IGB
Leibniz Institute of Freshwater Ecology
and Inland Fisheries

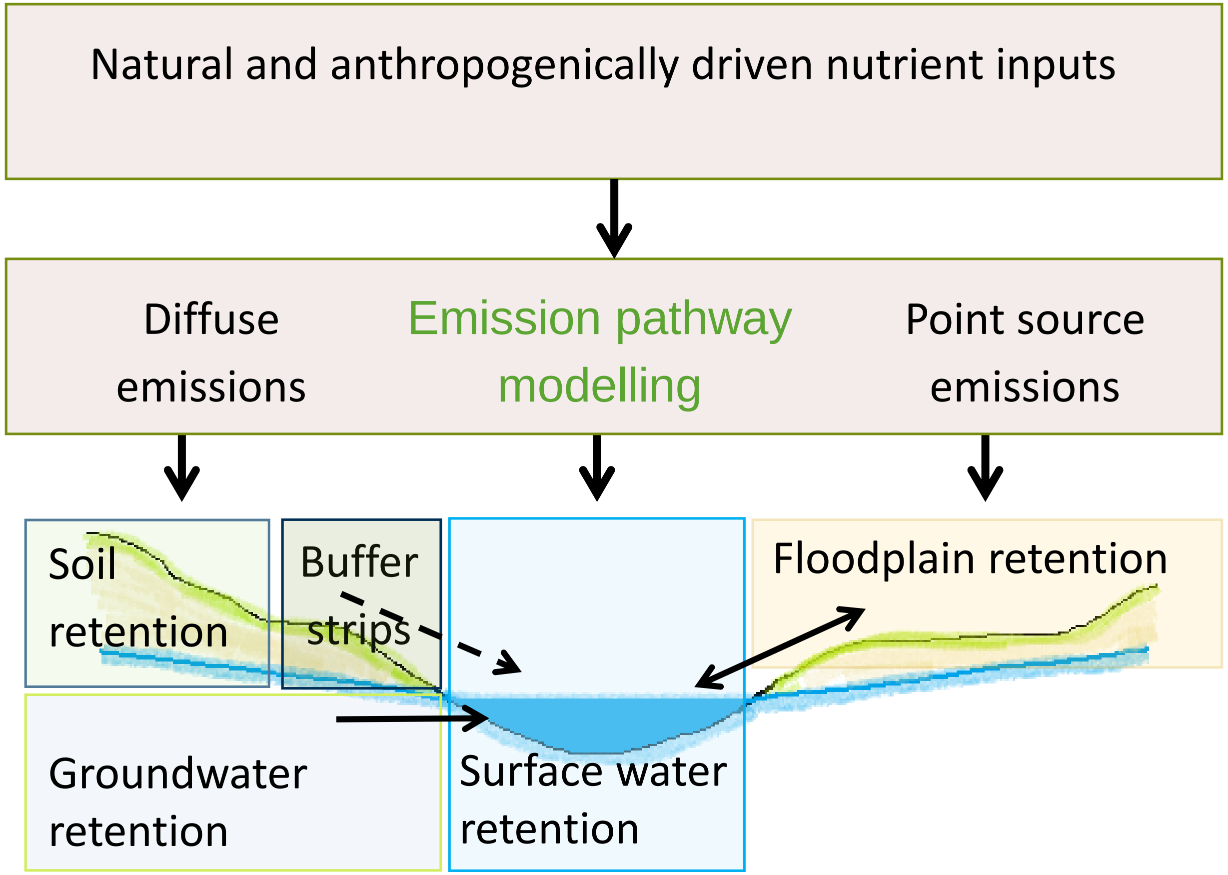
Modelling of nutrient emission in river systems (MONERIS):
Presenting new perspectives and current developments of a widely used emission model

Oprei, Anna; Huk, Victoria & Venohr, Markus

Wednesday, June 5, 2024, 09:00 AM

moneris

Nutrient and water quality model moneris



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moneris Model improvements

→ **Precipitation-runoff model**

High-quality input data

Combining different data sources

- *international/national/municipality level*
- *different reference years*
- *variable temporal resolution*
- *variable formats (polygons and raster)*

Increase of resolution

Temporal resolution: monthly

- *needed to account for ecological effects*
- *capture seasonal hydrological dynamics*
- *avoiding scaling issues*

Spatial resolution: 1 km^2

- *identify hotspots*
- *landuse-specific differentiation*
- *avoiding scaling issues*

Transfer to R environment

Modular and flexible setup

- *emission pathways, substances, resolution etc. can be adapted for every project*
- *transparent and traceable*
- *computationally feasible*

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Example for data collection

Landuse

<table>
<tr><th>Year</th><th>Europe</th><th>EU27</th><th>GER</th></tr>
<tr><td>2010</td><td rowspan="11">GLOBE-CORINE 2012</td><td rowspan="6">CORINE 2012</td><td rowspan="4">LBM 2012</td></tr>
<tr><td>2011</td></tr>
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<tr><td>2019</td></tr>
<tr><td>2020</td></tr>
</table>

Connection to sewer and WWTP

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<tr><th>Year</th><th>Europe</th><th>GER</th><th>Berlin</th></tr>
<tr><td>2010</td><td rowspan="11">annual data, country level</td><td rowspan="3"></td><td rowspan="11">annual data, house block level</td></tr>
<tr><td>2011</td></tr>
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<tr><td>2013</td><td rowspan="6">municipality level</td></tr>
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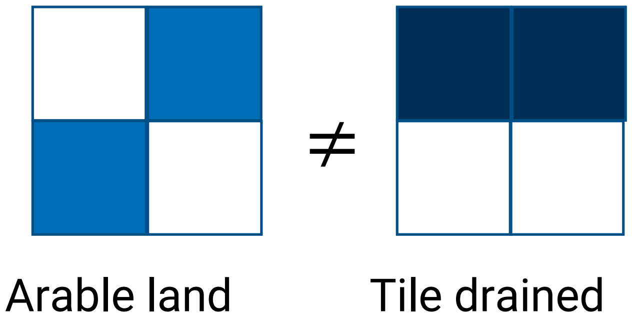
Increase of spatiotemporal resolution

- Heterogeneous input data cause inconsistencies in spatial overlapping



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- Spatial resolution of input data ranges between:
  - Polygons: 1:25.000 – 1:1.000.000
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- Modelling of retention and nutrient loads is still done on level of hydrological sub catchments

Model Extent

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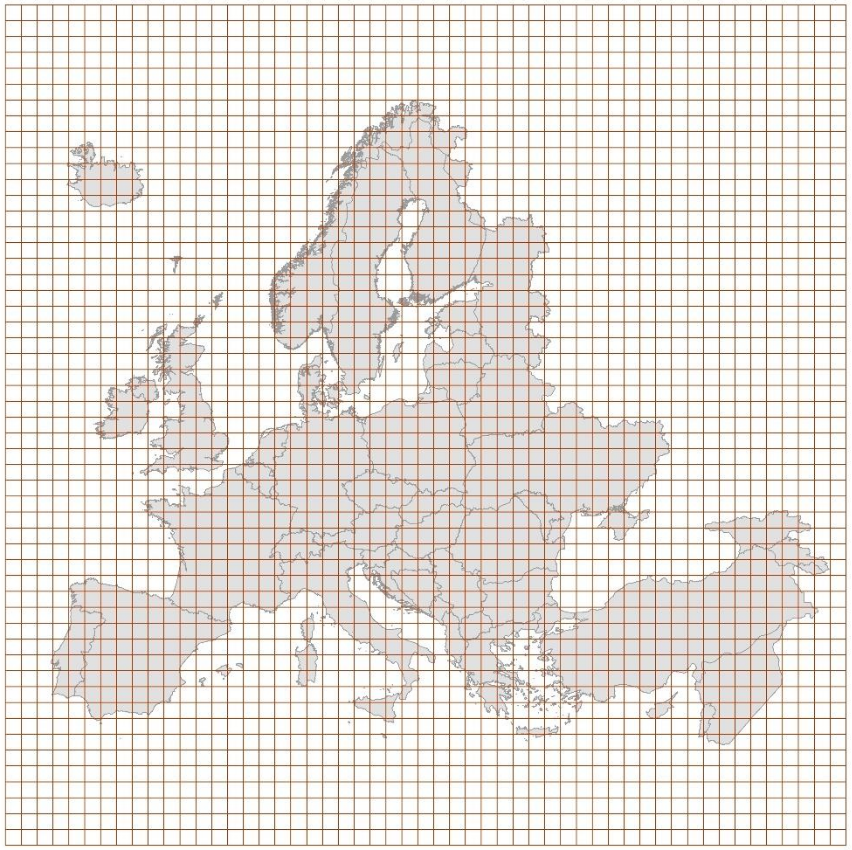
Model Extent -> Fractal Grids 100 km



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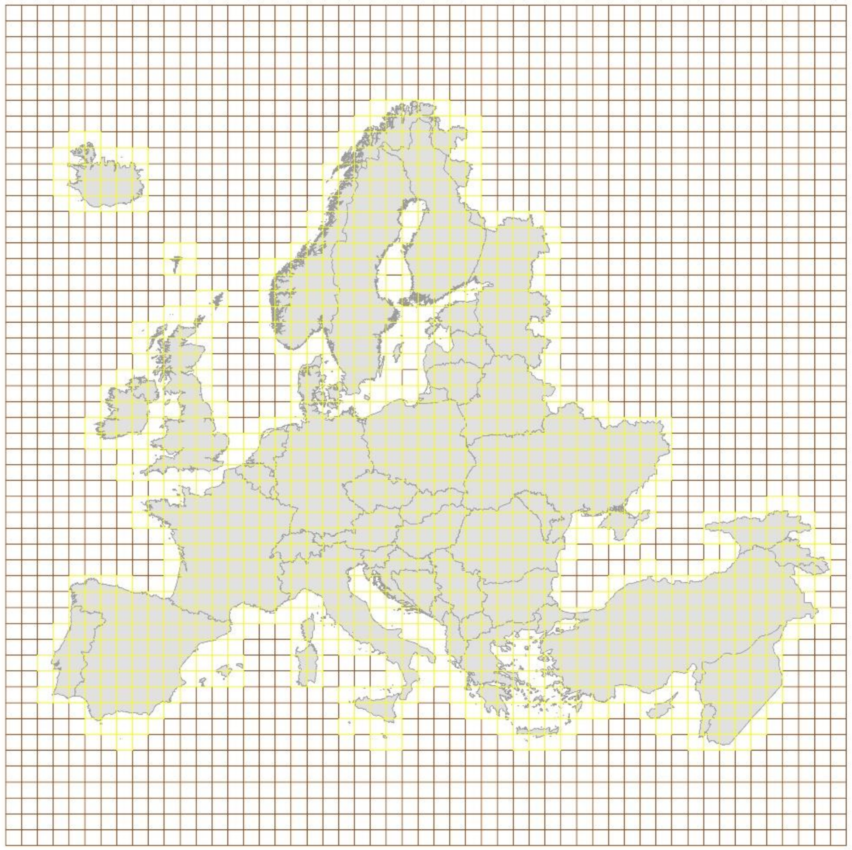

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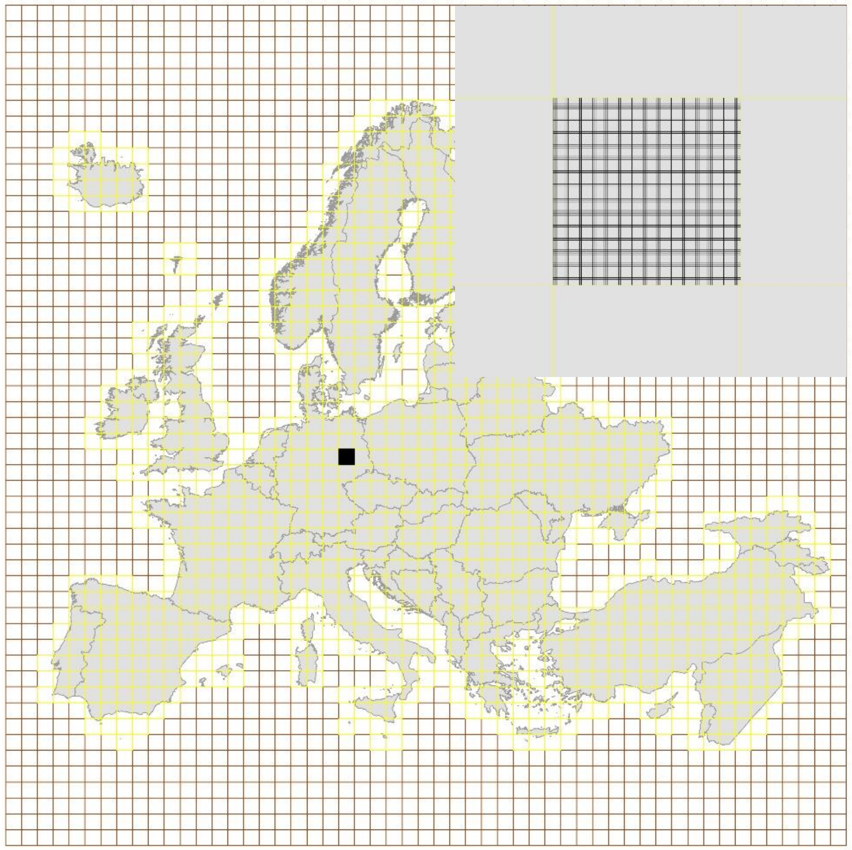
Model Extent -> Fractal Grids 100 km -> 1km



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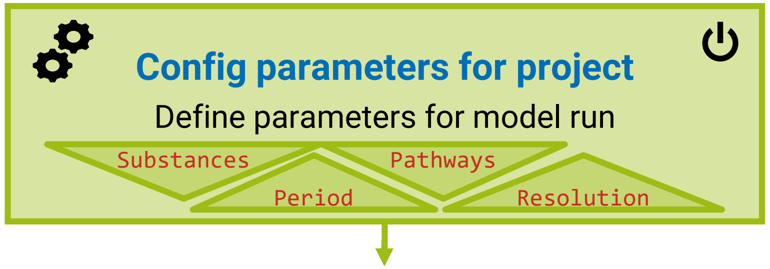


= Parallel processing = Loop

Config parameters for project

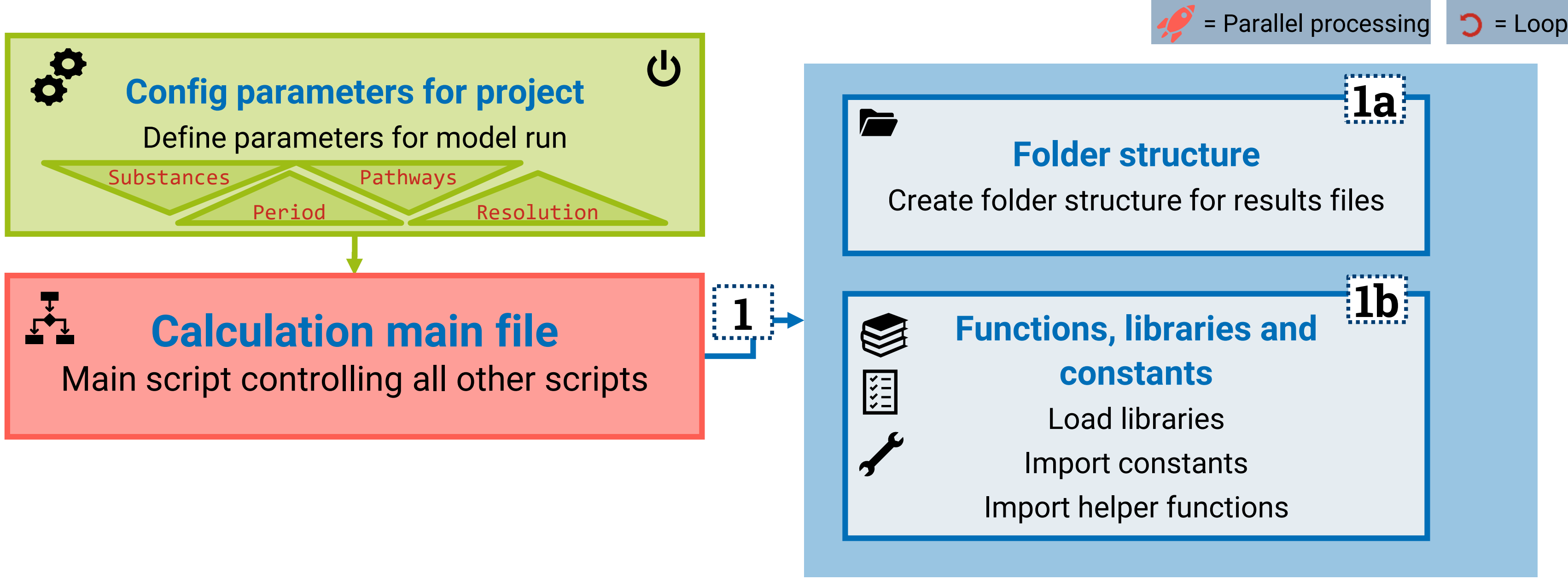
Define parameters for model run

Substances Pathways

Period Resolution

Calculation main file

Main script controlling all other scripts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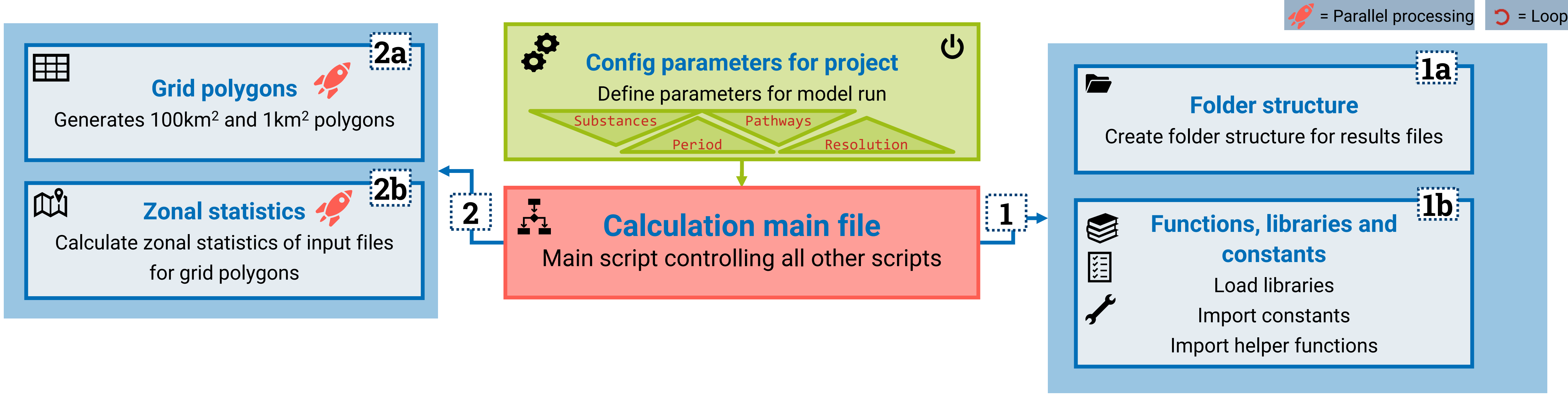
1a
Folder structure
Create folder structure for results files
1b
Functions, libraries and constants
Load libraries
Import constants
Import helper functions



= Parallel processing
= Loop
2a
Grid polygons
Generates $100km^2$ and $1km^2$ polygons
2b
Zonal statistics
Calculate zonal statistics of input files for grid polygons
Config parameters for project
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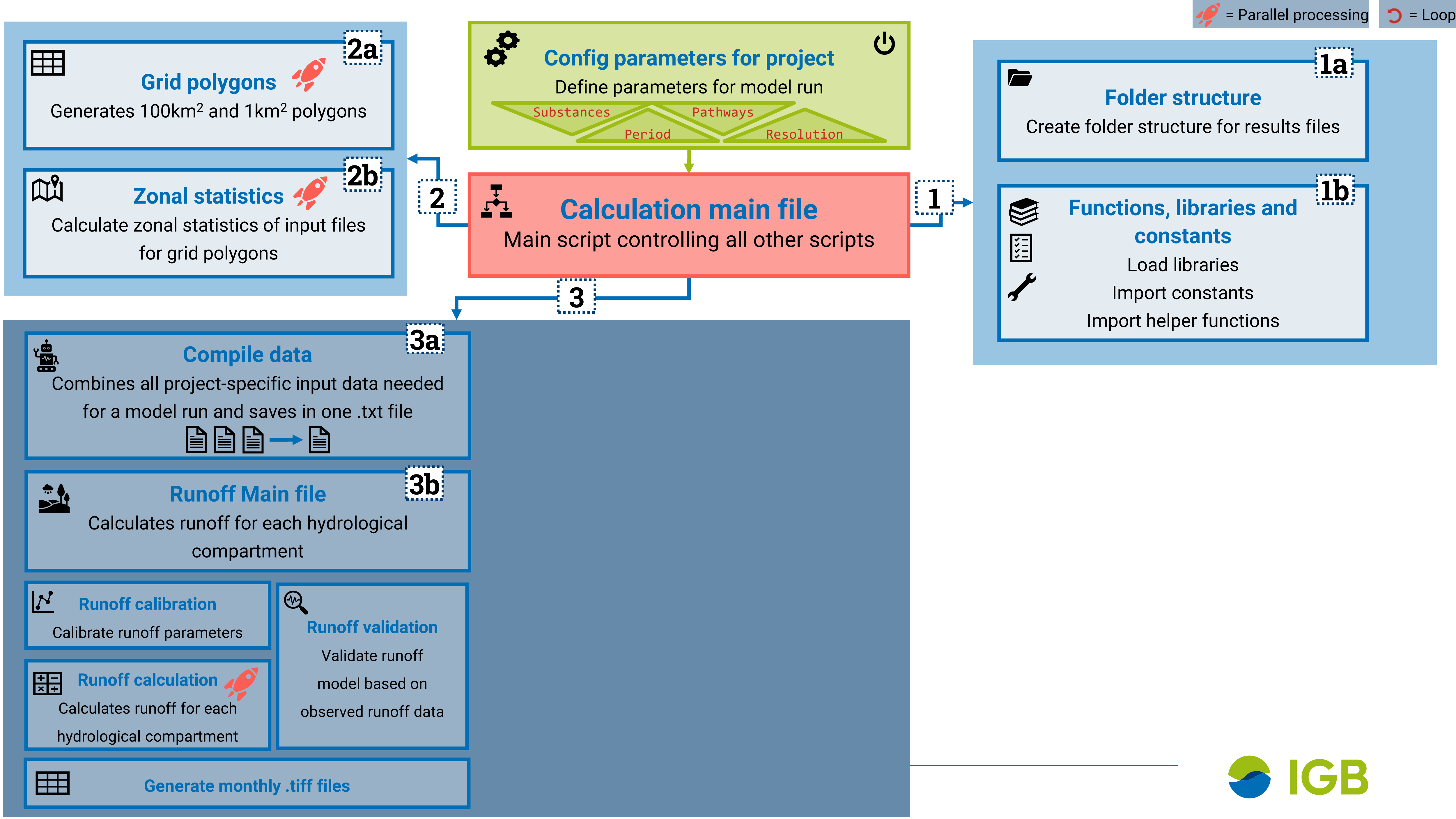
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Compile data
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3b
Runoff Main file
Calculates runoff for each hydrological compartment
Runoff calibration
Calibrate runoff parameters
Runoff validation
Validate runoff model based on observed runoff data
Runoff calculation
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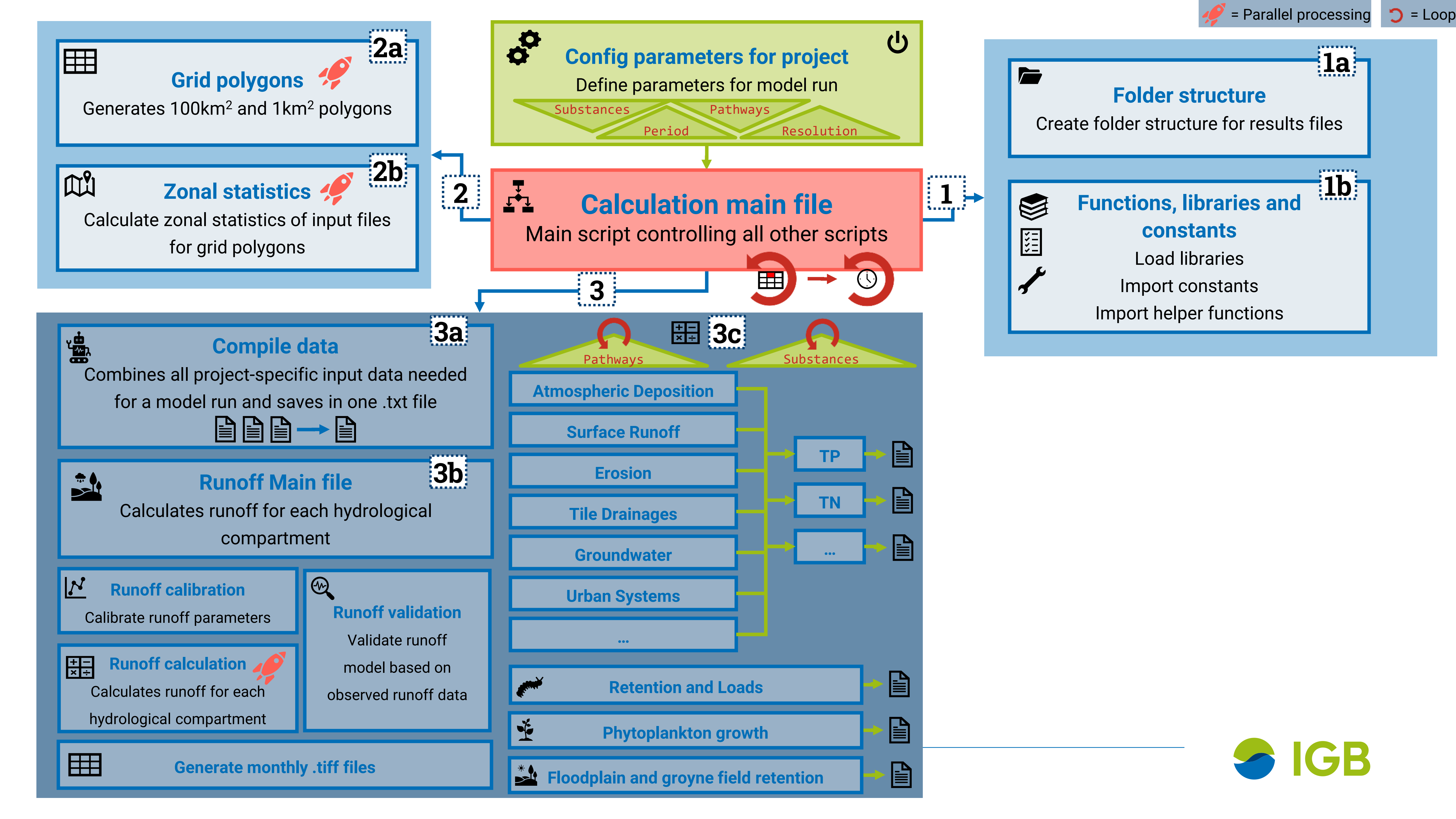
Generate monthly .tiff files
IGB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Floodplain and groyne field retention
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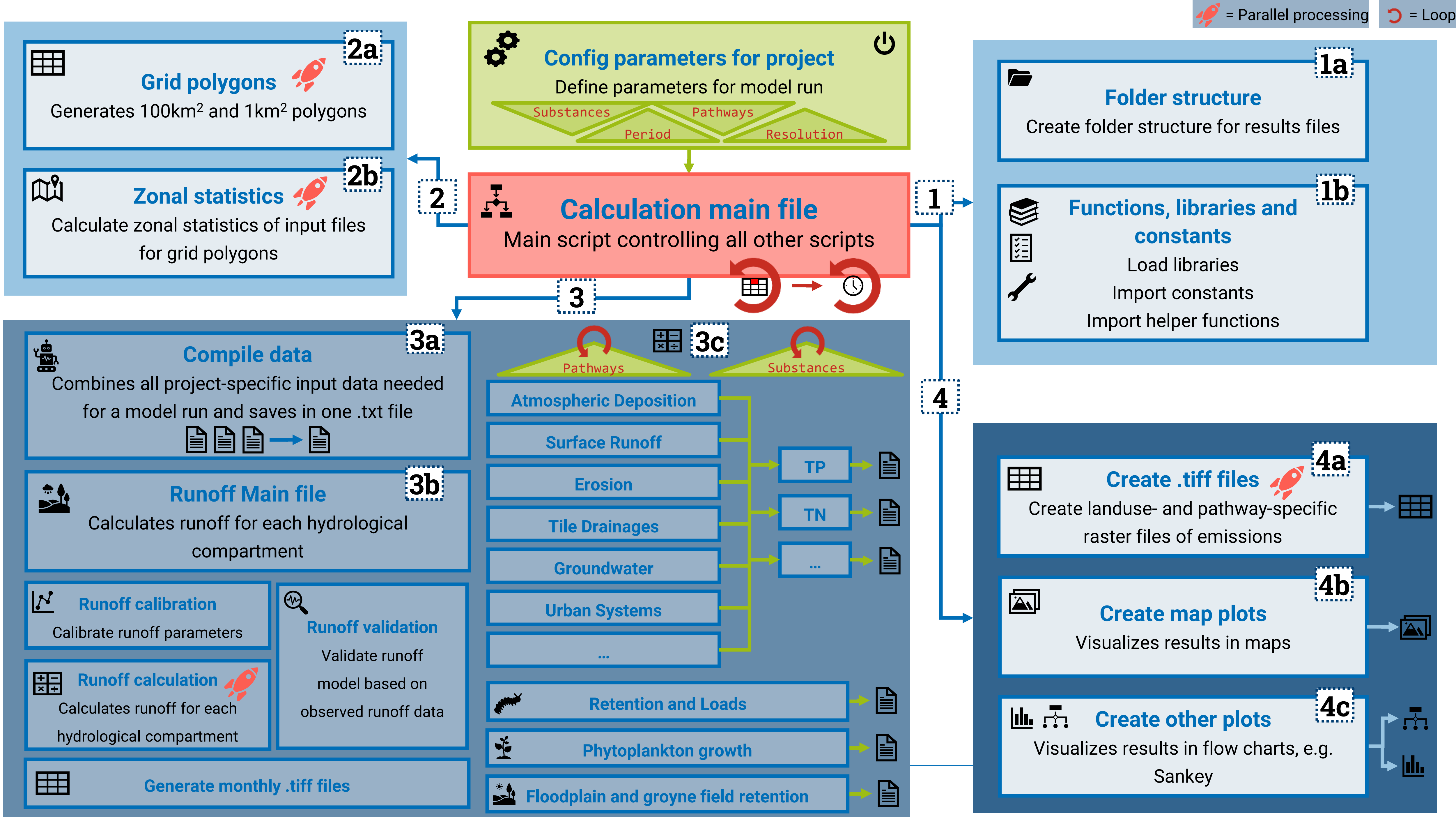

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4a
Create .tiff files
Create landuse- and pathway-specific raster files of emissions
4b
Create map plots
Visualizes results in maps
4c
Create other plots
Visualizes results in flow charts, e.g. Sankey

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Basic concept of P-R-Model

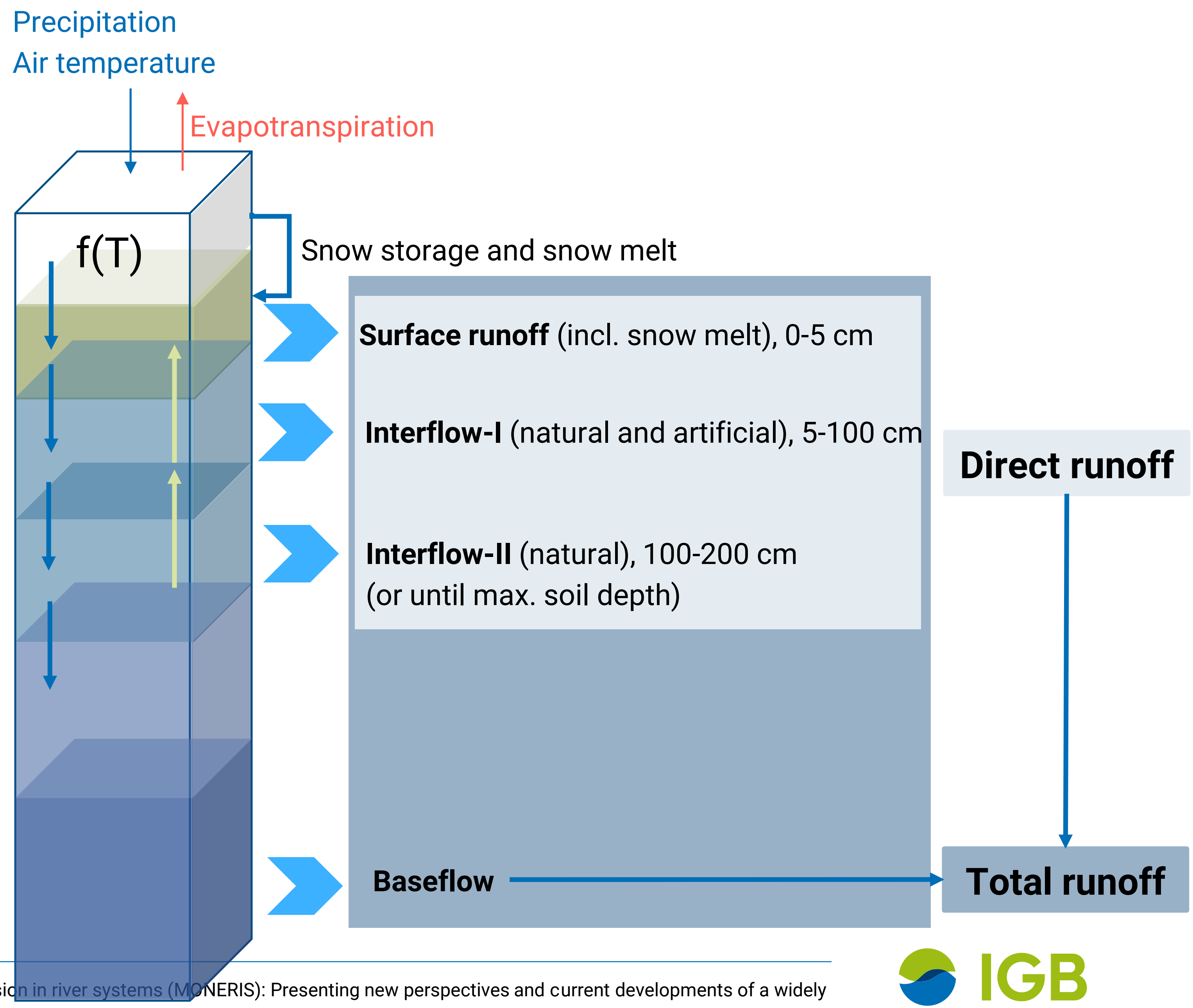
Snow coverage, snow melt = f(max(T_{mean}))

Evapotranspiration (ET) according to MODIS

Surface runoff: CN values according to Jafaar et al. (2019), slope correction, soil moisture based on soil water volume balance
-> selection of CN values based on antecedent runoff conditions (ARC)

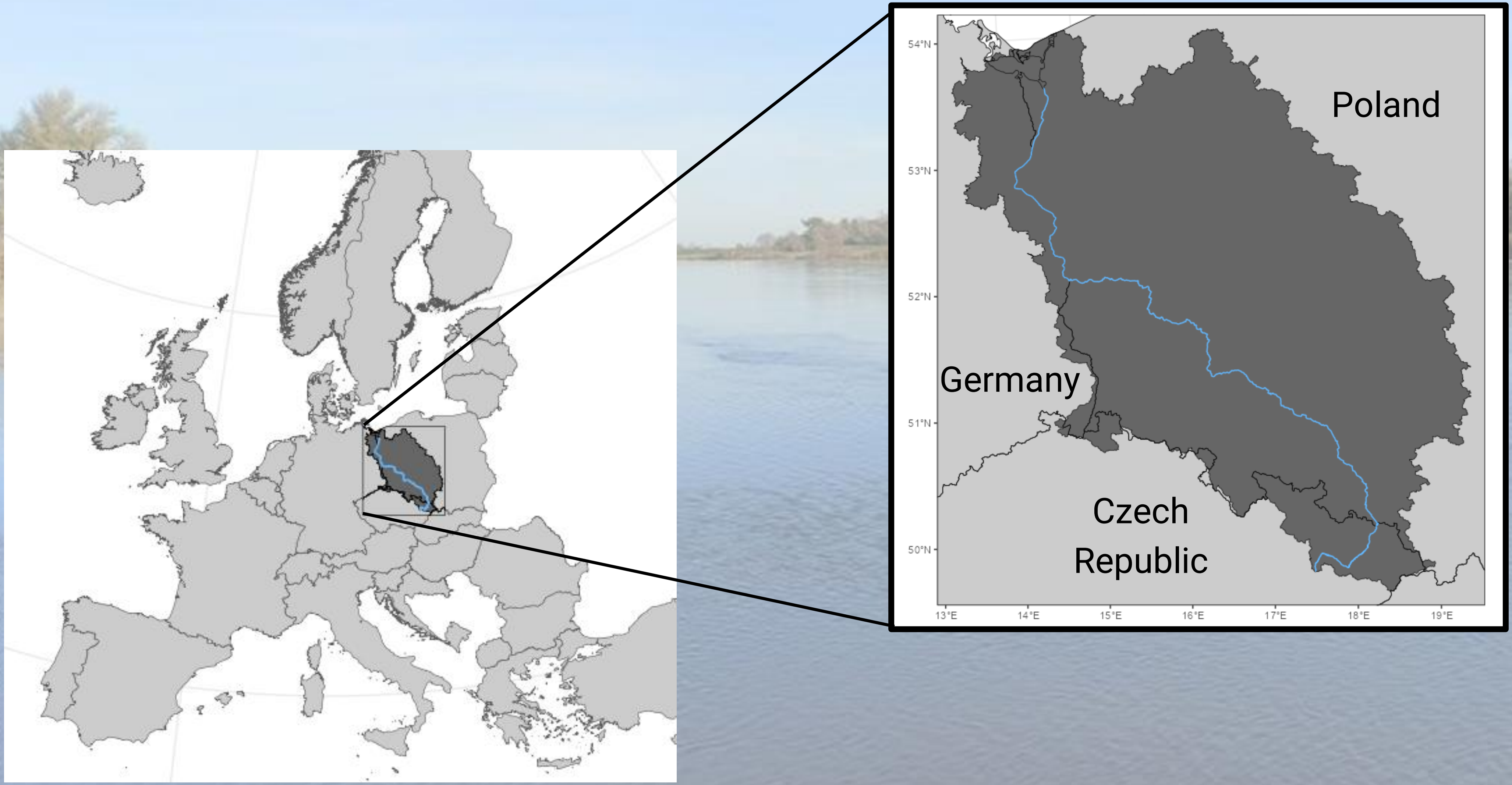
Interflow = f(usable field capacity, slope, tile drainage coverage, soil water content of deeper layers)
-> Capillary rise is limited by water content of deeper soil layers

Groundwater
Permeability and water storage capacity according to geohydrological classes



Oprei, A., Huk, V. & Venohr, M.: Modelling of nutrient emission in river systems (MONERIS): Presenting new perspectives and current developments of a widely used emission model

Case Study: Odra River Basin (total area 119,000 km²)



Runoff model validation – Model efficiency for each station

Observed data:

- separate measured direct runoff and baseflow via hydropgraph separation (WMO) (R-package: lftstat)
- allocate 1 km grid cells to catchment area of gauge (criterion: area share > 50 %)
- calibrate against observed runoff data from 11 independent upstream gauges:
  - Direct runoff (modelled vs observed)
  - Tile drainage interflow (modelled vs observed)
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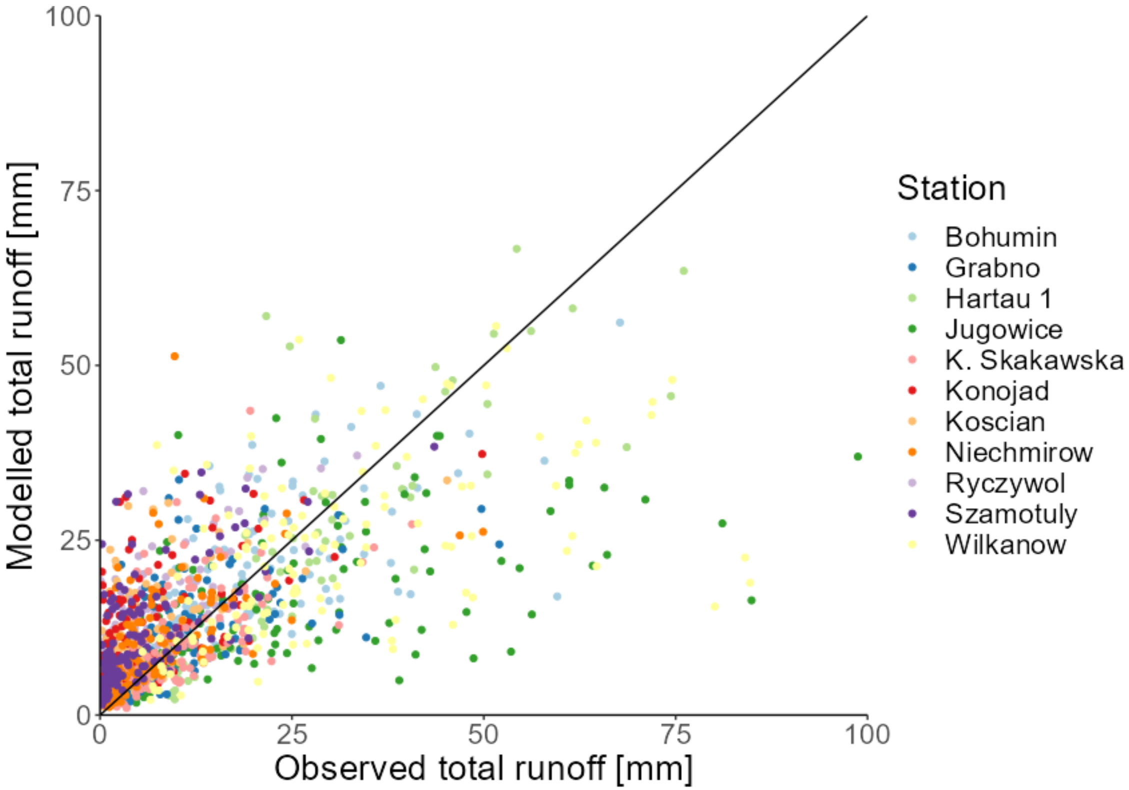
- validate by runoff data from 36 additional gauges (2010-2020)

Total runoff	MAD (mm)	PBIAS (%)	NSE (mm)
Monthly	176.9	2.70	0.89
Yearly	96.5	-10.9	0.22
All-time	40.6	-11.0	0.60



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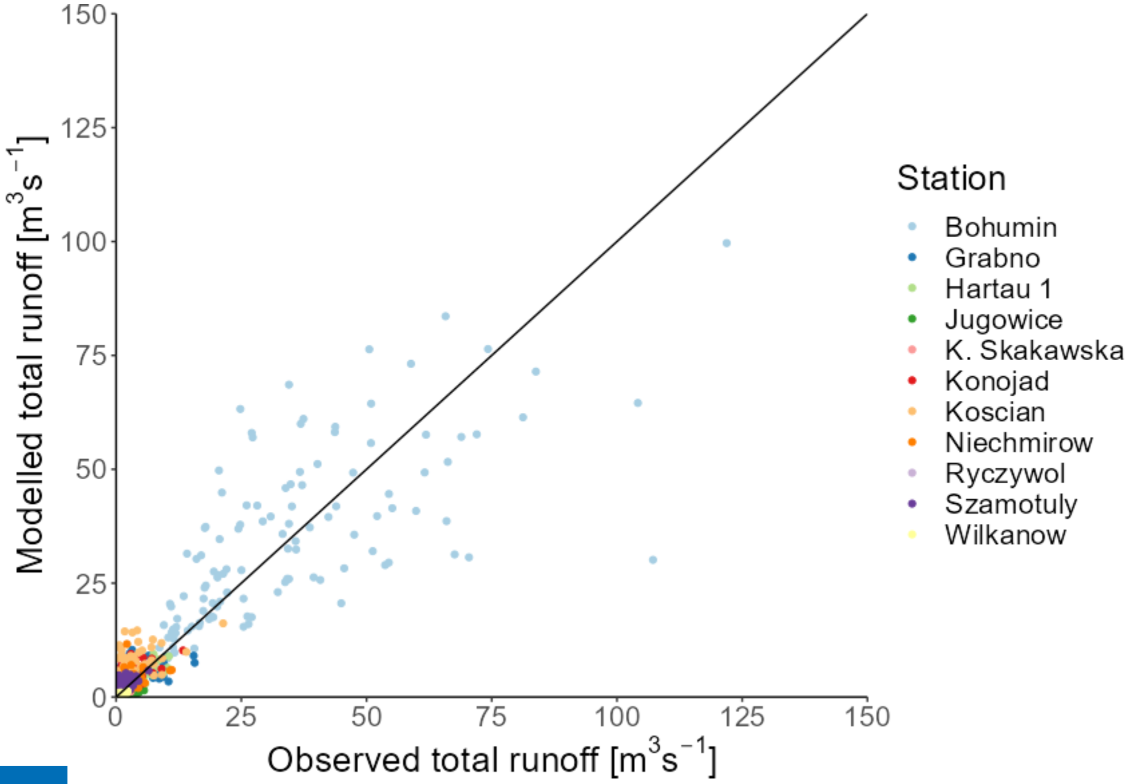

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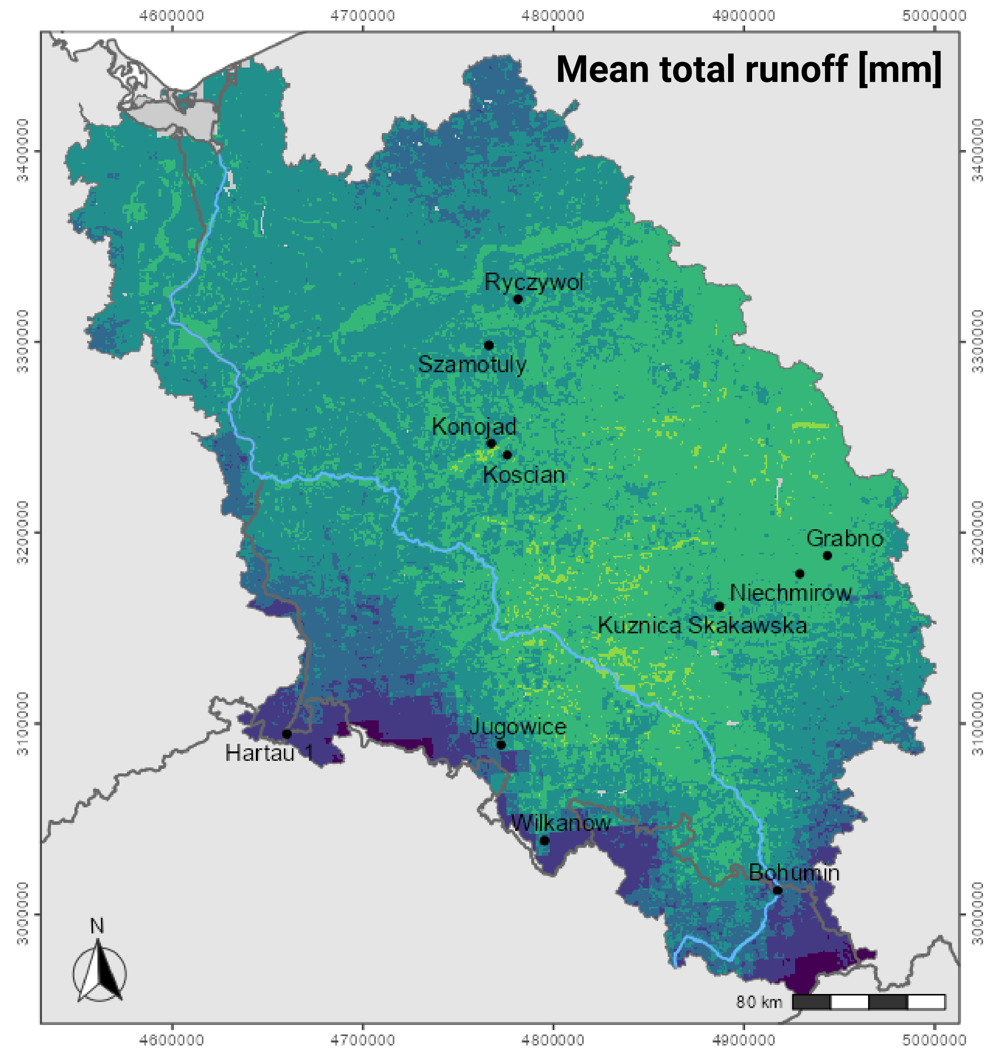
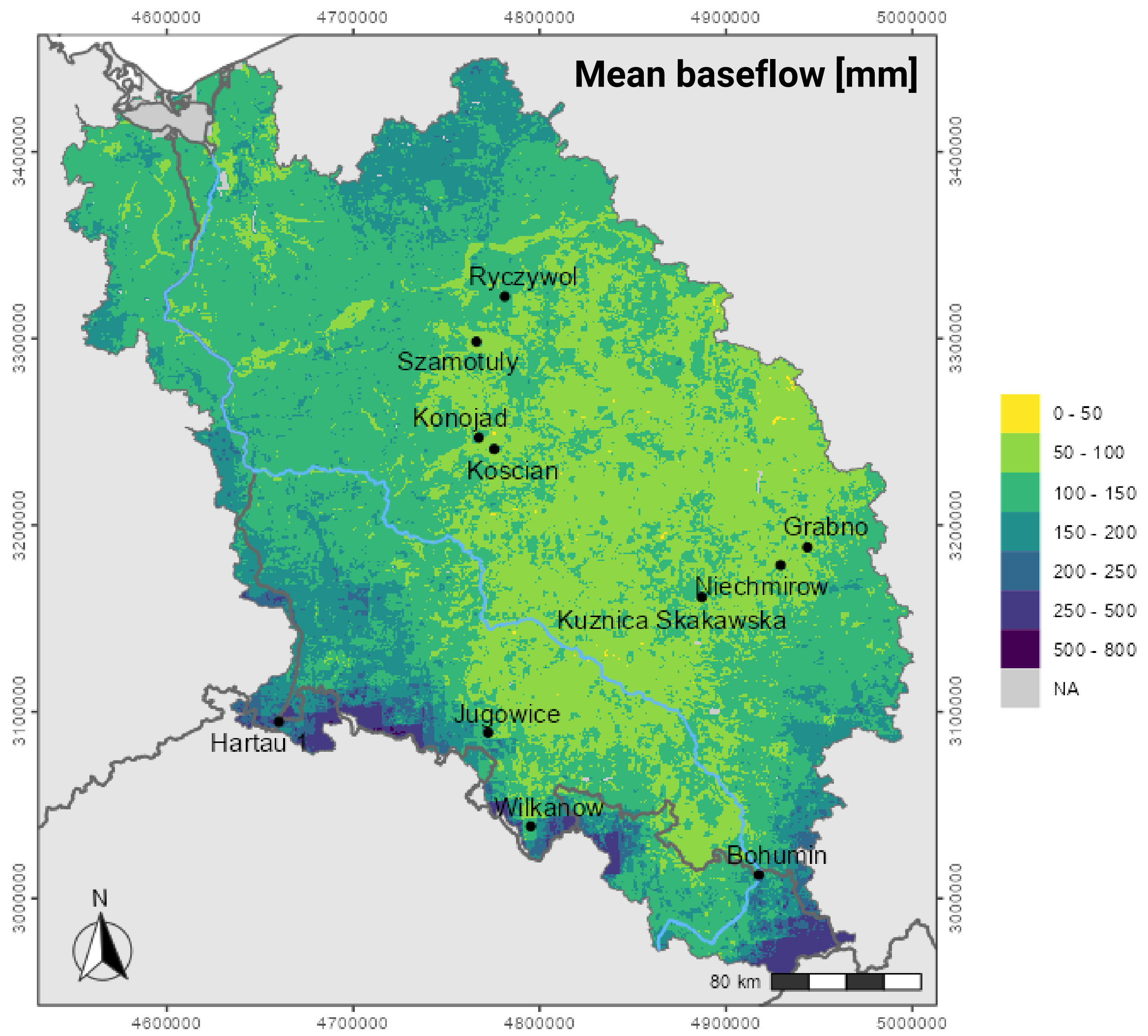
Case study: Odra River Basin, annual means 2010-2020





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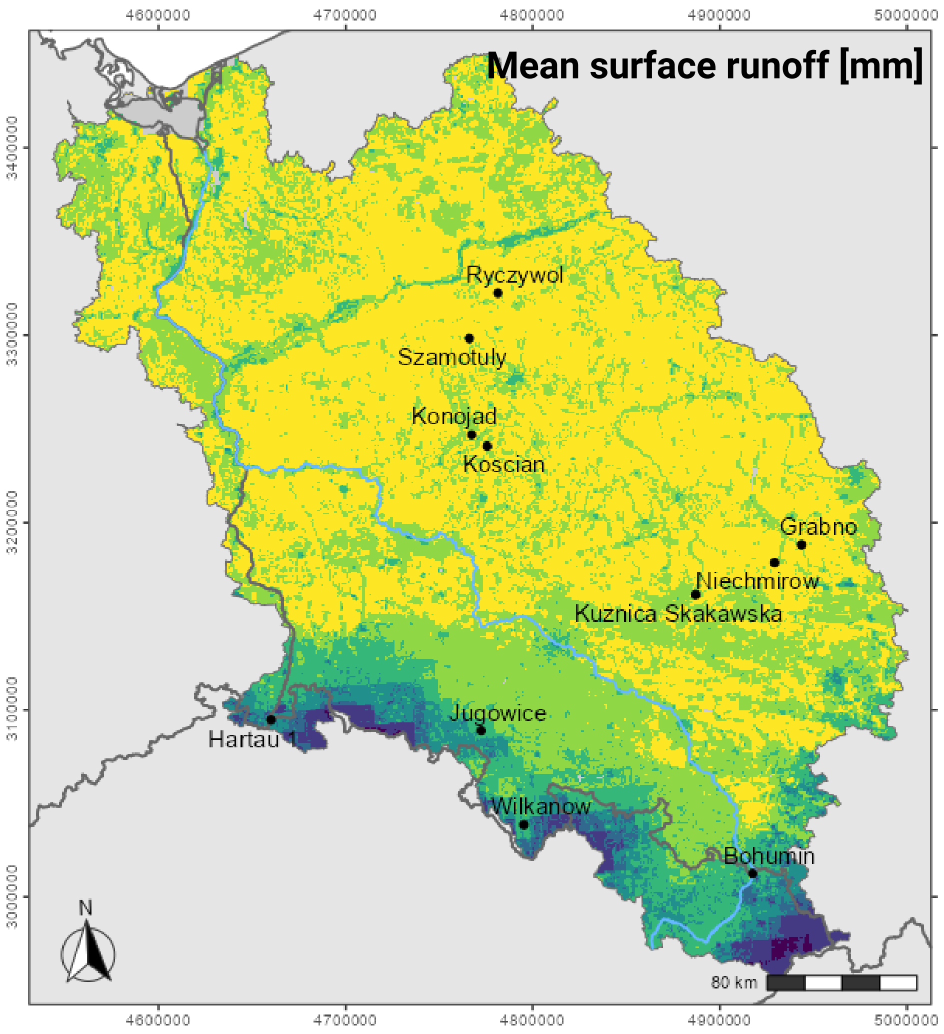

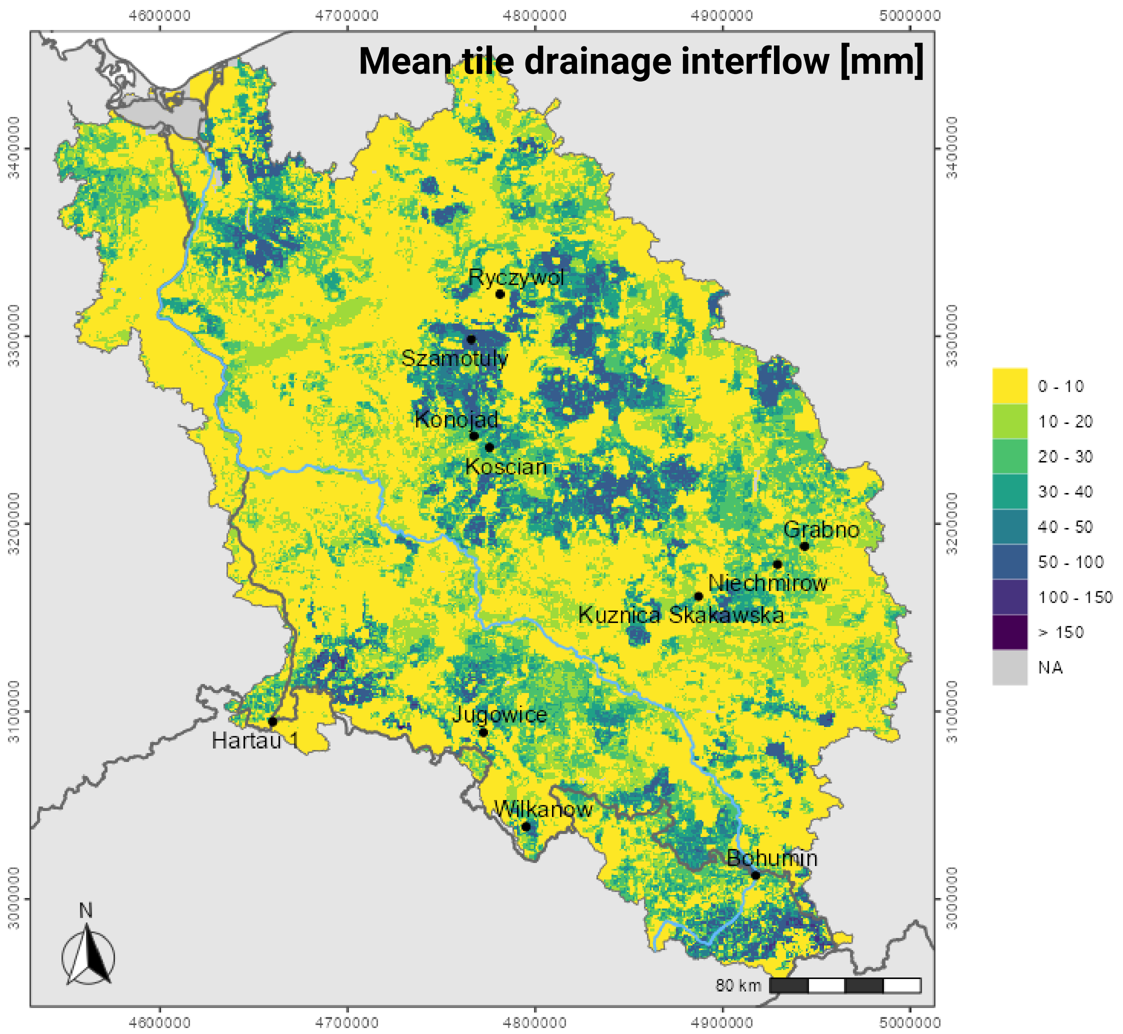

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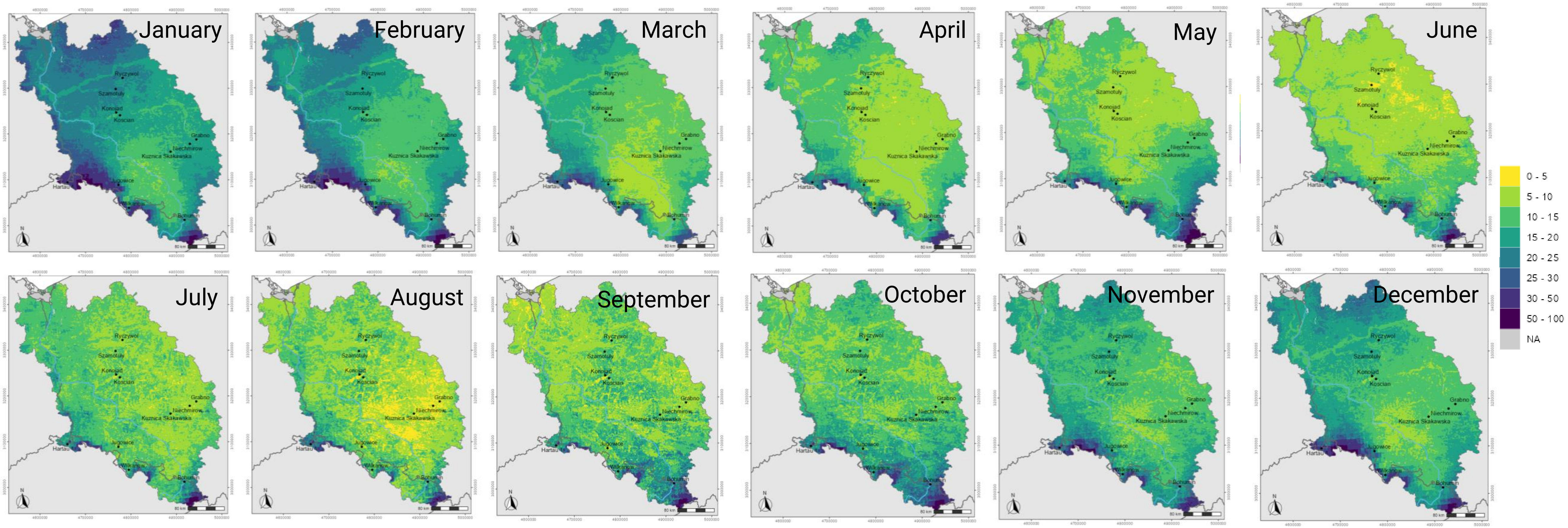
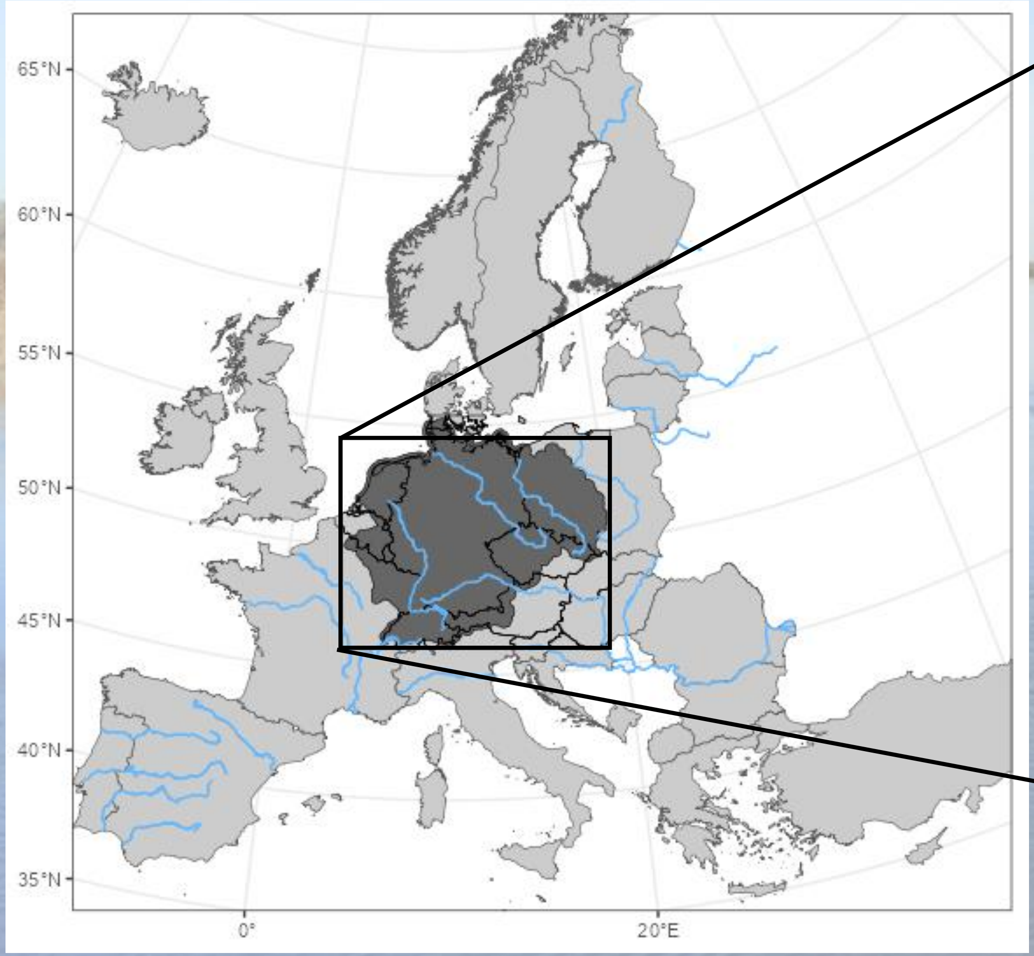
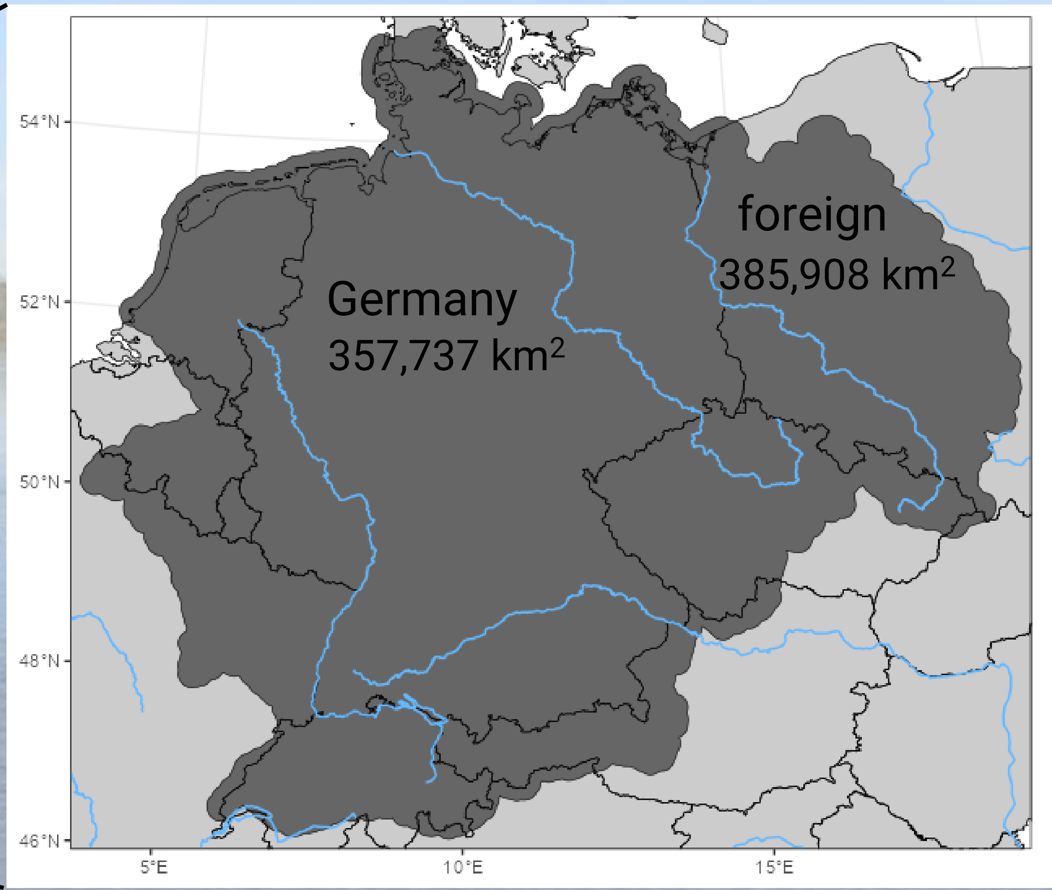
Case study: Odra River Basin, means 2010-2020, total runoff [mm]



Case Study: River basins in Germany (total area 743,646 km²)



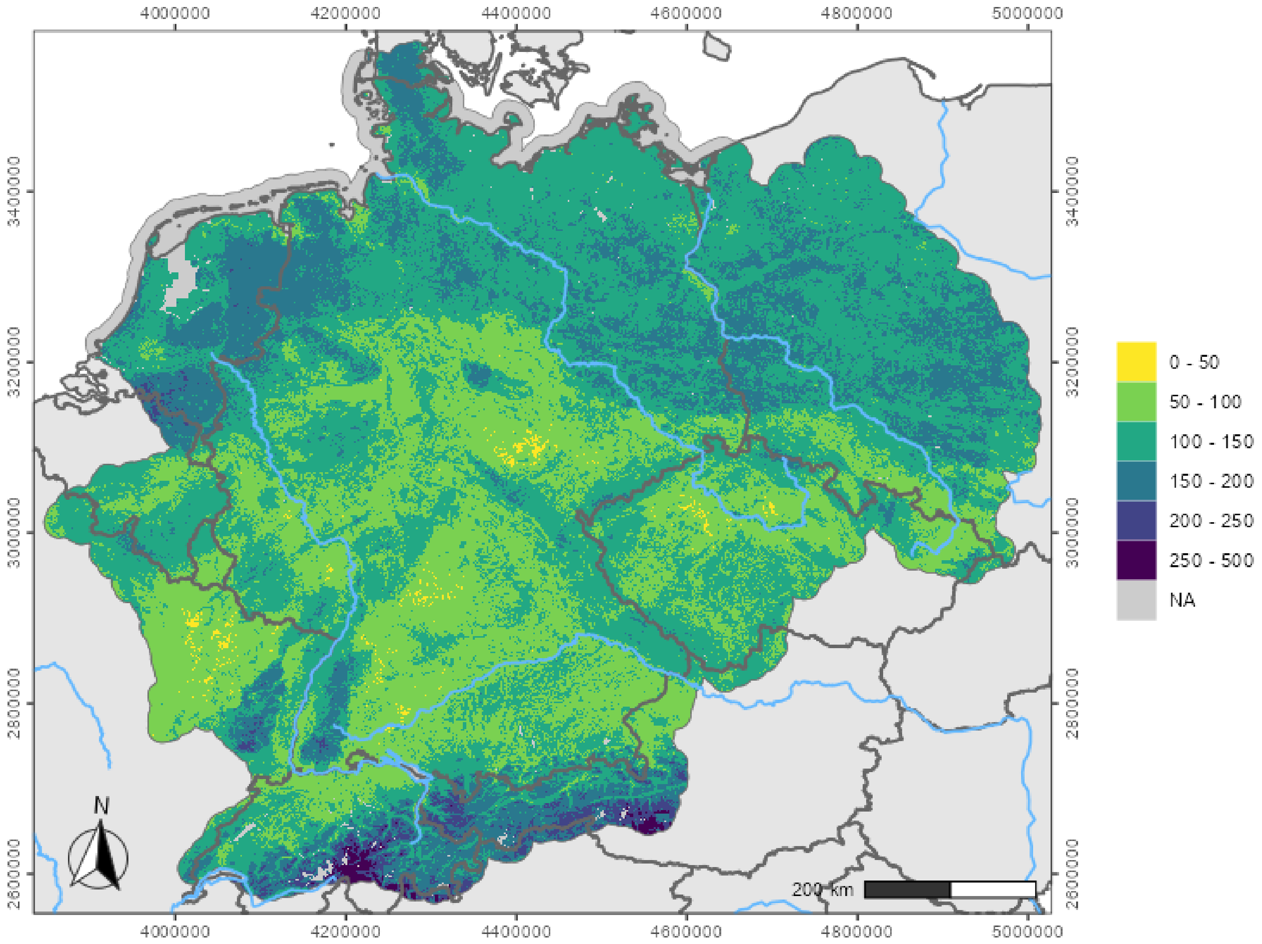


Area share Germany: 48%

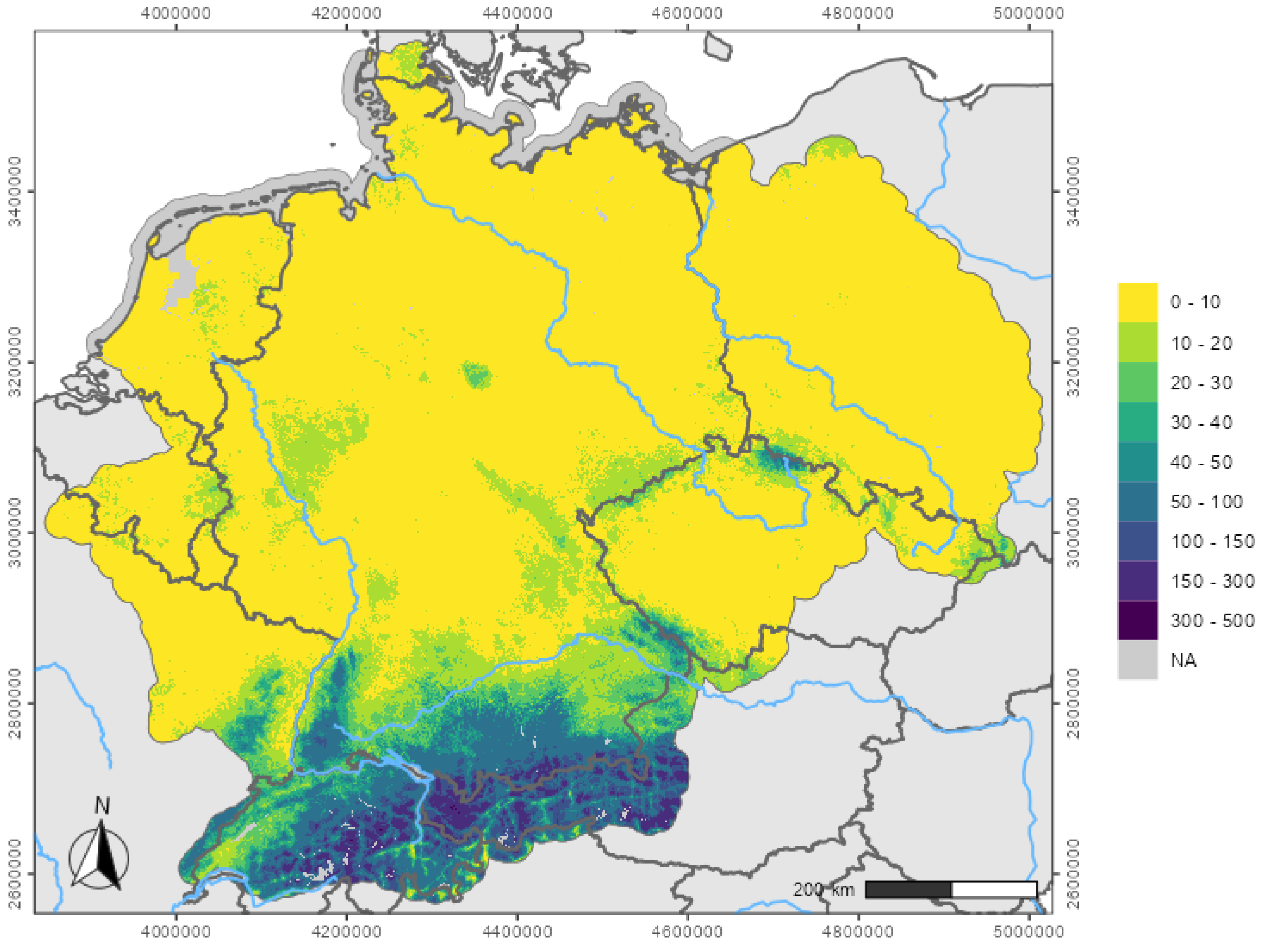
Area share foreign countries: 52%

Case study: Germany, total runoff [mm]

January 2014



June 2015



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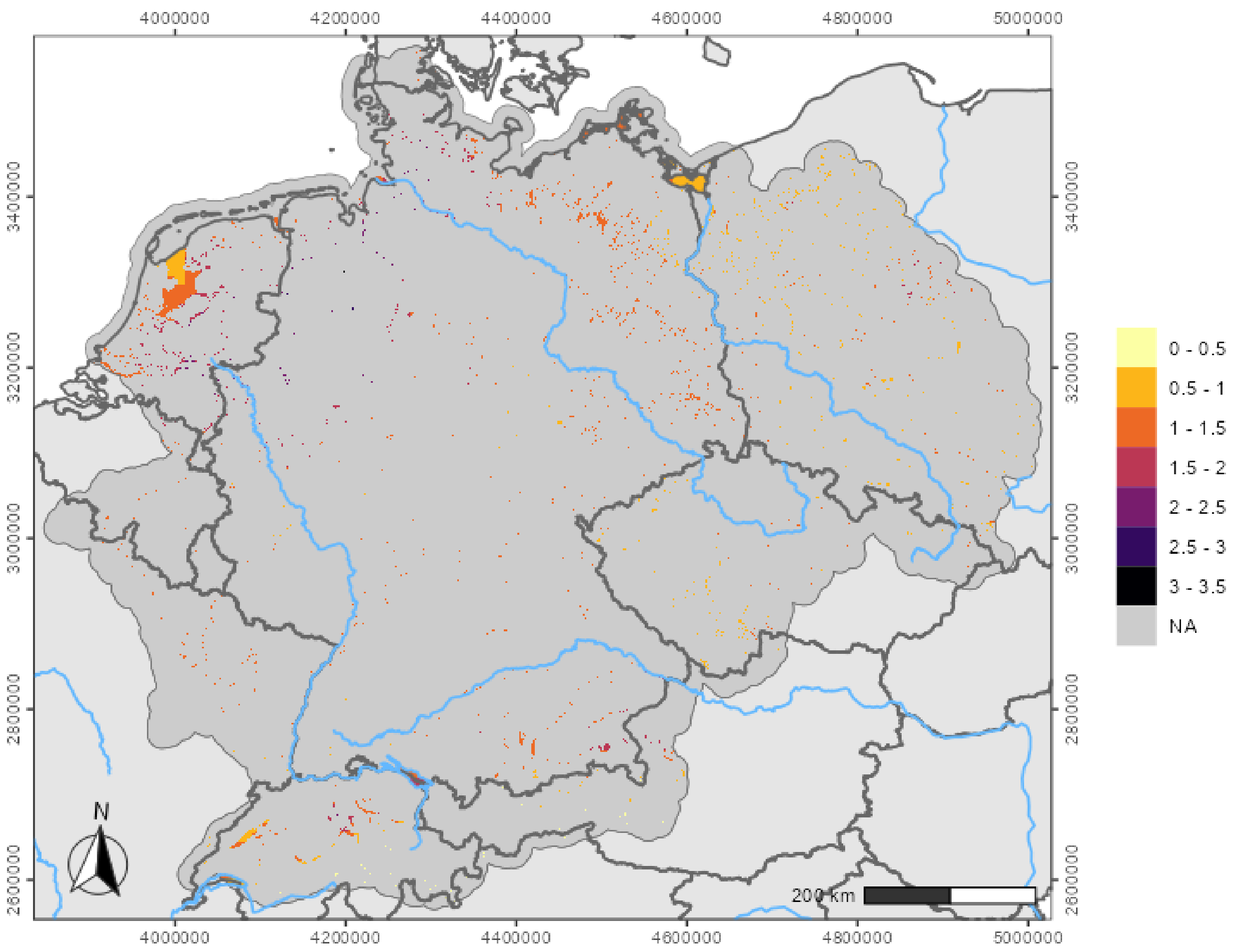
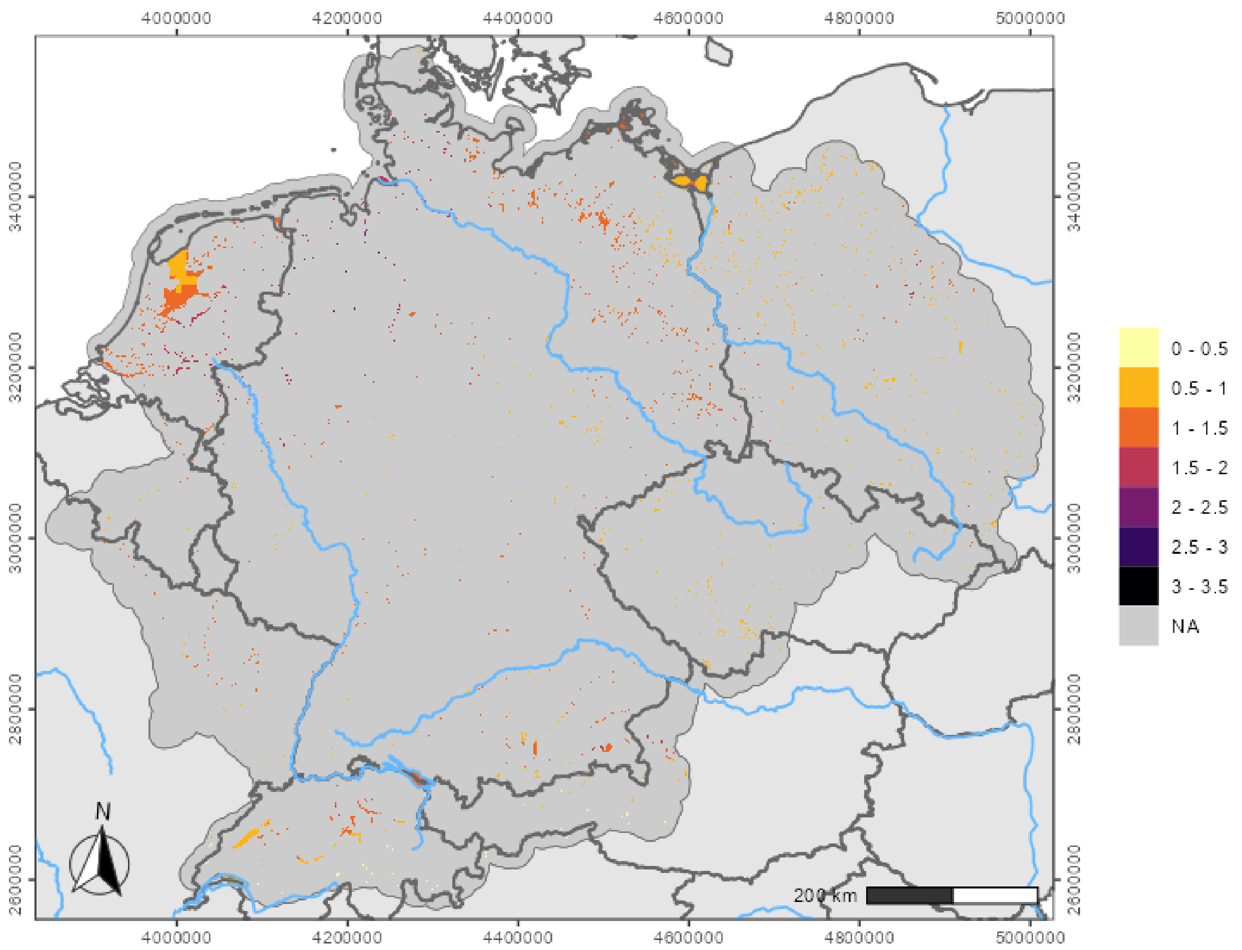
Case study: Germany, TN emissions from atmospheric deposition [kg ha^{-1}]

April 2015

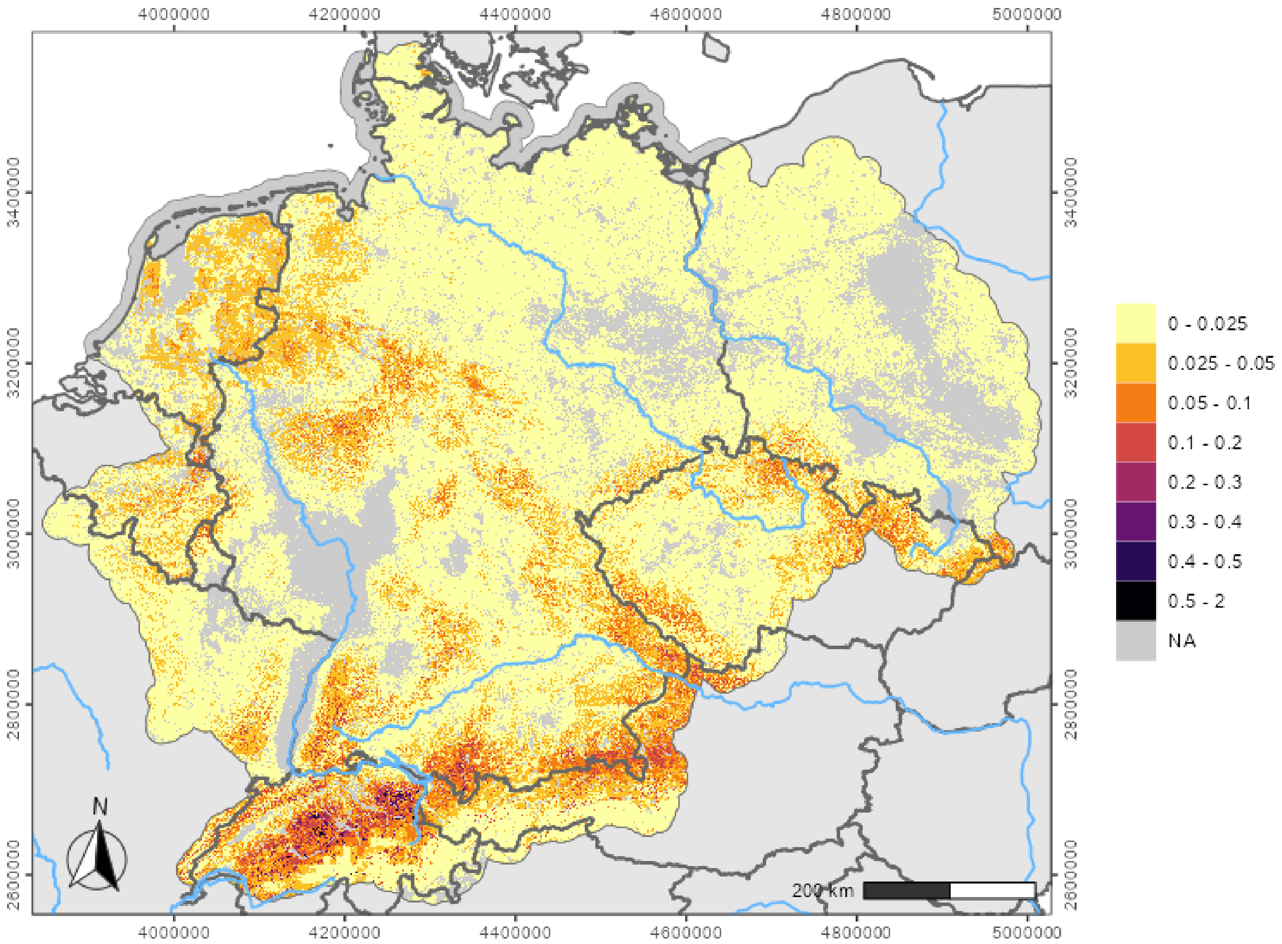


November 2015

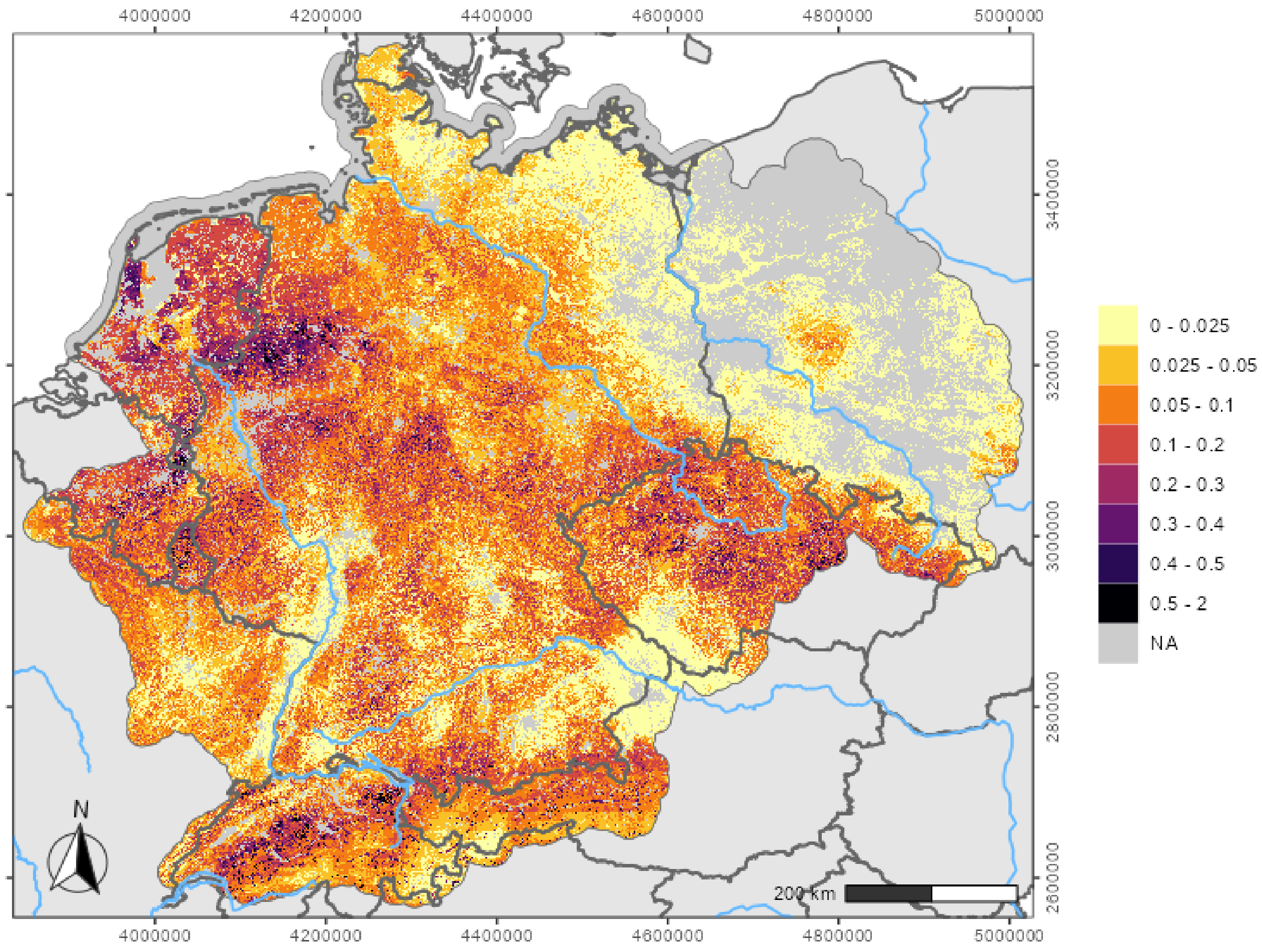


Case study: Germany, TN emissions from surface runoff [kg ha^{-1}]

March 2015



August 2015



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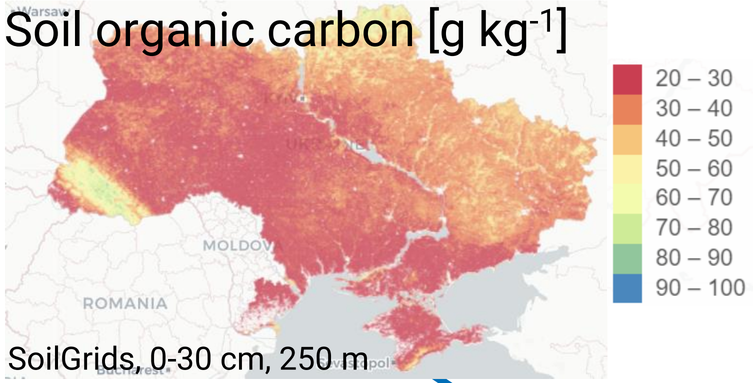
Case Study Ukraine: Modelling denitrification in inundated soils

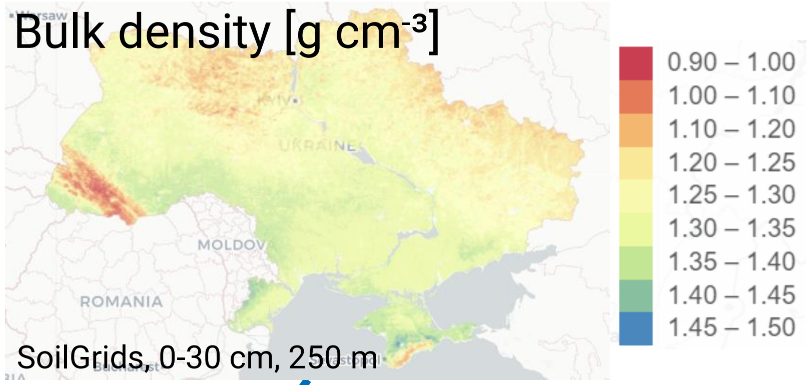
$$D = pD \cdot fpH \cdot fT \cdot fCS \cdot fNO3 \cdot Fd$$

D	= modelled denitrification of riverine NO3, in kg/ha/yr
pD	= potential Denitrification
fpH	= reduction function for top soil pH
fT	= temperature
fCS	= clay and silt content
fNO_3	= mean NO_3 concentration in water
Fd	= mean annual flooding duration

Tschikof et al. (2022): https://doi.org/10.1016/j.scitotenv.2022.156879

Potential Denitrifaction in Soils





pD = $(0.059\, SOC - 0.23) * BD * Uf$

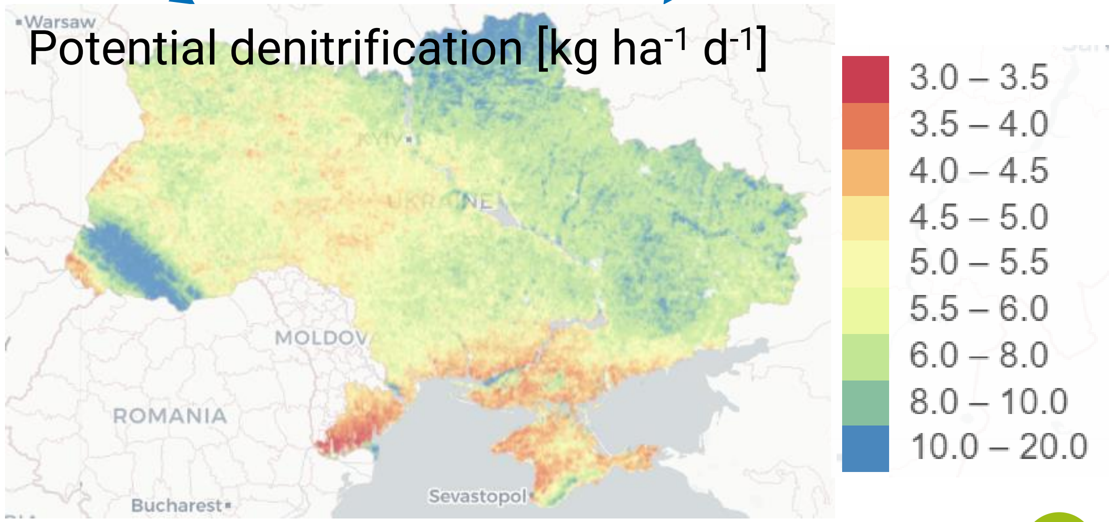
pD: potential Denitrification in kg ha^{-1} d^{-1}

SOC : Soil Organic Carbon, in g kg^{-1}

BD: Bulk Density, in g cm^{-3}

Uf = unit correction factor

(Dodla et al., 2008, modified)



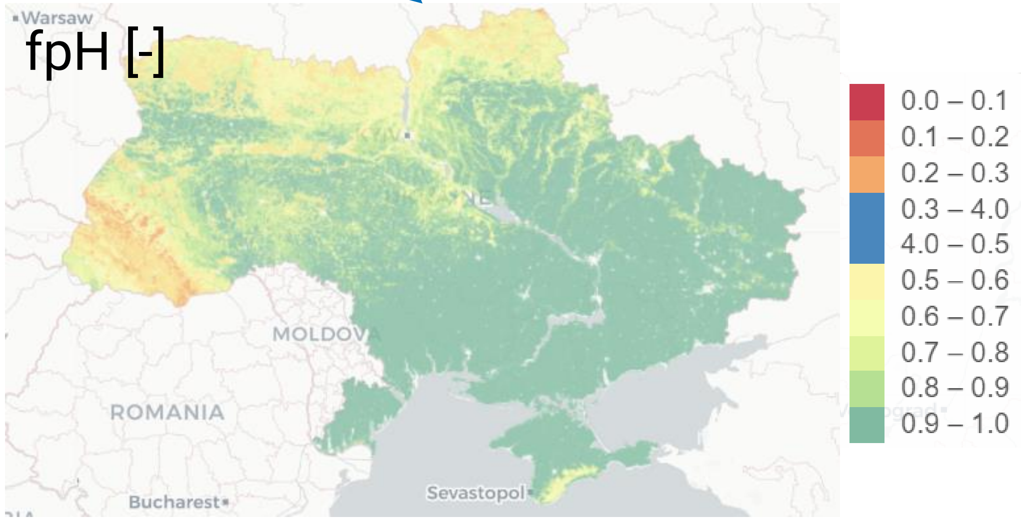
Reduktionfactor for pH due to increased pH values

$$\text{fpH} = e^{-(pH-7.25)^{\frac{2}{3}}}$$

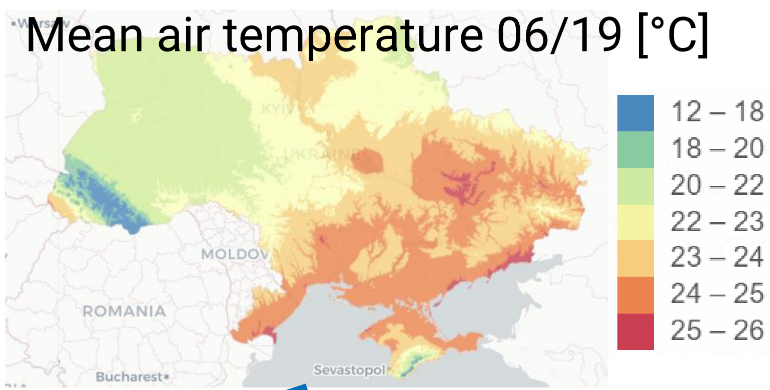
fpH: pH dependent reduction factor [-]

pH: pH value in soil water

(Heinen, 2006)



Reduction function due to low mean annual temperatures



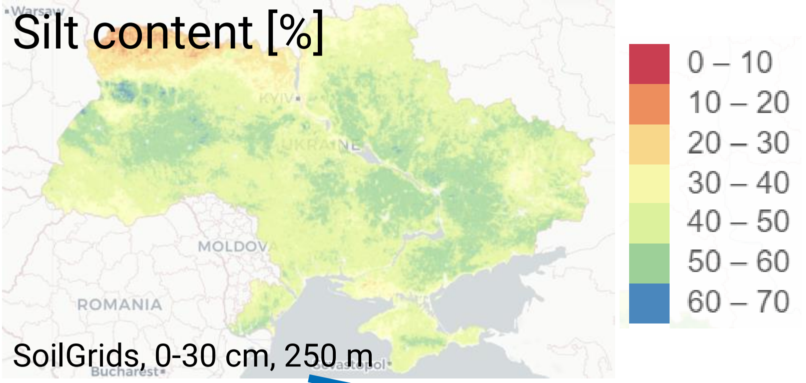
$$fT = 2^{\frac{T-16}{10}}$$

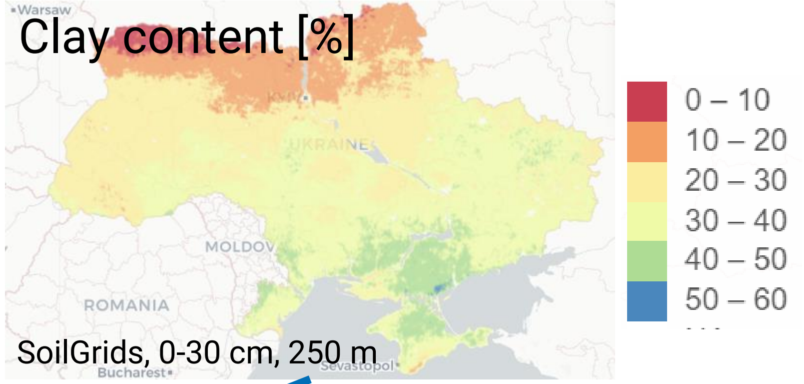
fT: Air temperature reduction factor [-]

T: Air temperature at ground level [°C]

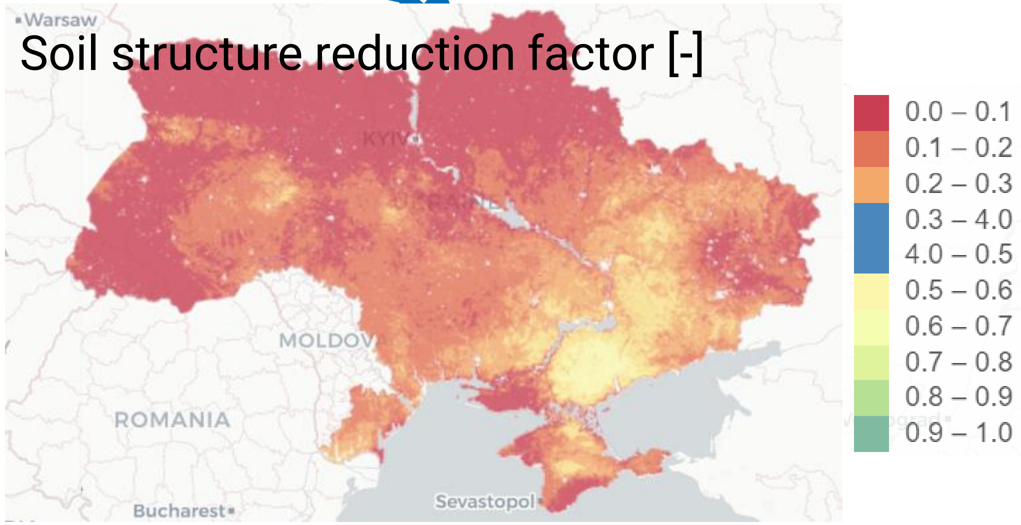
(Heinen, 2006)

Reduction function due to coarser soil structure





fCS = $0.0897^{\,0.0426\,(100-CS)}$



fCS: soil structure reduction factor [-]

CS: share of clay + silt in topsoil [%]

(Pinay *et al.*, 2000, 2007, modified)

Adaption function according to changing riverine NO_3 concentrations and local elevation

$fNO_3 = \frac{N}{K+N}$

fNO_3: riverine concentration adaption factor, without unit

N: NO_3 concentration in mgL^{-1}

K: constant reference concentration (7.2 mgL^{-1})

fNO_3 = 0.33 (for N = 3.5 mgL^{-1})

fNO_3 = 0.49 (for N = 7 mgL^{-1})

(Heinen, 2006; Ghane, Fausey and Brown, 2015)

$Fd = -70.559 \ln(z + 0.50) + 88.711$

Fd: adaption factor due to flooding frequency, without unit

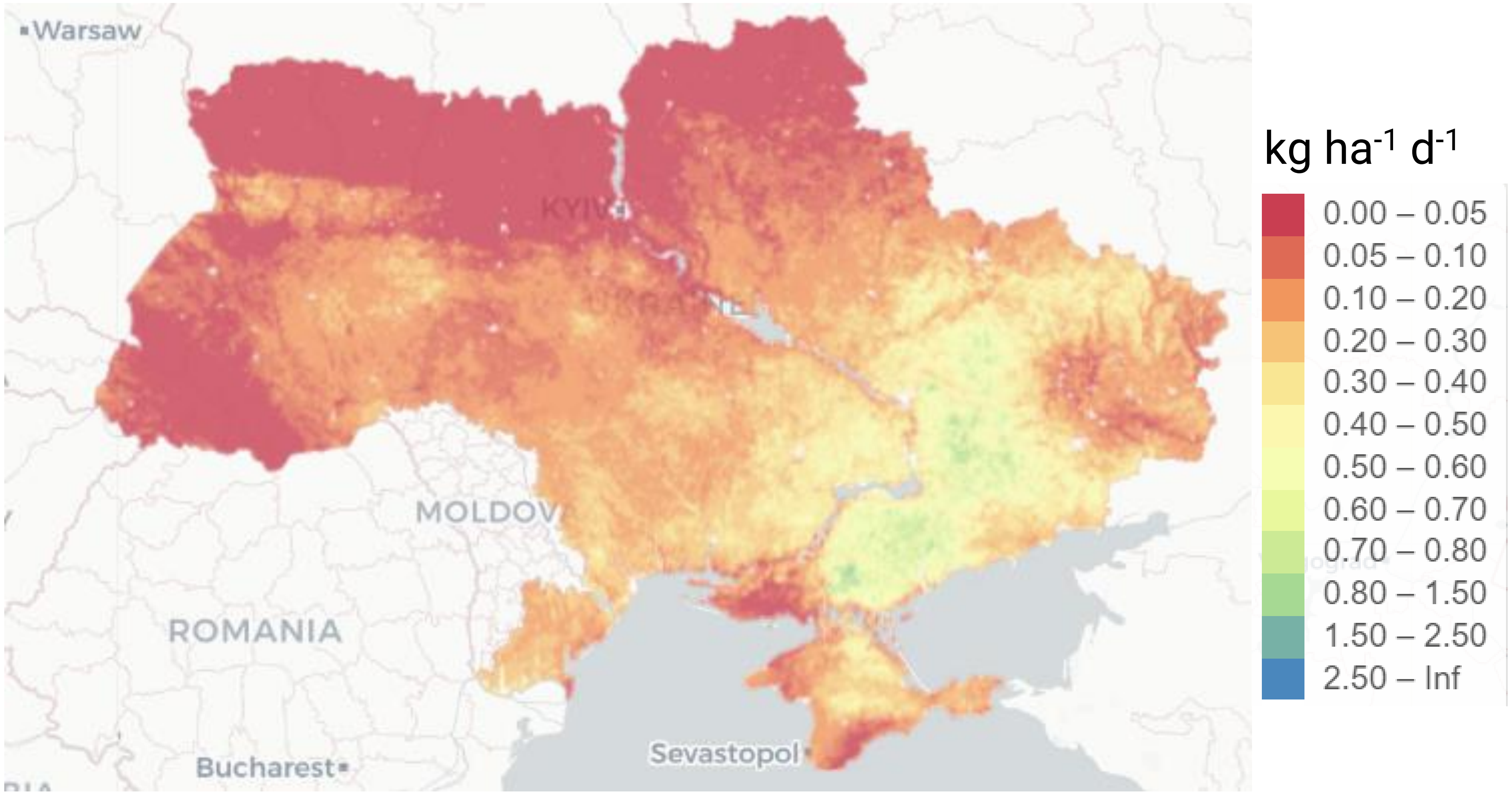
z: elevation relative to mean water level in m

Needs to be calibrated for local conditions.

In case of Kakhovka dam breach flooding frequency does not have to be derived.

(Schleuter, 2016)

Modelled denitrification of riverine NO_3 in inundated areas



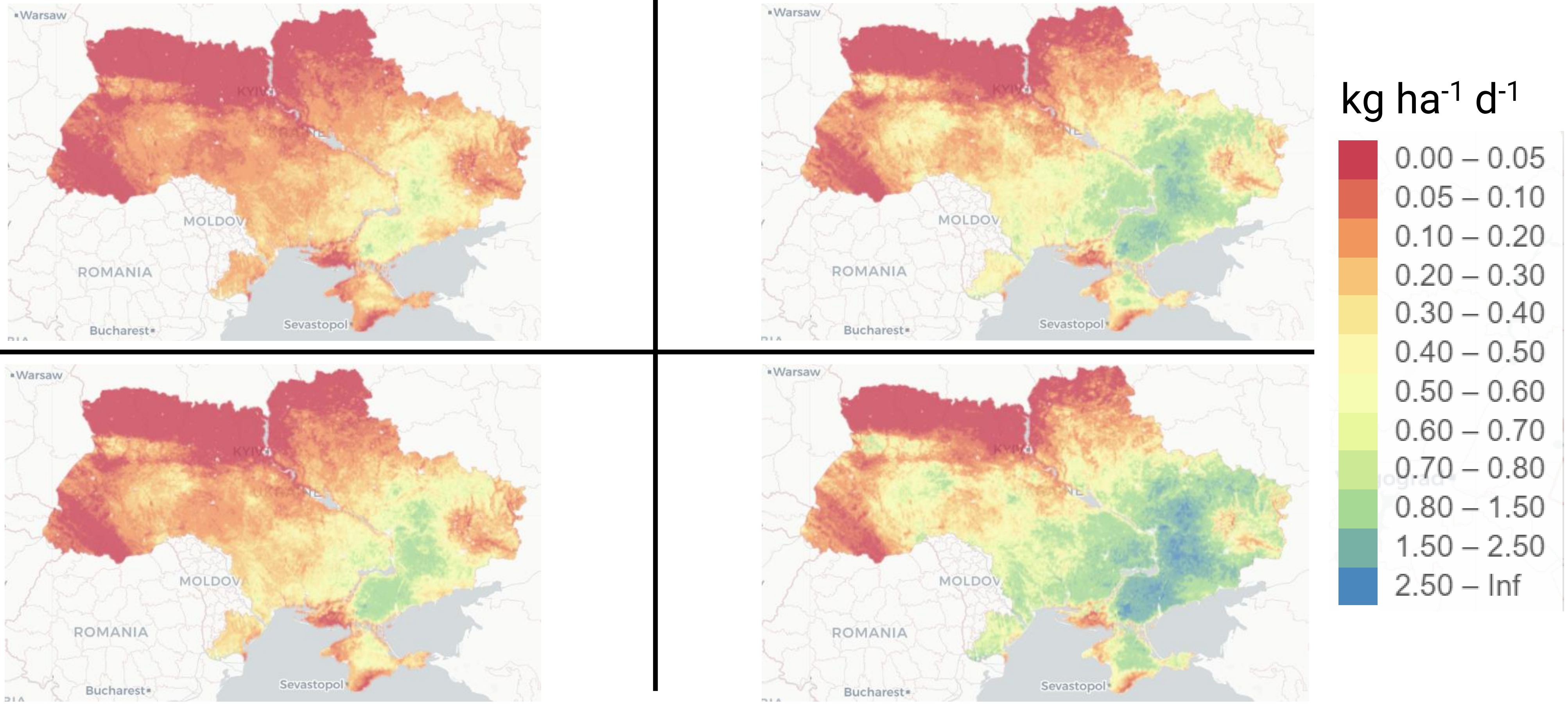
Variable denitrification rates

Mean annual air temperature in 2019 | Mean air temperature in June 2019

Riverine NO_3 concentration

3.5 mgL^{-1}

7 mgL^{-1}



Oprei, A., Huk, V. & Venohr, M.: Modelling of nutrient emission in river systems (MONERIS): Presenting new perspectives and current developments of a widely used emission model

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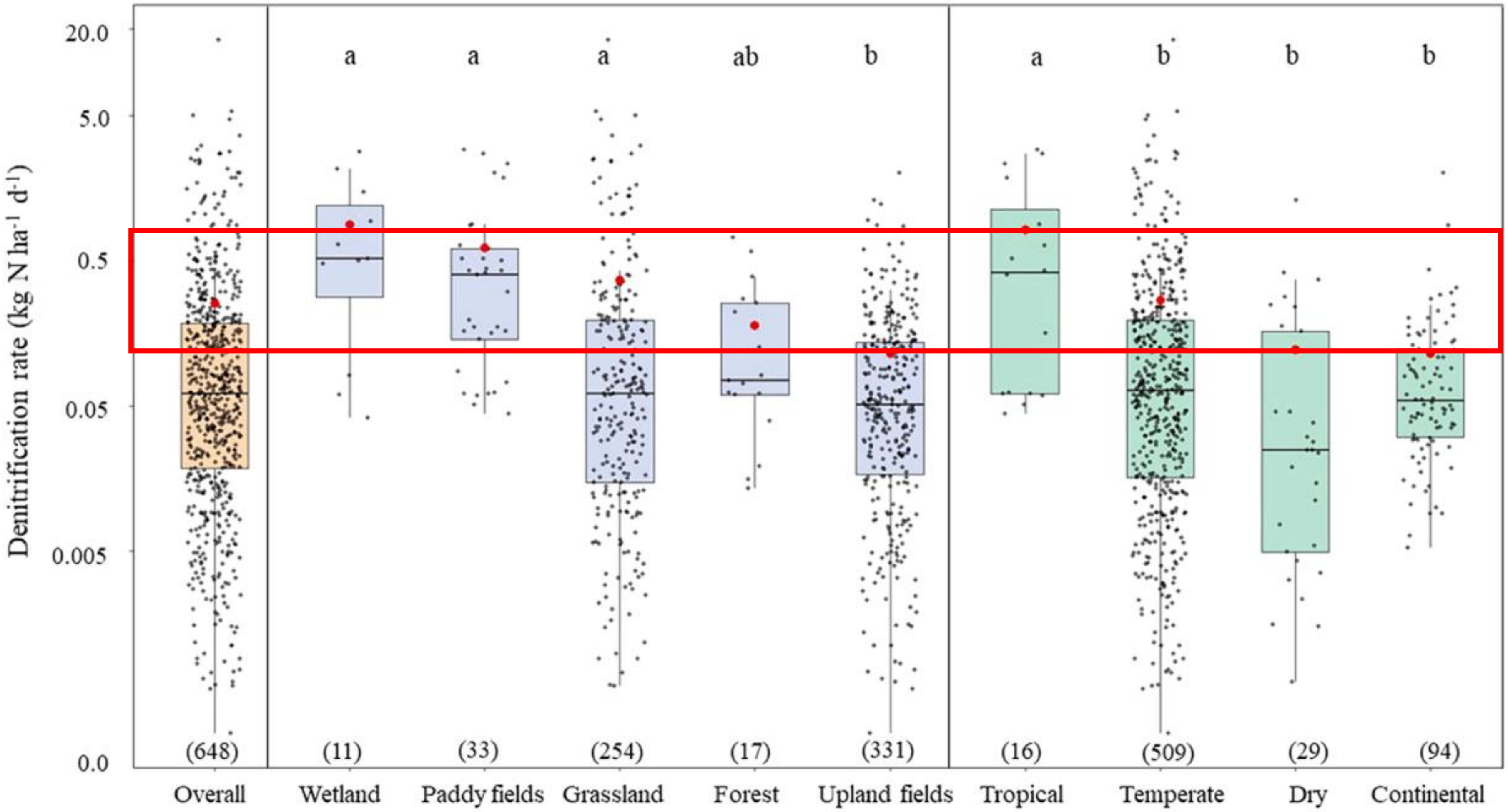
Comparison with globally monitored denitrification rates

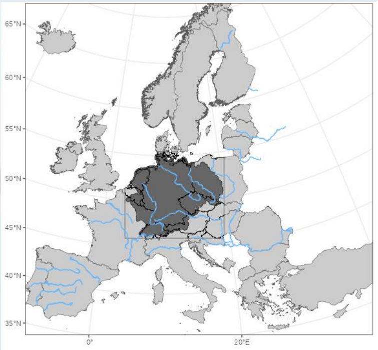


Pan et al. (2022), https://doi.org/10.1016/j.agee.2021.107850

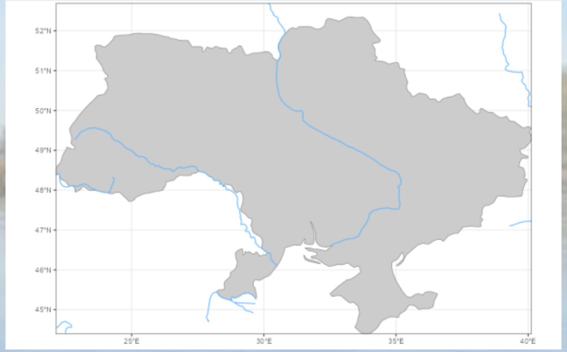
Showcase examples…

Odra river

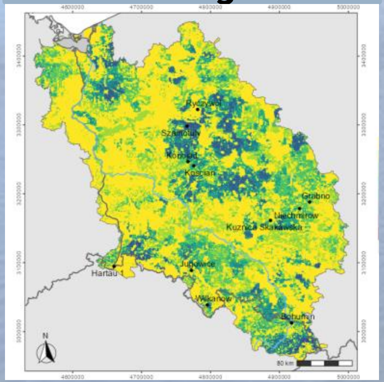
German river basins



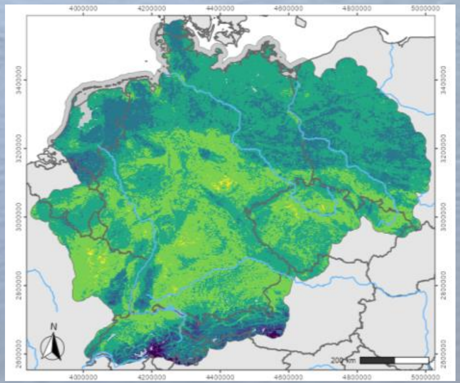
Ukraine



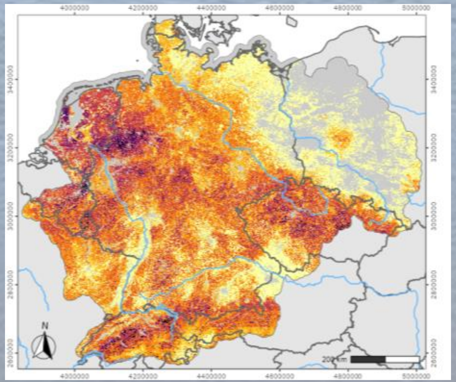
Mean runoff from tile drainages



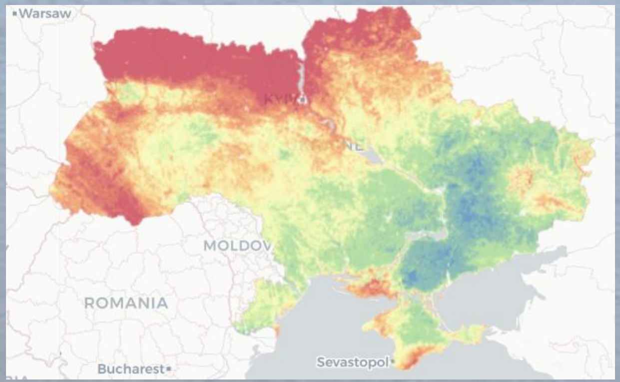
Monthly total runoff



TN emissions from surface runoff



Denitrification rates



What next?

- Incorporate phytoplankton, floodplain and groyne field retention
- Allow modelling of other substances (e.g. salinity, heavy metals or priority substances)
- Develop an open modelling platform

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Thank you for your attention!

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moneris