 4.12. Hotan
- 4.13. Jinhe
- 4.14. Zerafshan
- 4.15. Tupalanga
- 4.16. Zhabay
- 4.17. Kafirnigan
- 4.18. Murgab
- 4.19. Buhtarma
- 4.20. Meghna
- 4.21. Brahmaputra

P I K

Literature

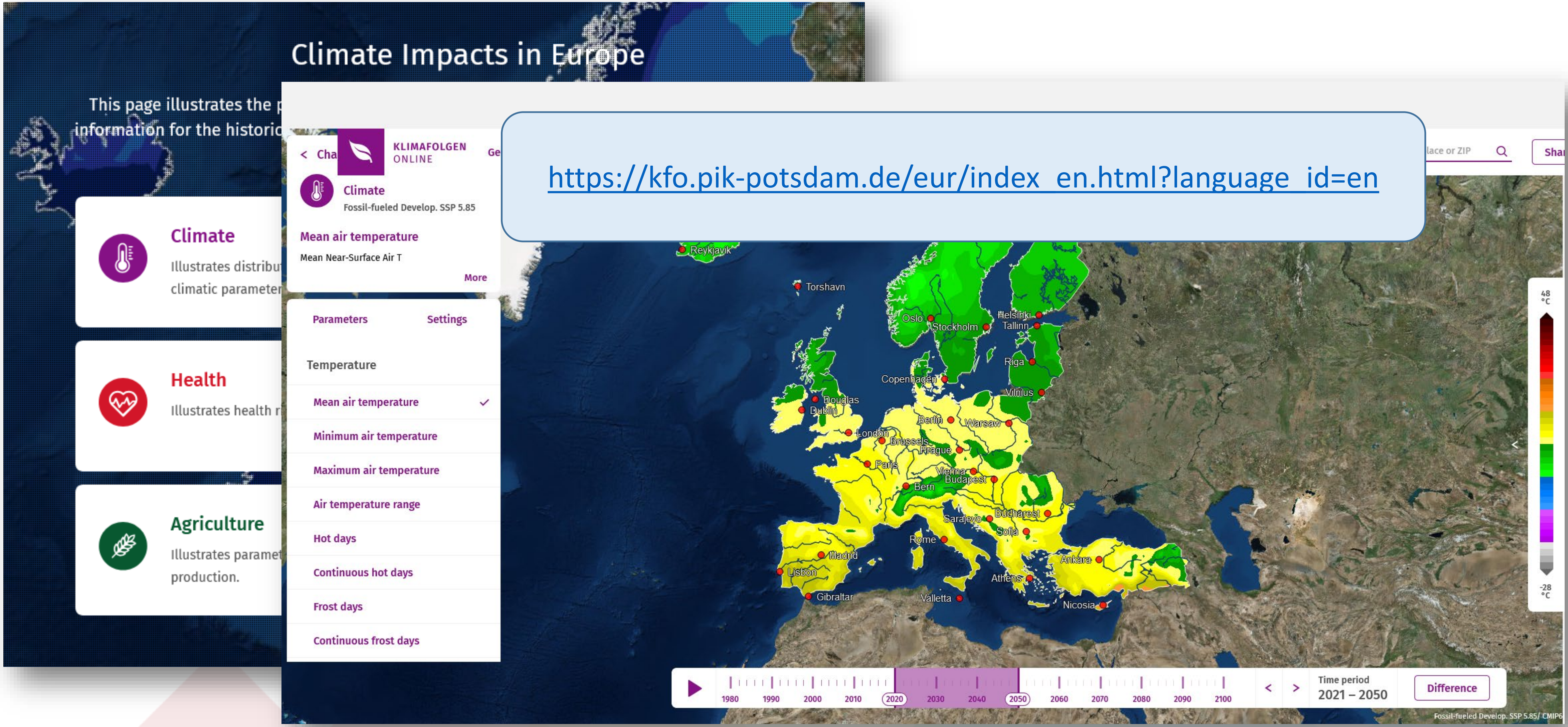
Model description

Krysanova, V., Müller-Wohlfeil, D.I. & A. Becker (1998). Development and test of a spatially distributed hydrological/water quality model for mesoscale watersheds. Ecological Modelling, 106, 261-289.

Hattermann, F. F., Huang, S., Koch, H. (2015): Climate change impacts on hydrology and water resources. - Meteorologische Zeitschrift, 24, 2, 201-211.

Krysanova, V., Hattermann, F., Huang, S., Hesse, C., Vetter, T., Liersch, S., Koch, H. & Z. W. Kundzewicz (2015). Modelling climate and land use change impacts with SWIM: lessons learnt from multiple applications. Hydrological Sciences Journal, 60, 606-635.

Web portal for data and information



https://kfo.pik-potsdam.de/eur/index_en.html?language_id=en

https://kfo.pik-potsdam.de/eur/index_en.html?language_id=en

WEPP Water Erosion Pred

Link: https://wepp.cloud/weppcloud/

1. Land use 43 – mixed forest and Forest Silt-Loam Soil
2. Land use 83 – small grain and Forest Silt-Loam Soil
3. Land use 83 – small grain and Forest High Sev Fire Sandy Loam

Apply WEPP to investigate the relevance of vegetation cover

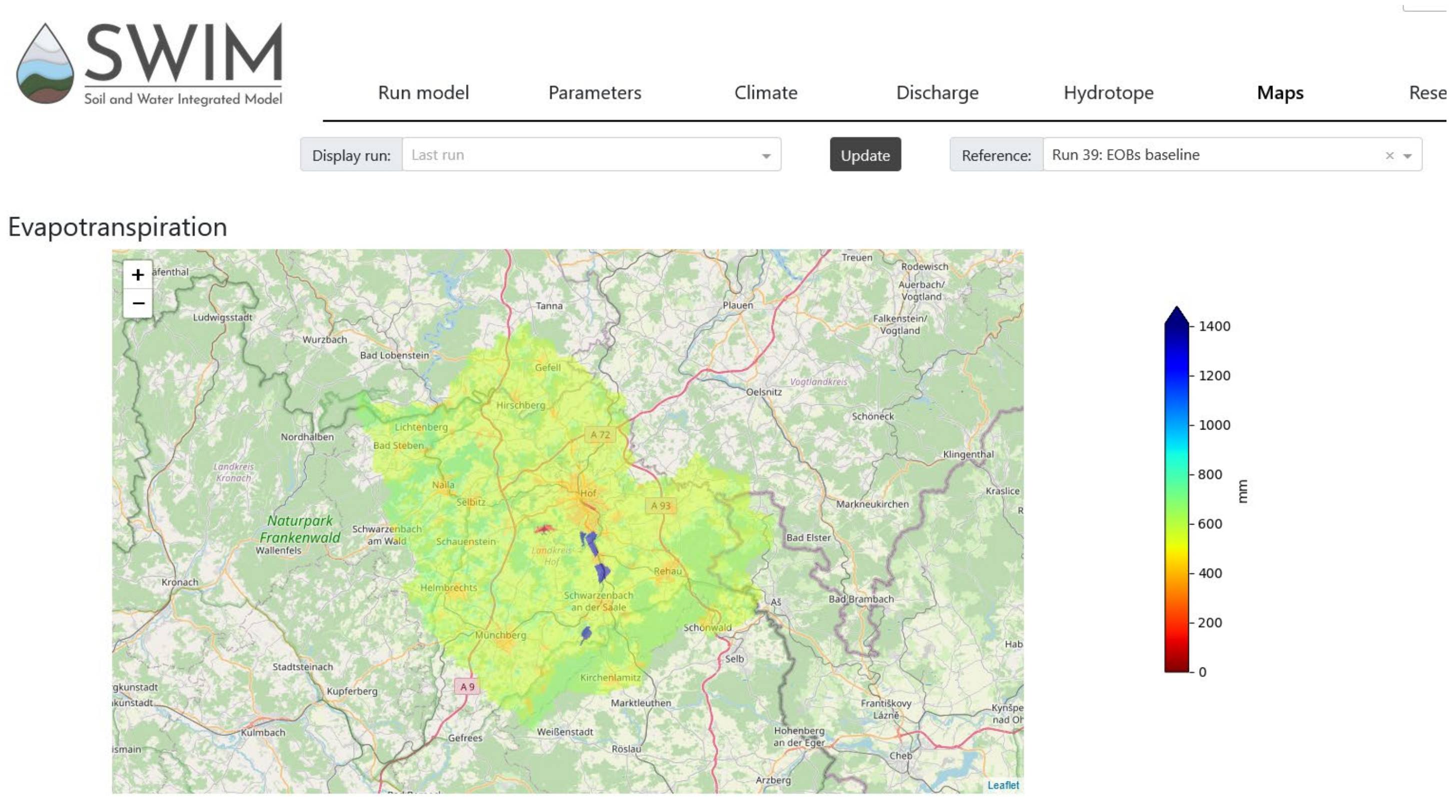
Example 1: Erosion and water balance under forest cover

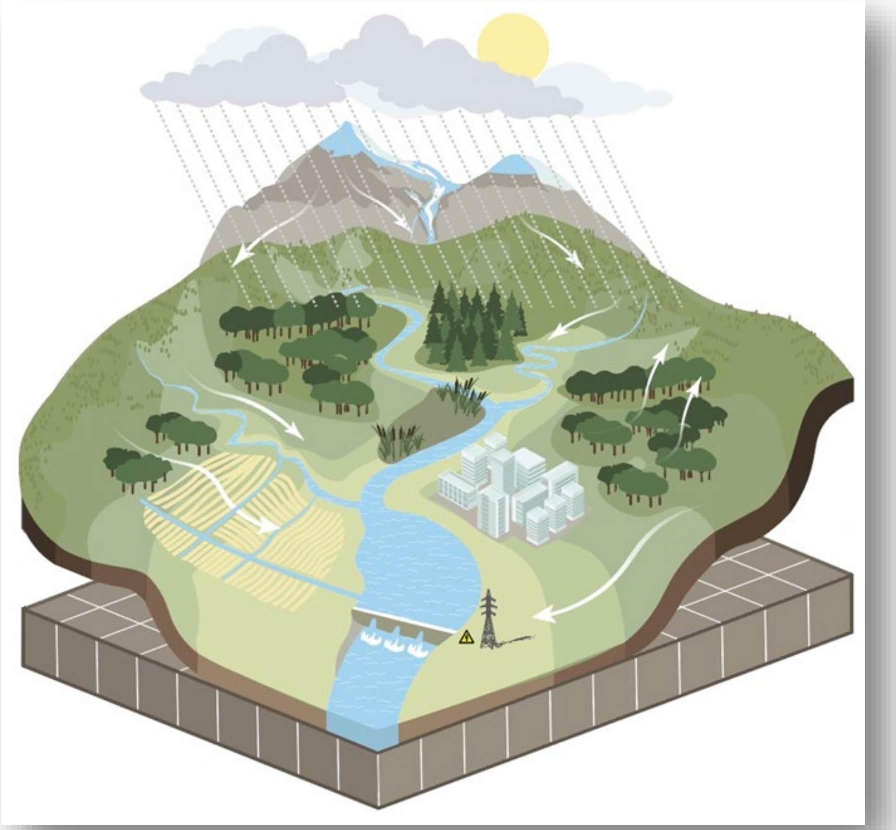
Example 2: Erosion and water balance under agriculture

Link: https://wepp.cloud/weppcloud/

PIK

Climate change impacts





Climate change impacts

Apply SWIM to investigate impacts of climate scenarios:

Example 1: Calibrate model

Example 2: Do climate scenario runs