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Testing the distributed hydrological wflow_sbm concept across different geographical domains

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Hills Rwanda, Photo Mark de Bel,

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Introduction

- Wflow_sbm, a distributed hydrologic model, fits well between low-resolution, low-complexity and high-resolution, high-complexity hydrologic models:
  - *gravity-based infiltration and vertical flow throught the soil column as well as capillary rise represents a simplified version of the Richards' equation. A1-D kinematic wave approach for channel, overland and lateral subsurface flows similar to TOPKAPI (Todini and Ciarapica , 2002), G2G (Bell et al. , 2007), 1K-DHM (Tanaka and Tachikawa , 2015) and Topog_SBM (Vertessy and Elsenbeer , 1999) is used as an approximation for dynamic waves and variably saturated subsurface flow (Richards' equation).*
  - The advantage of this approach is that most wflow_sbm parameters have a clear physical meaning and at the same time wflow_sbm has a run time performance well suited for large scale modelling.
- This allows us to automatically setup a high resolution (~1km^2) wflow_sbm model for any basin in the world:
  - We apply available point-scale (pedo)transfer functions (PTFs) with upscaling rules (see Imhoff et al., 2020) to global datasets to ensure flux matching across scales (Samaniego et al., 2010, 2017)
  - A new method ("Connecting Outlets Method" (COM)) to automatically upscale flow direction data to model resolution shows promising results (Eilander et al., *in prep*, "Global multi-resolution hydrography data")
- As a final result we have a ***calibration-less*** wflow_sbm model:
  - depending on the geographical area of interest two model parameters, besides anthropogenic interference like reservoir and lake management, show most sensitivity: rooting depth and horizontal saturated hydraulic conductivity.

- Here we test the wflow_sbm concept across different geographical domains (USA, Europe, Africa, New Zealand and more testing and applications are underway)

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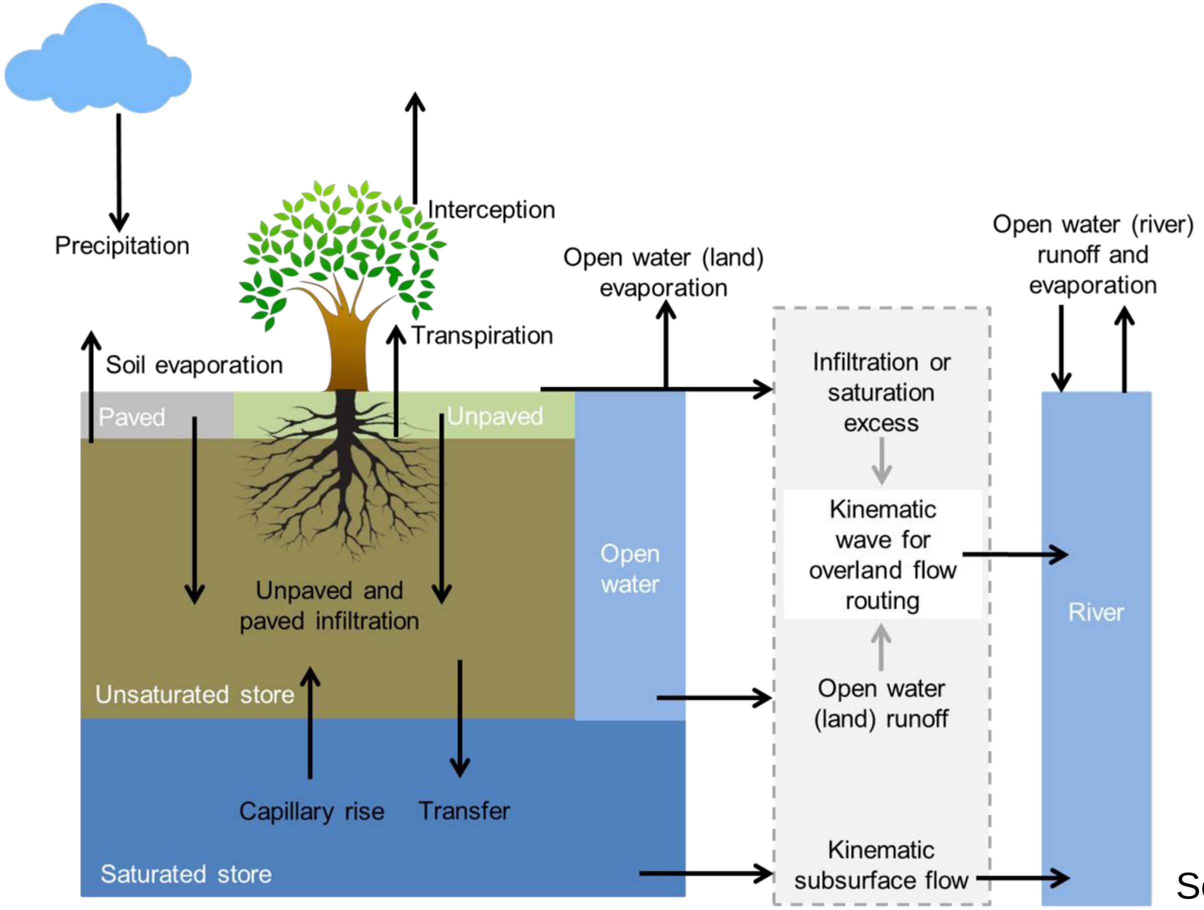
Wflow_sbm (simple bucket model)

Part of wflow, the Deltares' OpenStreams project, an open source modelling framework for distributed hydrologic modelling



Loosely based on Topog_SBM (Vertessy and Elsenbeer, 1999), main differences:

- Addition of evapotranspiration and interception losses.
- addition of a root water uptake reduction function (Feddes et al. , 1978).
- addition of capillary rise.
- addition of glacier and snow build-up and melting processes (where relevant).
- routes water over an eight direction (D8) network
- multiple soil layers optional

See also:
https://wflow.readthedocs.io/en/latest/wflow_sbm.html
https://wflow.readthedocs.io/en/latest/

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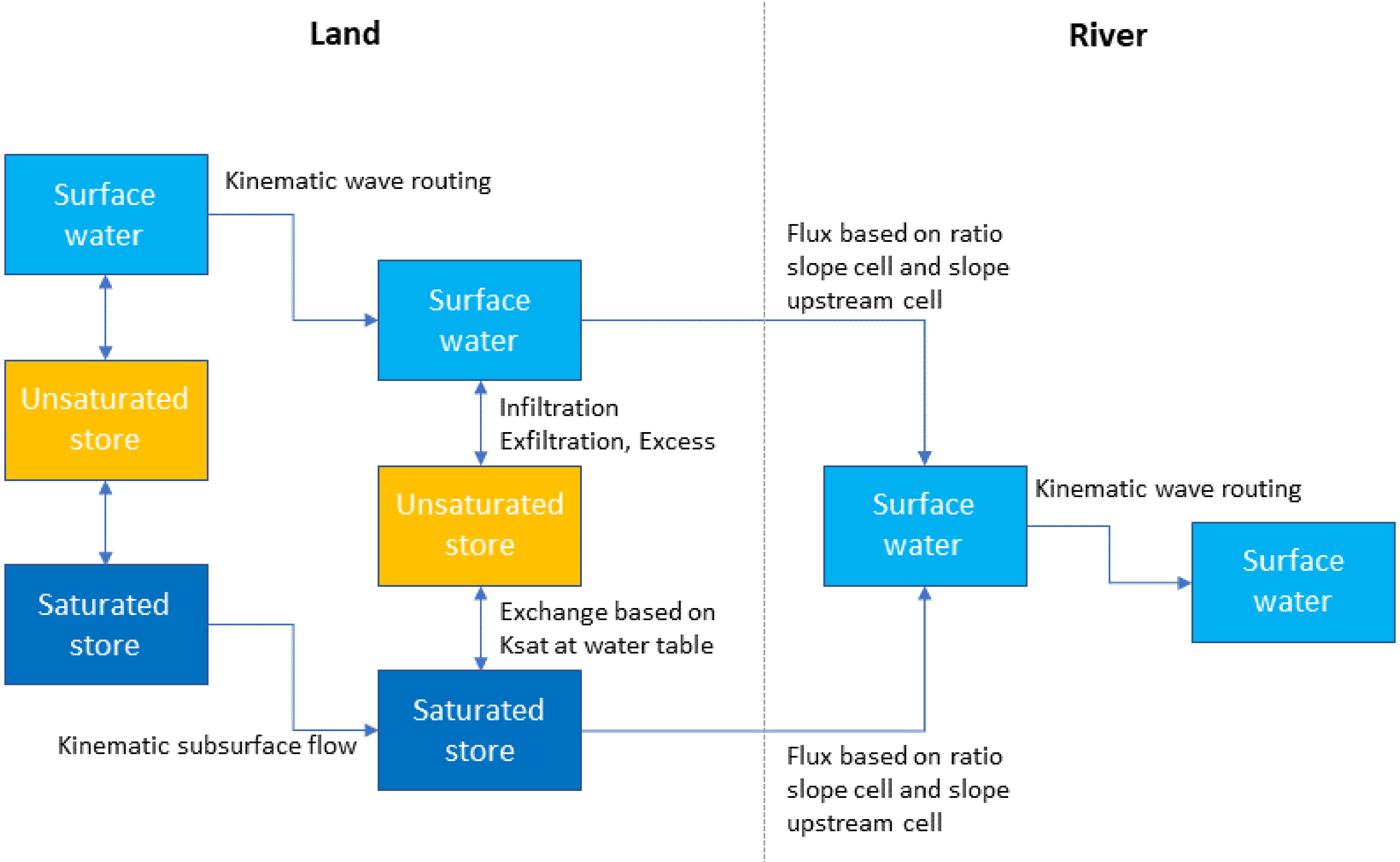
Wflow_sbm processes and modules



Schematisation of the soil and the connection to the river within the wflow_sbm model

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Estimation of wflow_sbm parameters

- Based on earlier work by Imhoff et al (2020) that focused on the entire Rhine basin.
- Using available point-scale (pedo)transfer functions (PTFs) with upscaling rules to ensure flux matching across scales (Samaniego et al., 2010, 2017, Imhoff et al., 2020)
- Data sets (global) used to setup a wflow_sbm model for any basin in the world (Python scripts):

Soil:

- SoilGrids (Hengl et al. (2017)) at ~250 m resolution
- Depth to impermeable layers for Europe (ESDAC, 2004)

Land cover:

- GlobCover-2009 (Arino et al., 2010) at ~300 m resolution

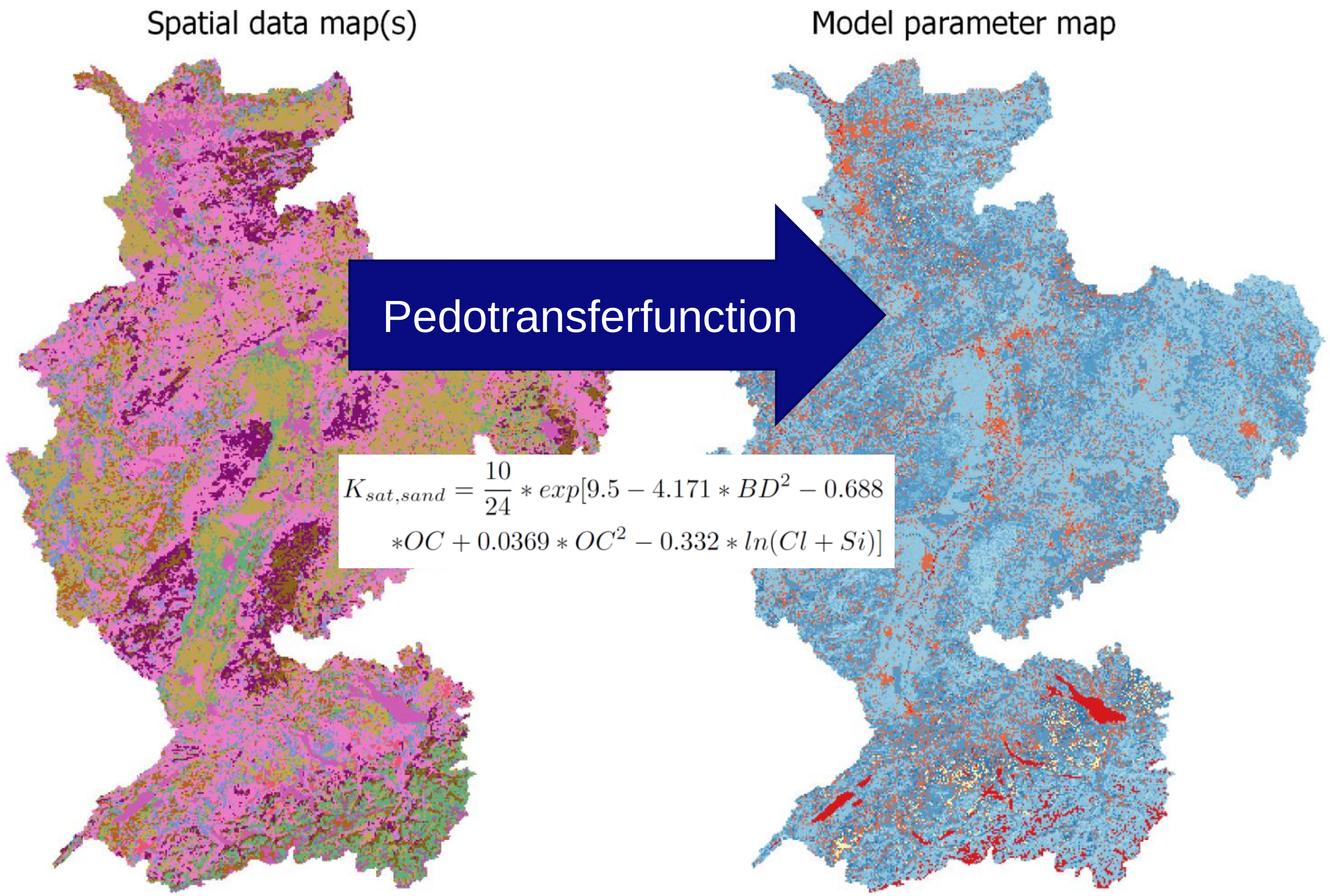
Hydrography (flow direction, upstream area, stream order, river slope β_{river}, river length L_{river}, river width W_{river})

- MERIT Hydro (Yamazaki et al., 2019) at ~90 m resolution
- Discharge data from Global Runoff Data Center (GRDC)
- CHELSEA dataset at ~1 km resolution (Karger et al., 2017)
- Köppen–Geiger climate zone map (Kottek et al. , 2006)

Lake and reservoir model parameters:

- HydroLAKES Version 1.0 (Messager et al. , 2016)
- GRanD v1.01 (Lehner et al. , 2011)
- GWSO (Pekel et al., 2016) extracted with https://github.com/openearth/hydro-engine

Wflow_sbm parameter estimation (global)



$$K_{sat,sand} = \frac{10}{24} * exp[9.5 - 4.171 * BD^2 - 0.688 * OC + 0.0369 * OC^2 - 0.332 * ln(Cl + Si)]$$

PTFs and upscaling operators

A = arithmetic mean
λ = pore size distribition index (Brooks Corey, 1964)

Parameter	PTF by	Upscaling operator	Additional notes
c	Rawls and Brakensiek (1989)	$\log A$	λ upscaled with $\log A$, c determined from λ at model resolution
k	Van Dijk and Bruijnzeel (2001)	A	Look-up table from land cover
kv	Brakensiek et al. (1984)	$\log A$	For the soil depths z: 0, 5, 15, 30, 60, 100 and 200 cm
LAI	Myneni et al. (2015)	A	
M			Fitting exponential function between kv and z
N_{land}	Engman (1986); Kilgore (1997)	A	Lookup table land cover
N_{river}	Liu et al. (2005)	A	Lookup table land cover
RTD	Schenk and Jackson (2002); Fan et al. (2016)	A	d_{75} rooting depth, lookup table land cover
Sl, S_{wood}	Pitman (1989); Liu (1998)	A	Lookup table land cover
β_{river}, L_{river}			Based on MERIT Hydro
W_{river}			Based on MERIT Hydro, GRDC, CHELSEA, Köppen–Geiger climate zones
β_{land}	Horn (1981)	A	Based on MERIT Hydro
$Soilthickness$	Hengl et al. (2017); ESDAC (2004)		
θ_s, θ_r	Tóth et al. (2015)	A	

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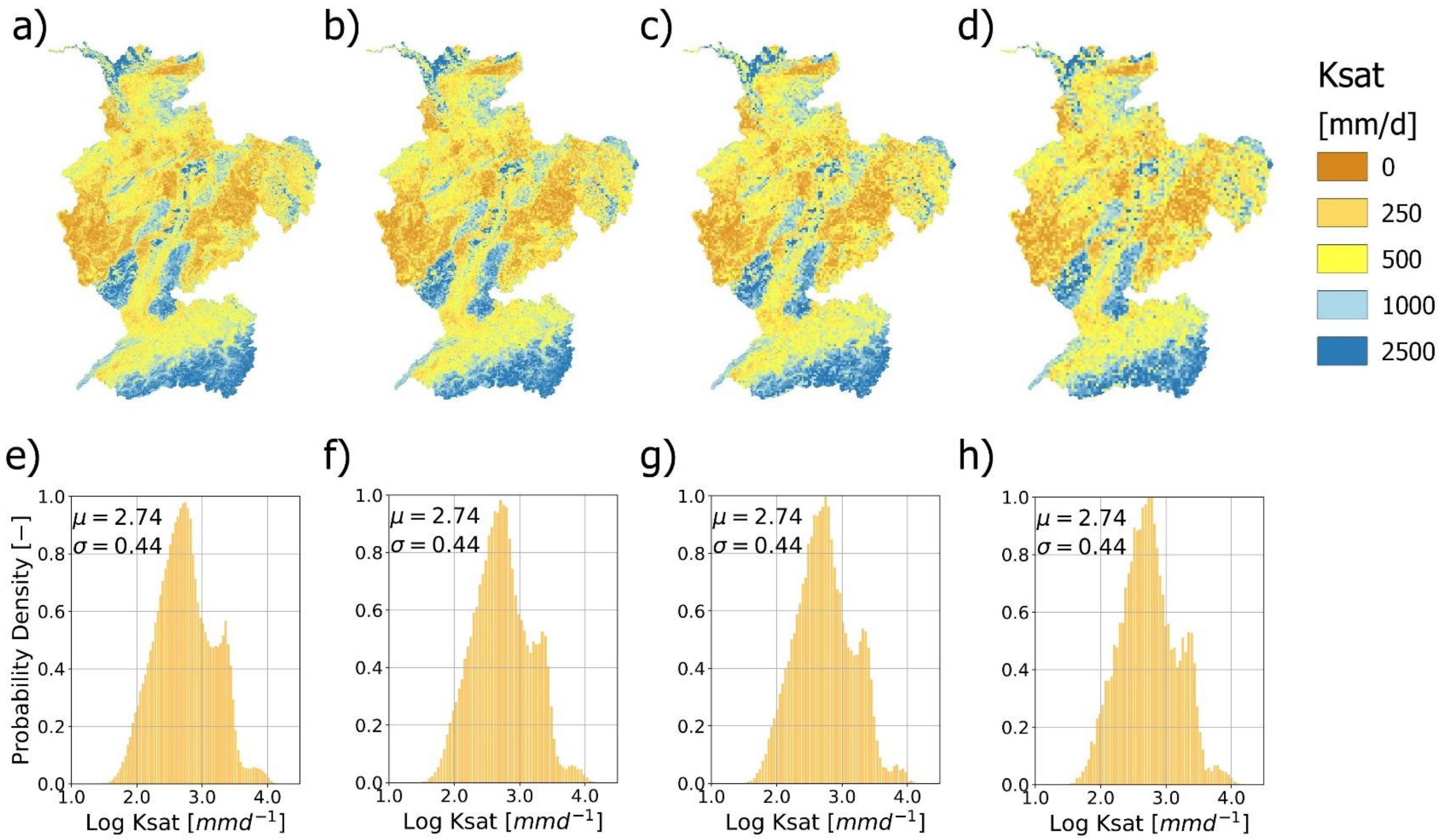
wflow_sbm parameter upscaling



Imhoff, R. et al., *Water Resources Research, 2020.*

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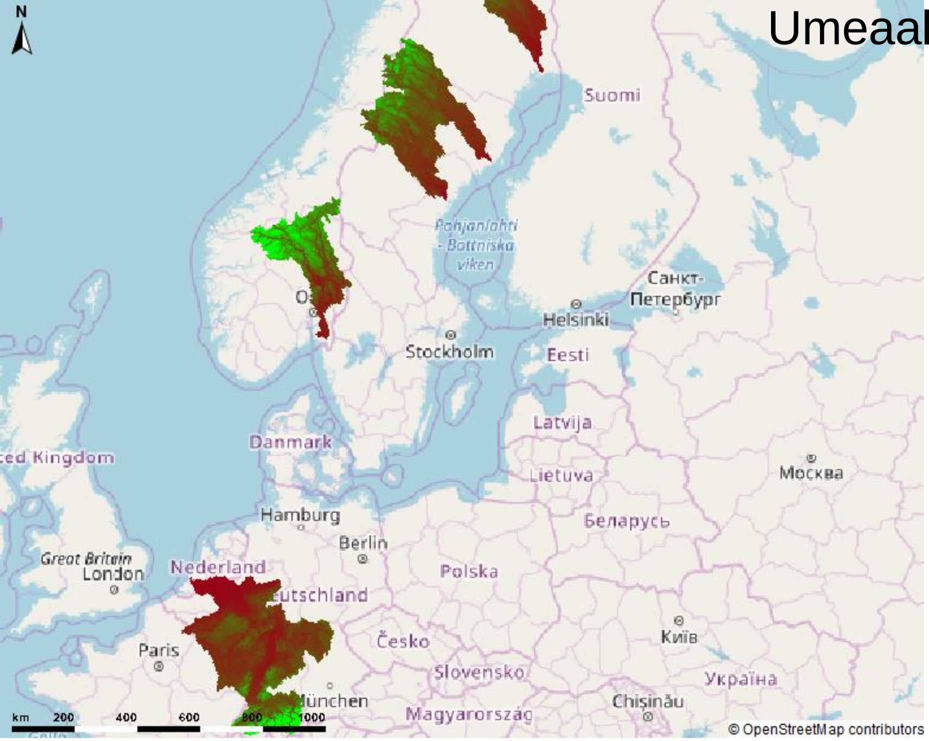
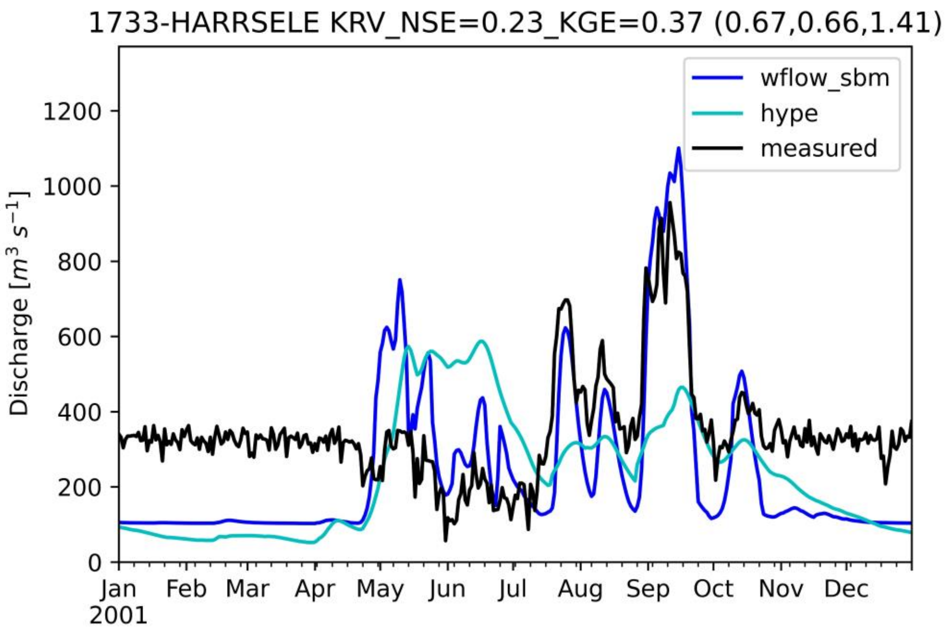
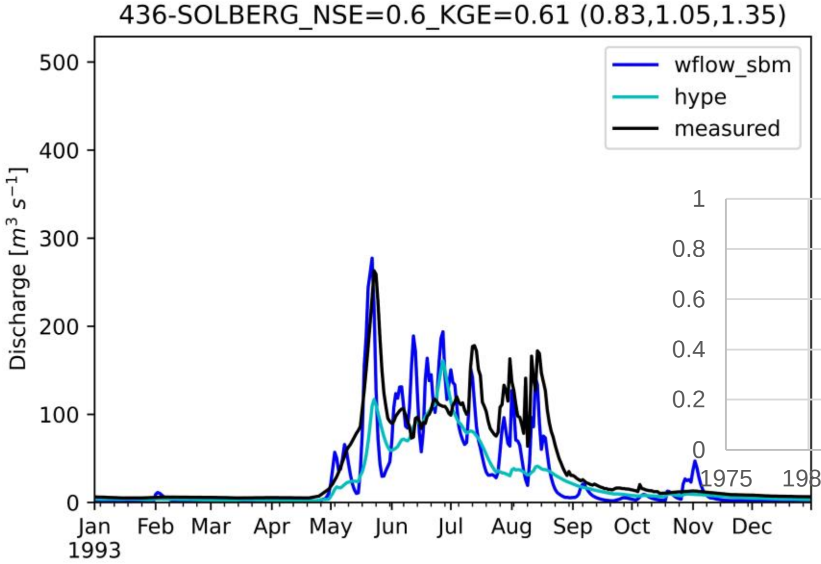
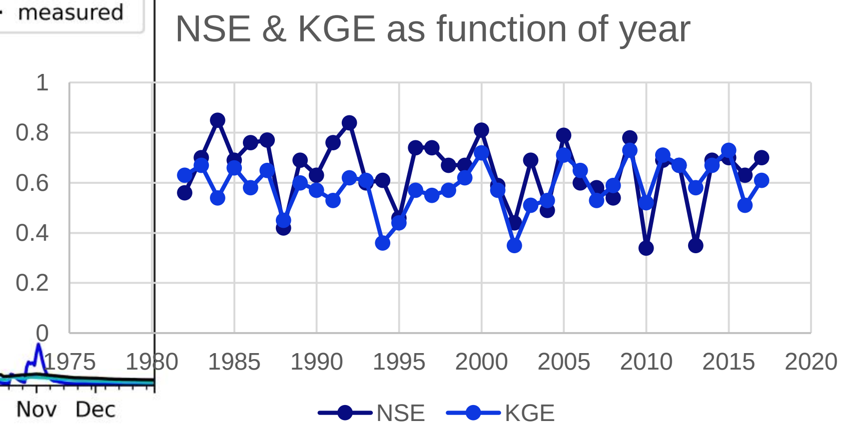
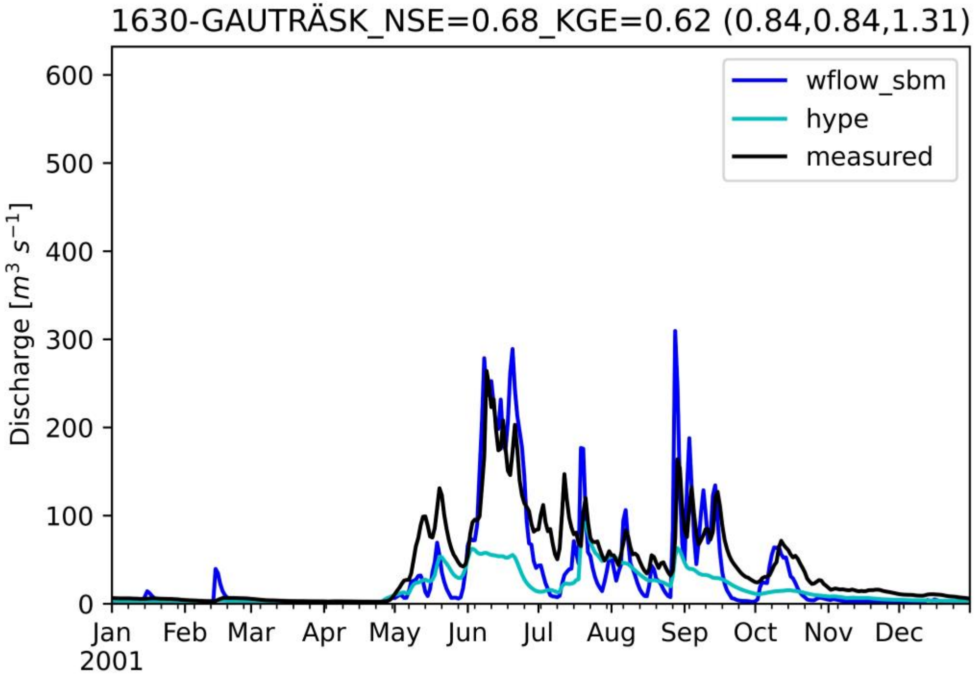
Umeaalven (forcing ERA5 rainfall and ERA5 PET (de Bruin et al. 2016)







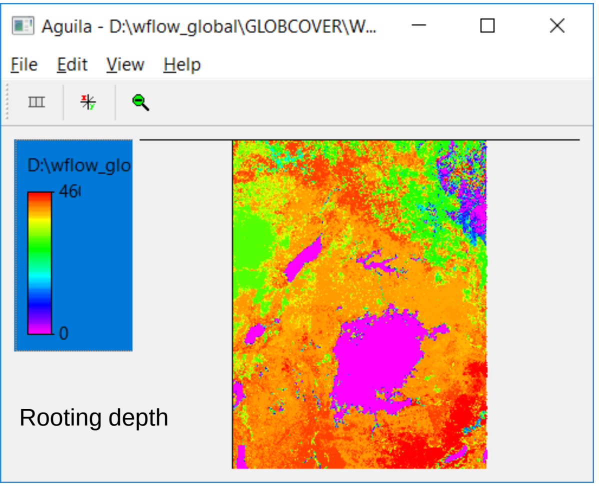


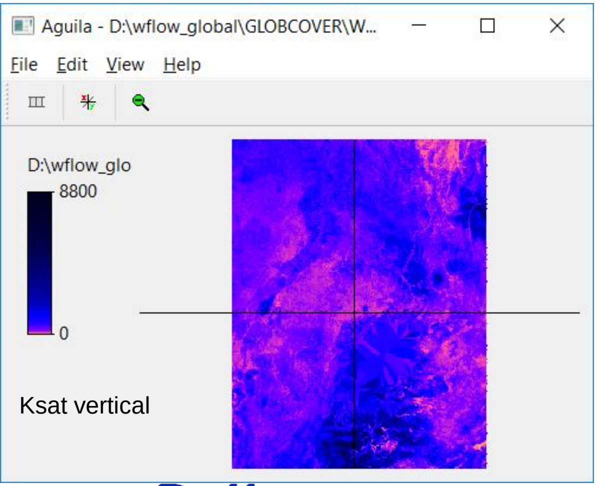


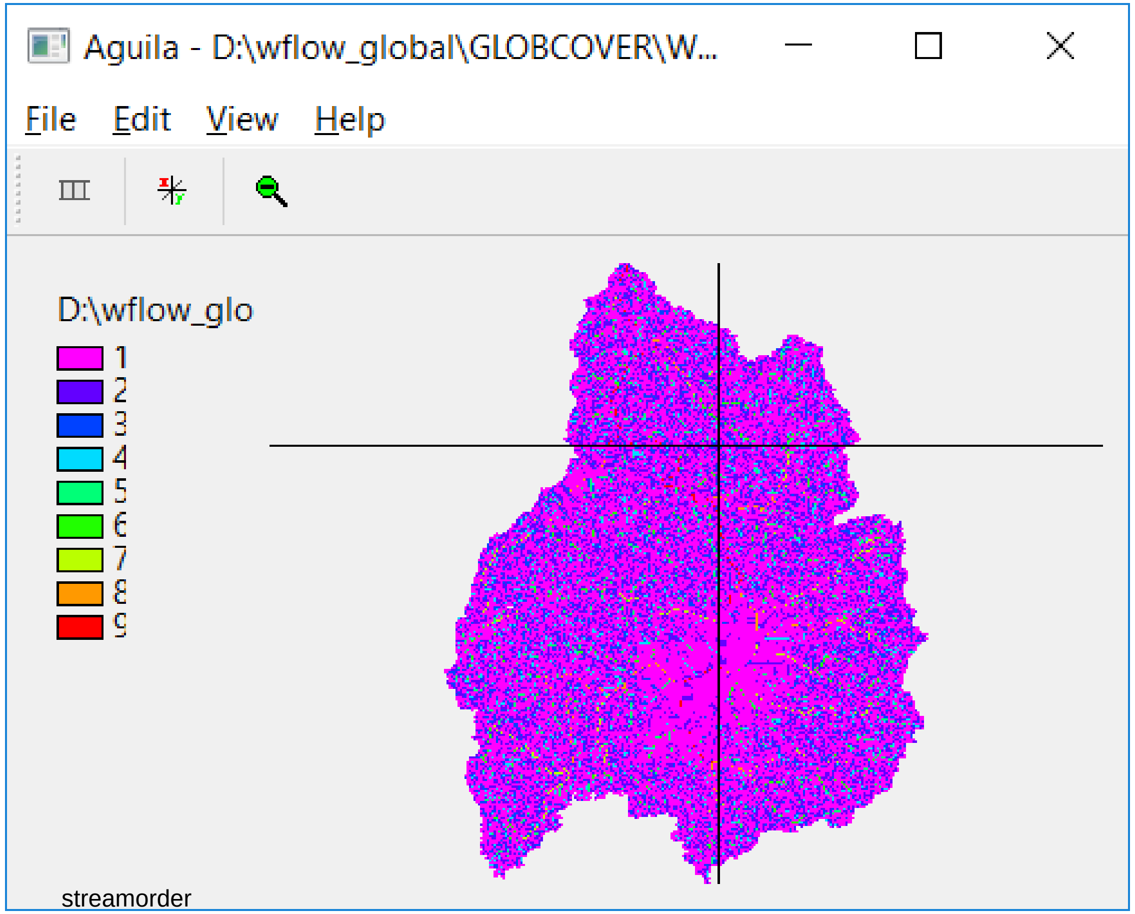
Rhine see Imhoff et al. 2020 WRR

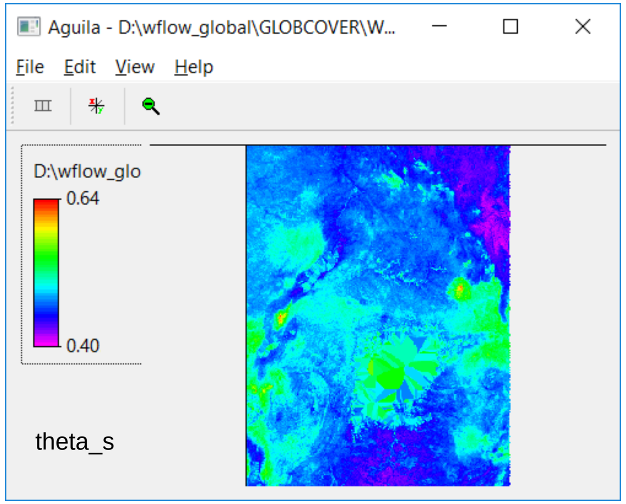
White Nile (upstream of Juba)

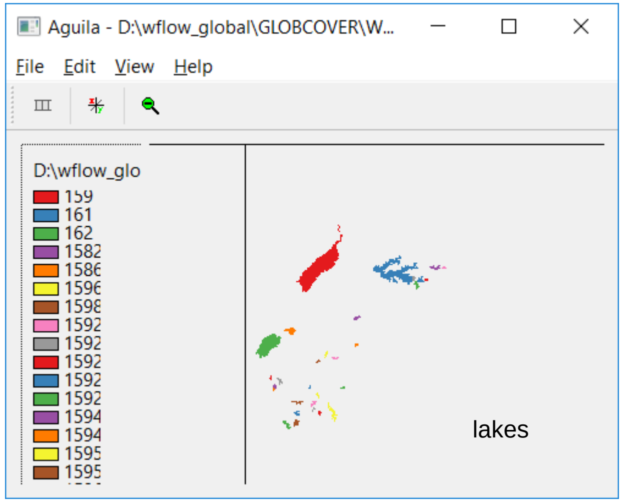
- Use of CHIRPS for rainfall, downscaled ERA5 for estimating PET (de Bruin et al., 2016)
- Ksathorfrac=100 (lateral conductivity)





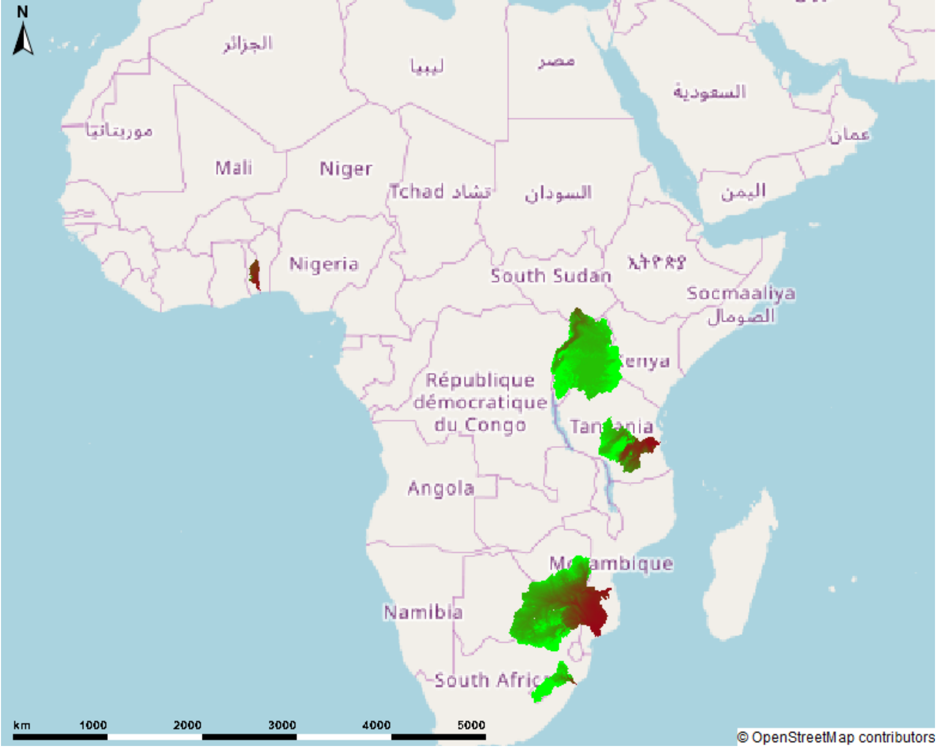


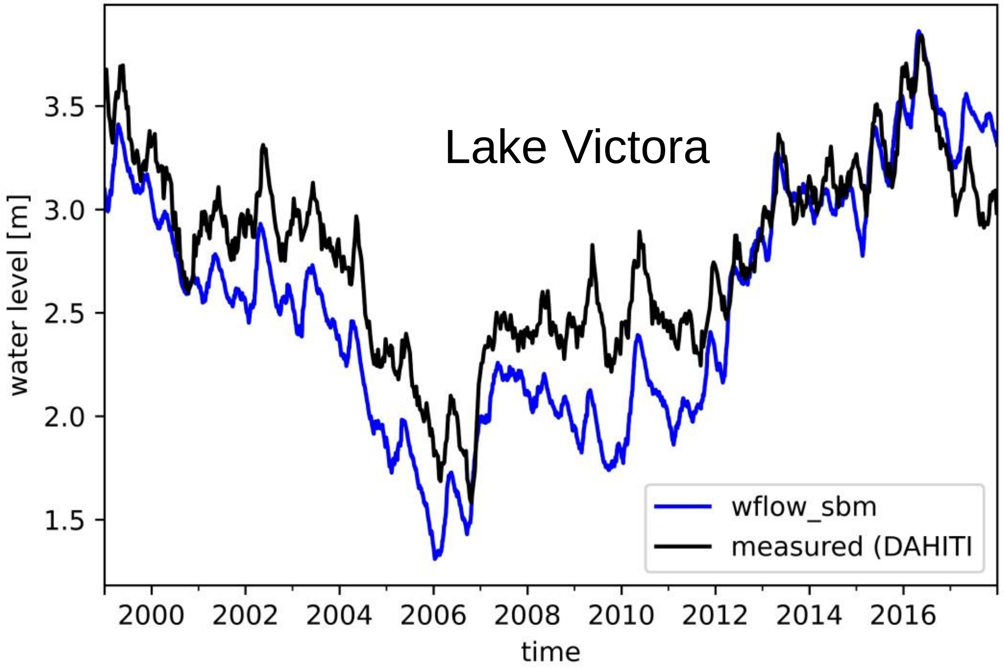


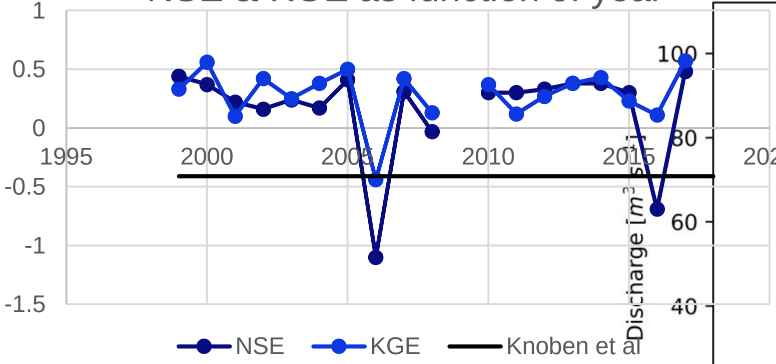


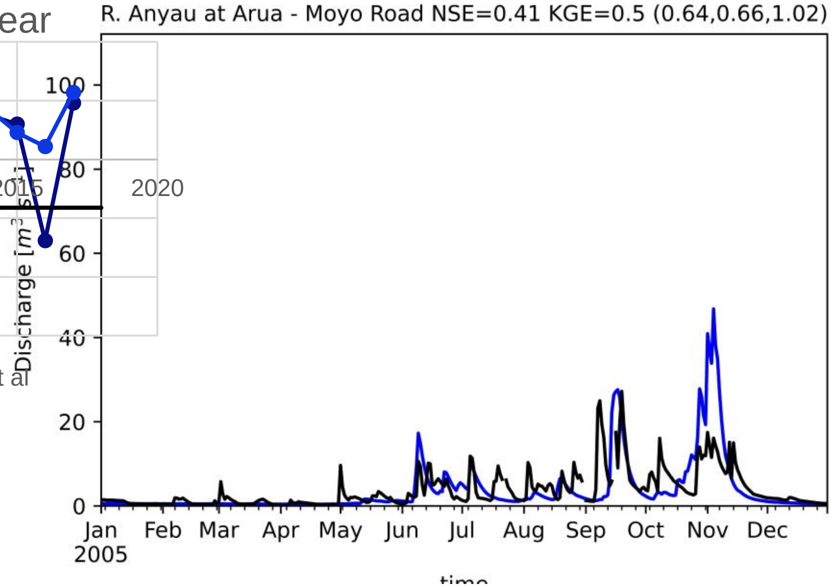
White Nile (upstream of Juba)

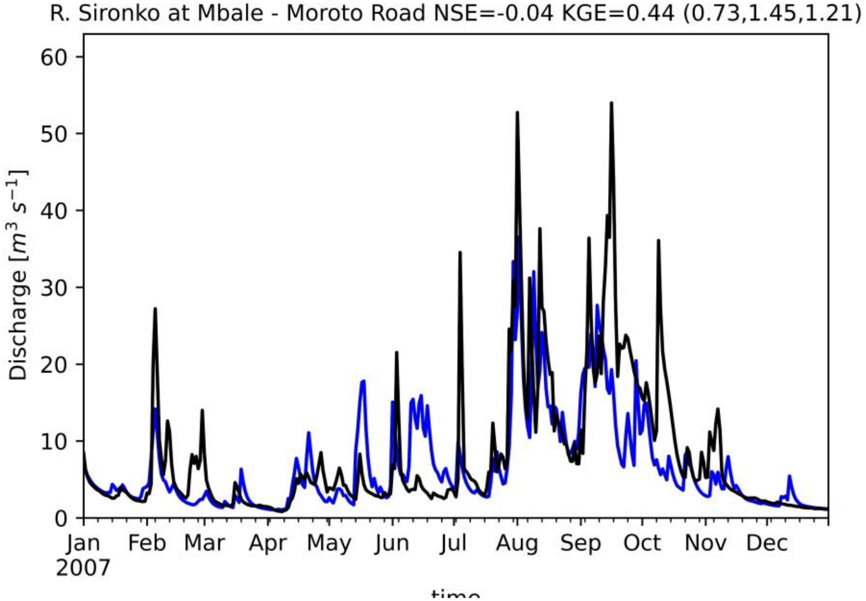
In collab with Nynke Hofstra











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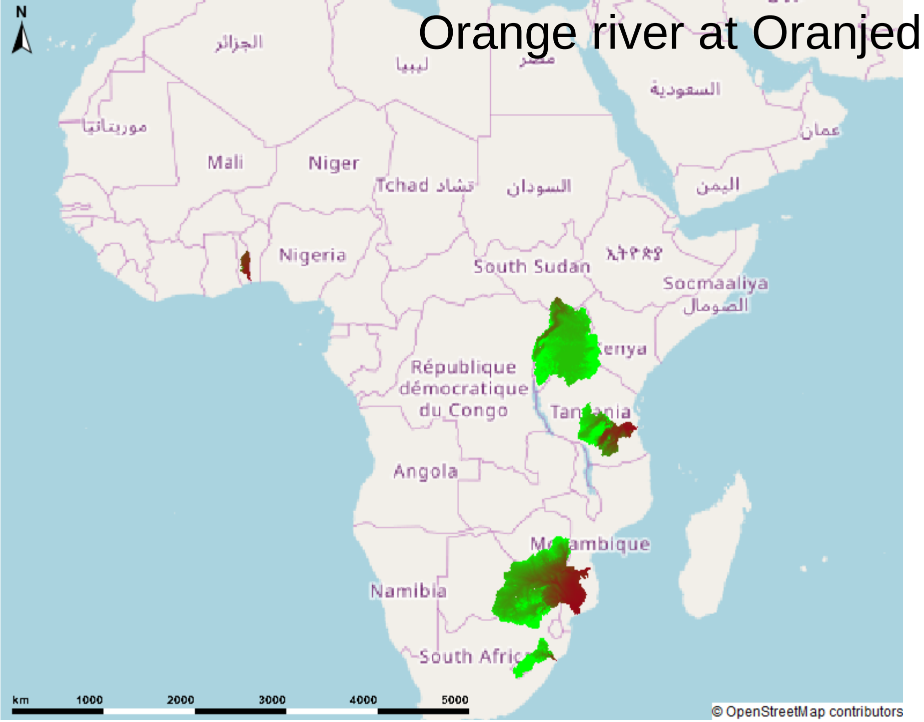
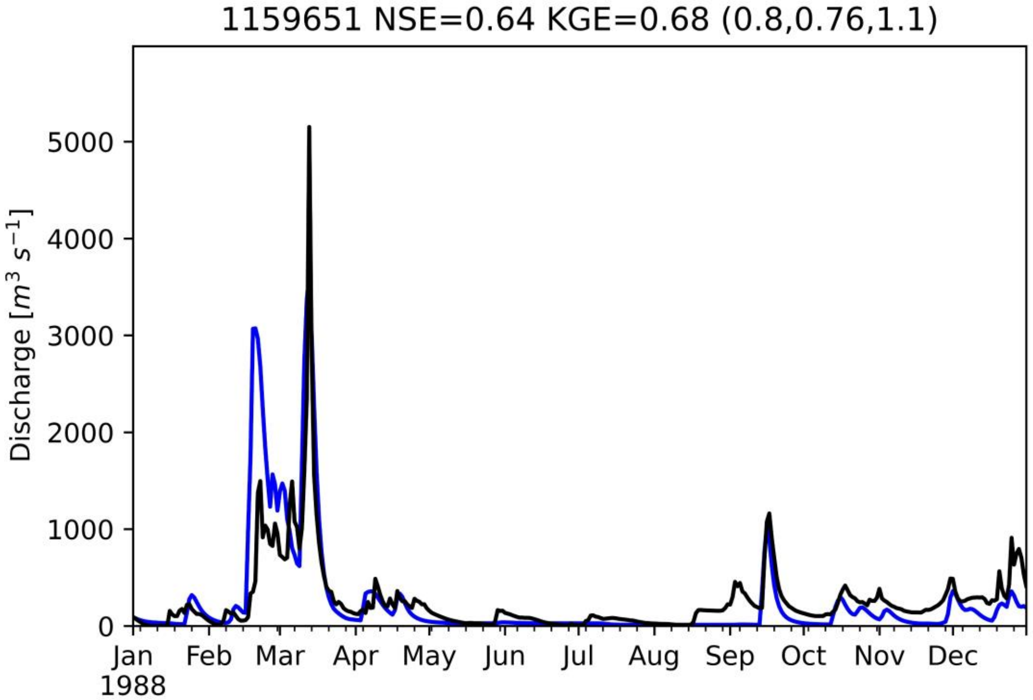
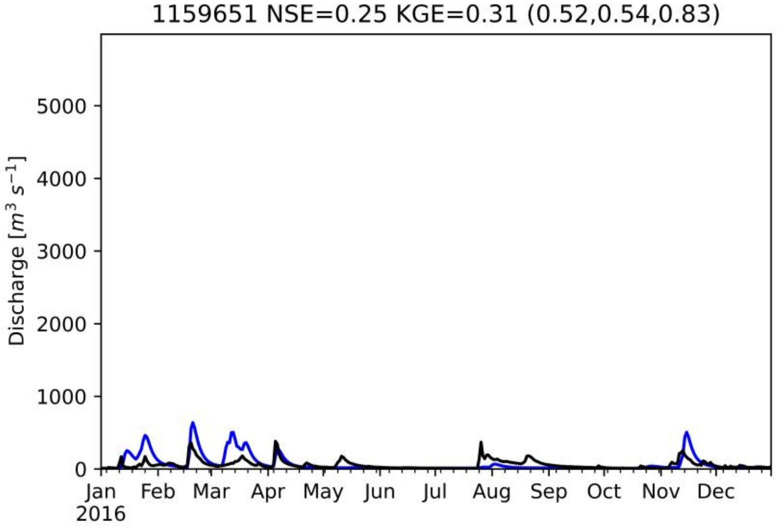
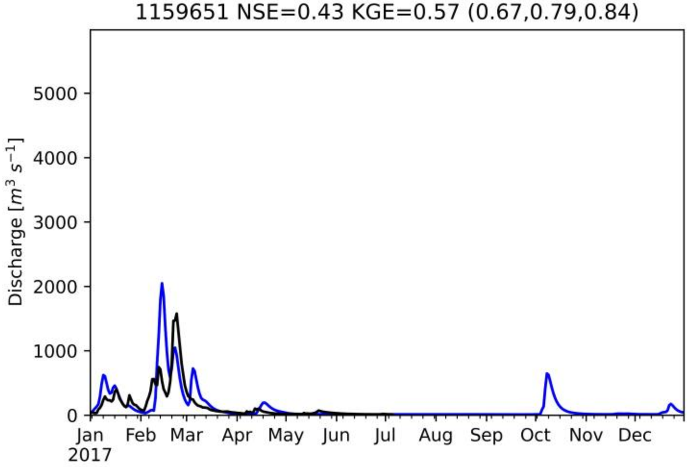
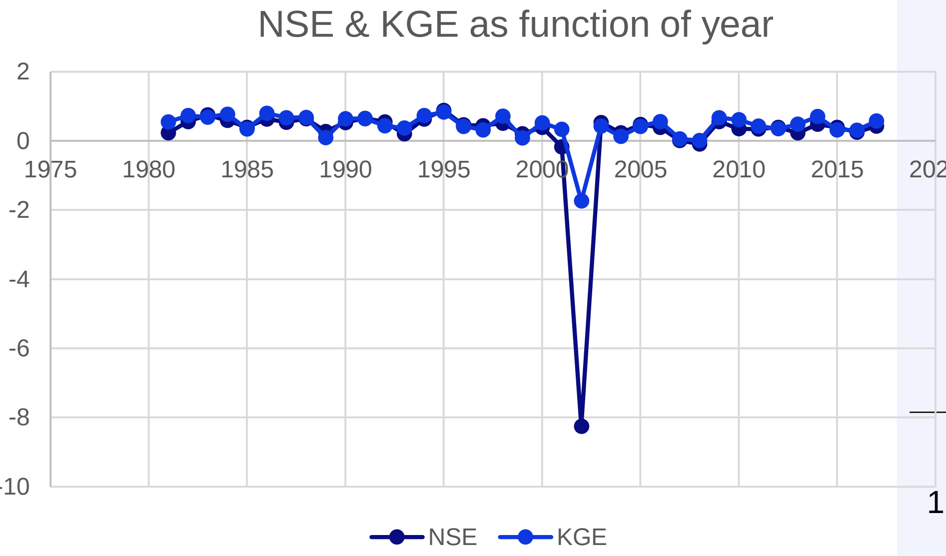
Orange river at Oranjedraai (CHIRPS rainfall and ERA5 Temperature and PET de Bruin et al 2016











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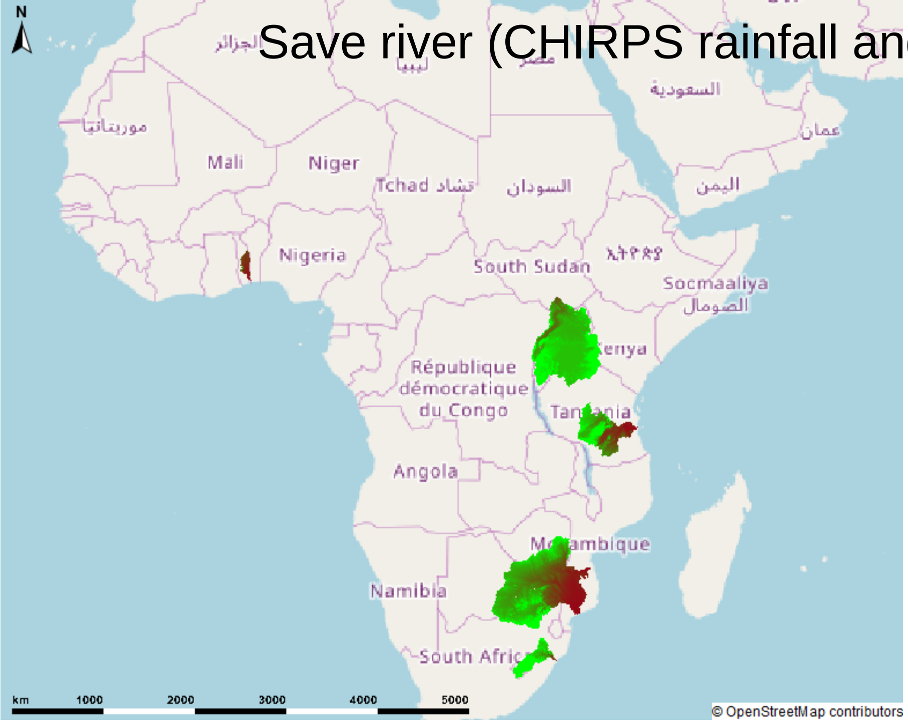
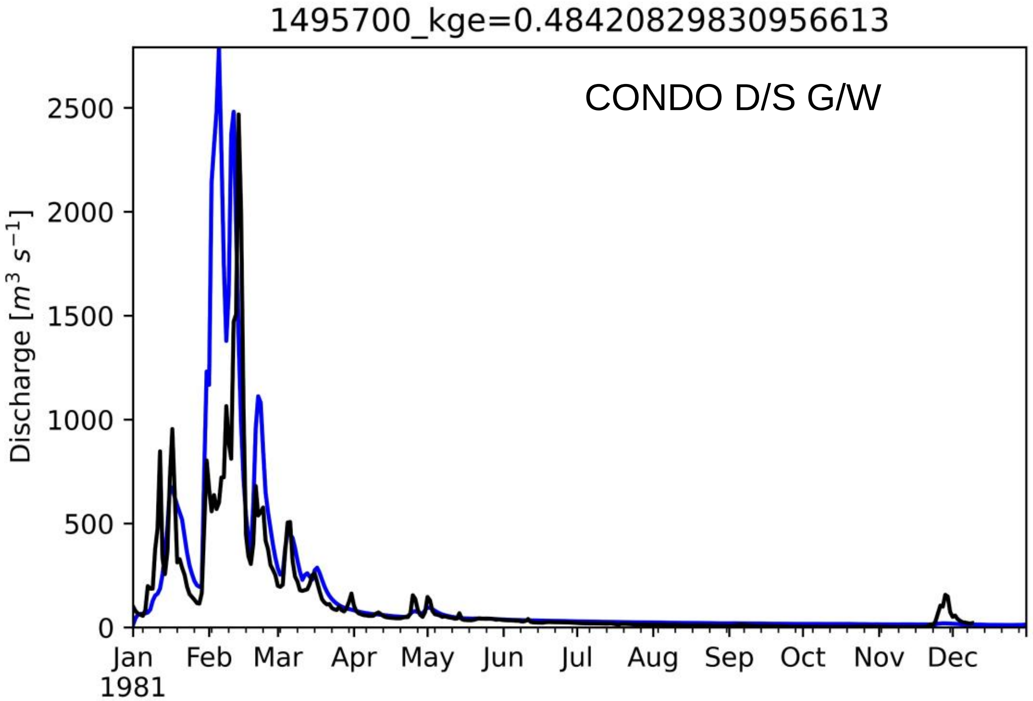
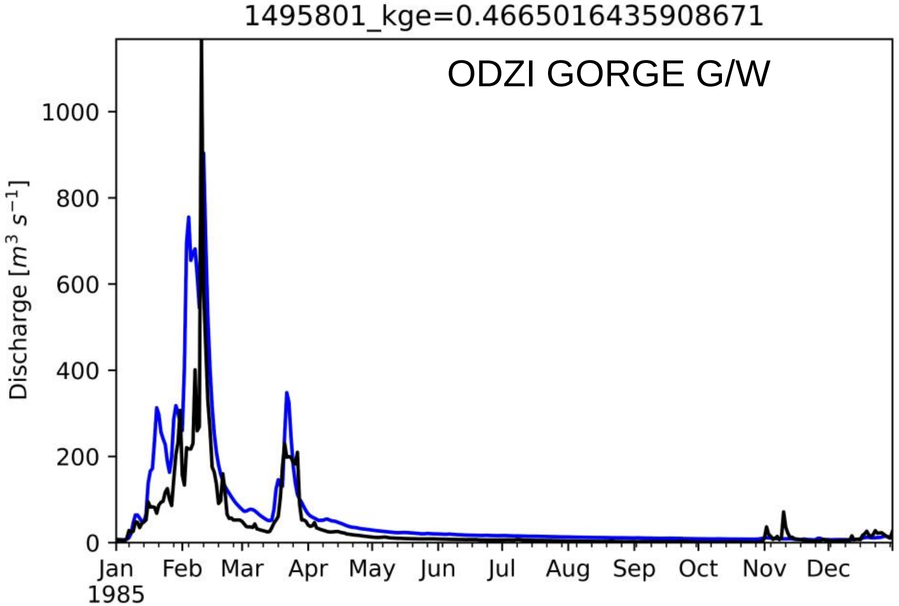
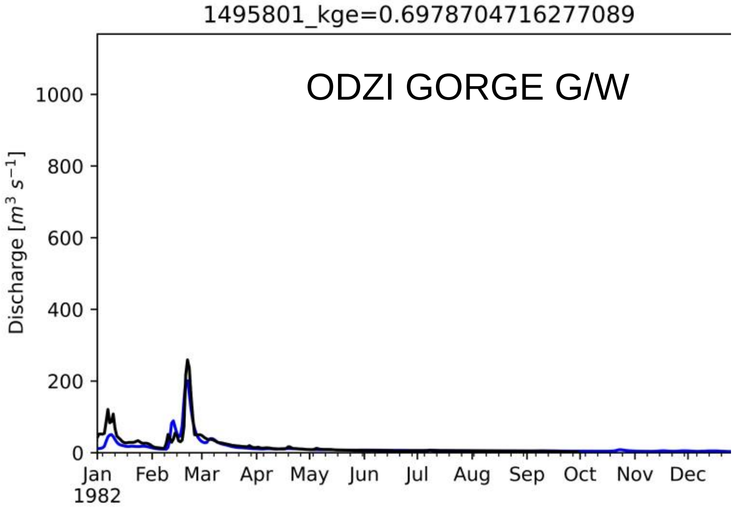
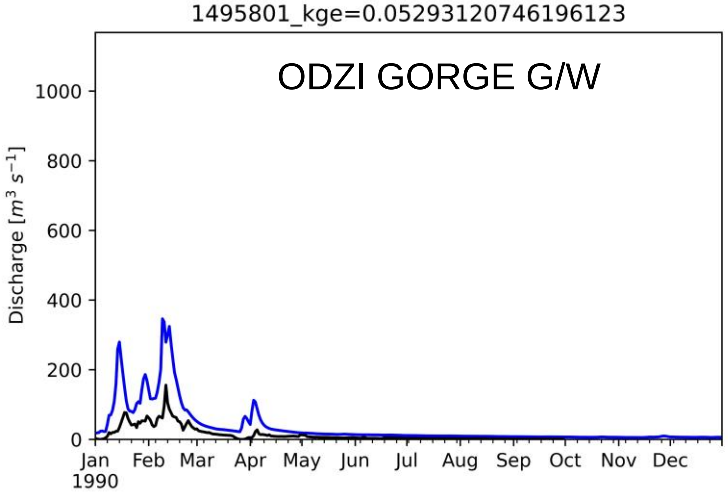
Save river (CHIRPS rainfall and ERA5 Temperature and PET de Bruin et al 2016)

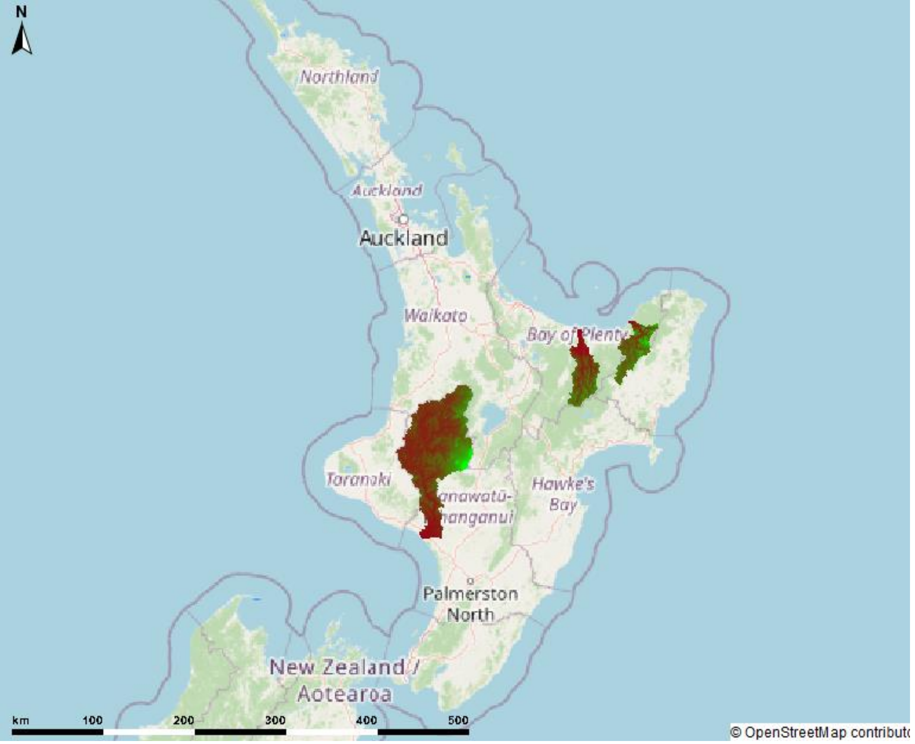


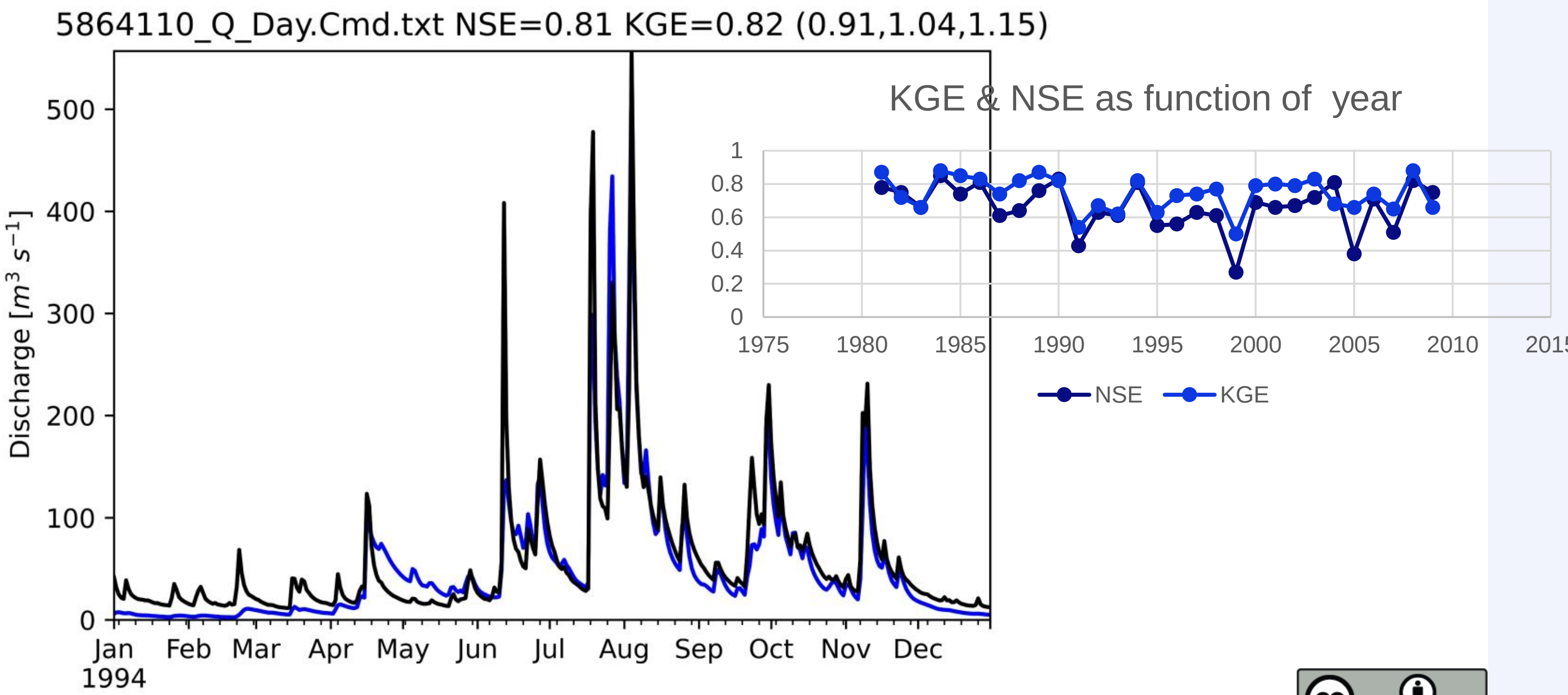




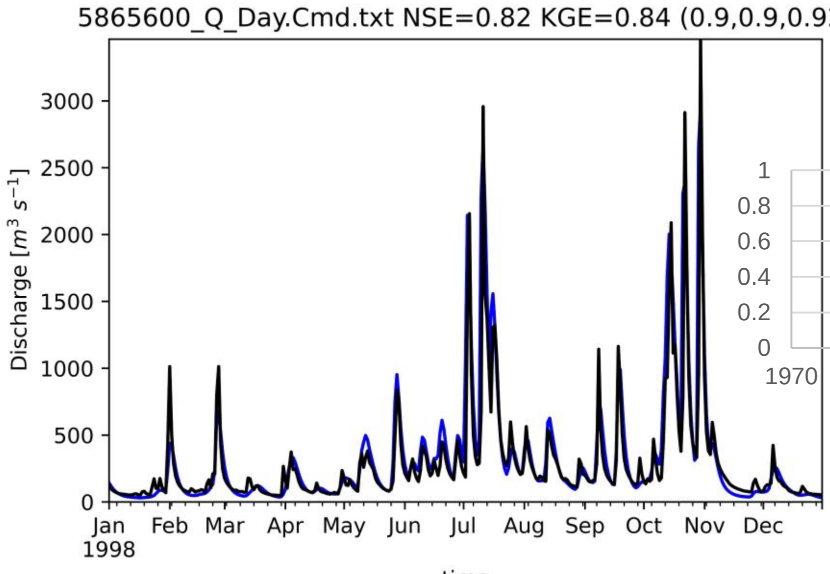


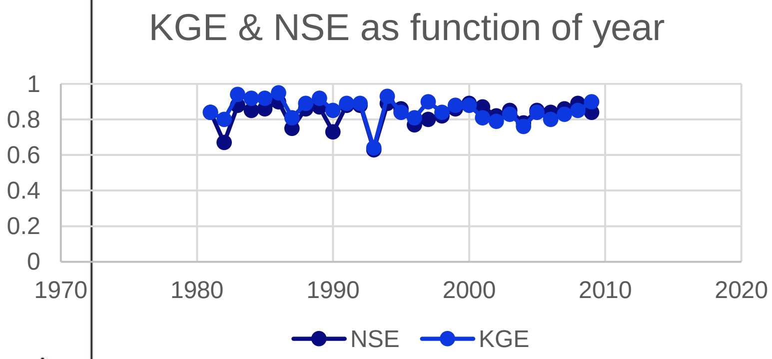






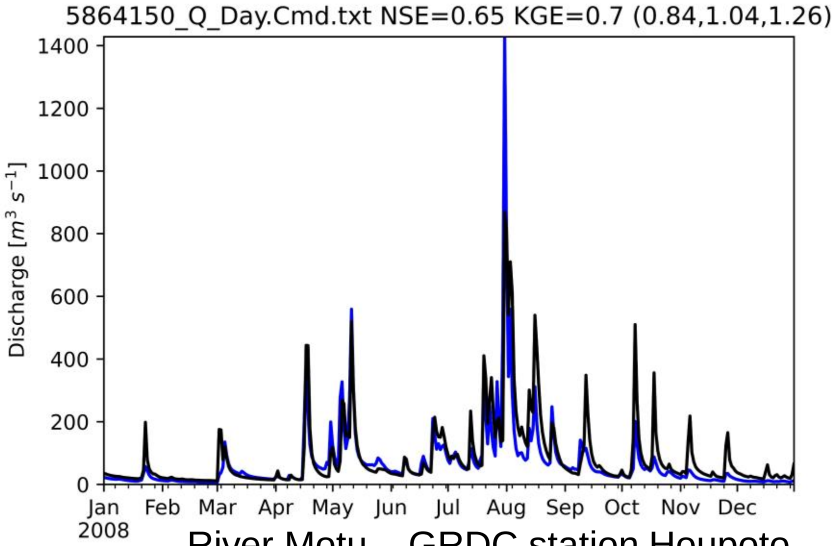
River Whakatane – GRDC Station Whakatane





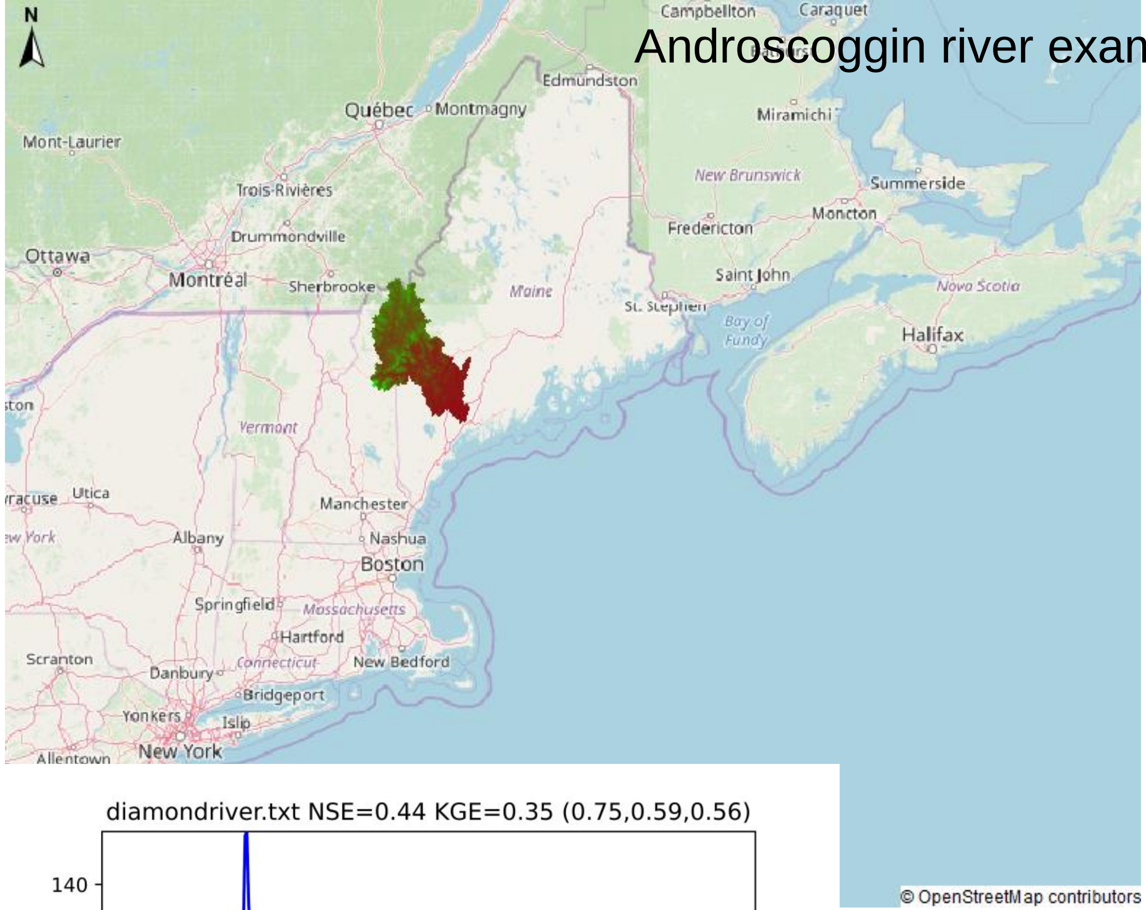
River Whanganui – GRDC station Paetawa

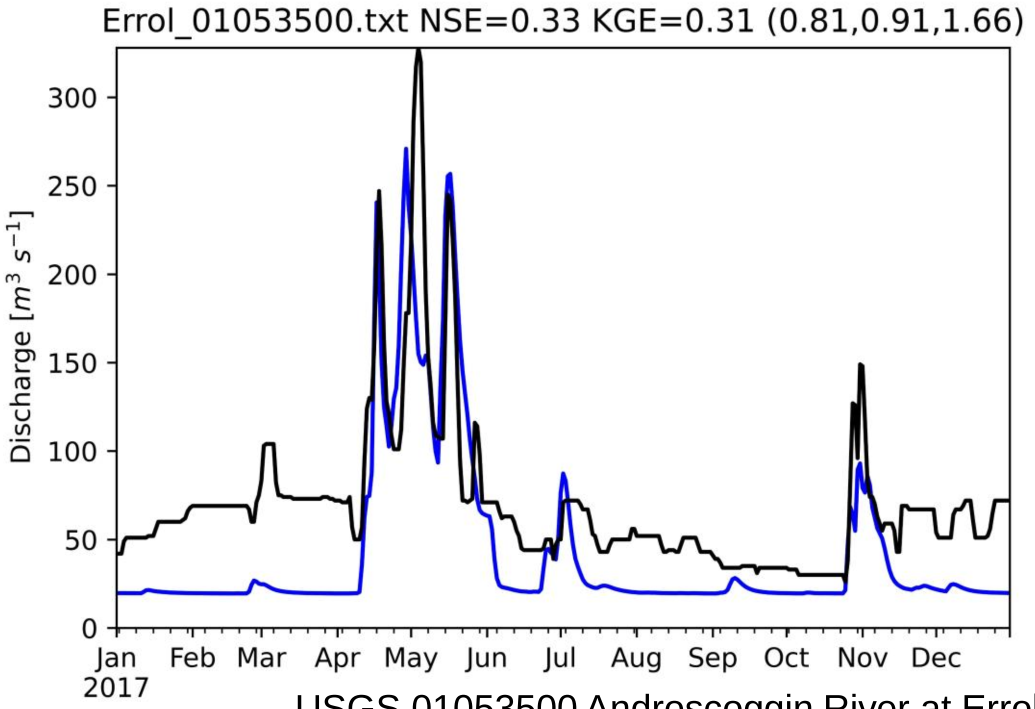
Acknowledgement NIWA for sharing their high res forcing data set



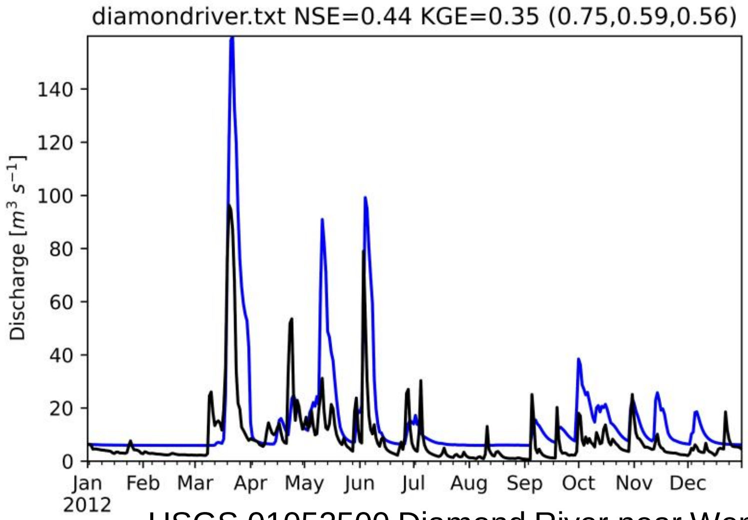
River Motu – GRDC station Houpoto

Androscoggin river example (ERA5 rainfall, temperature and PET de Bruin et al, 2016)

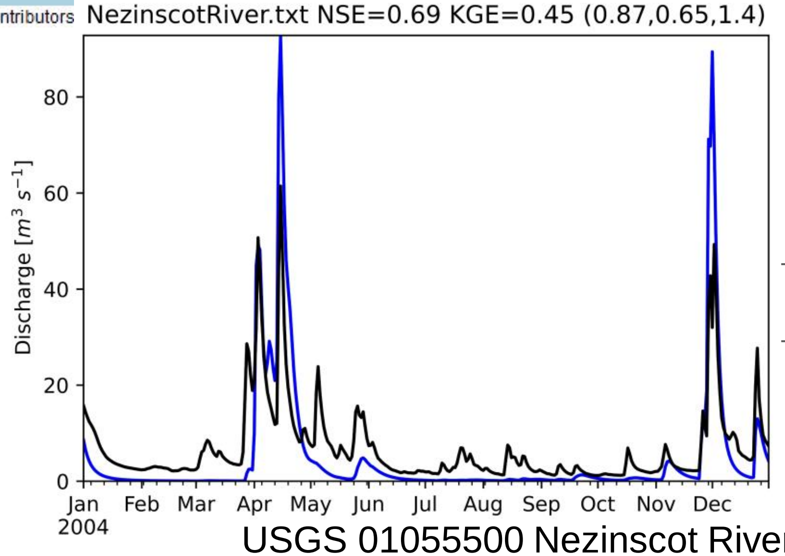




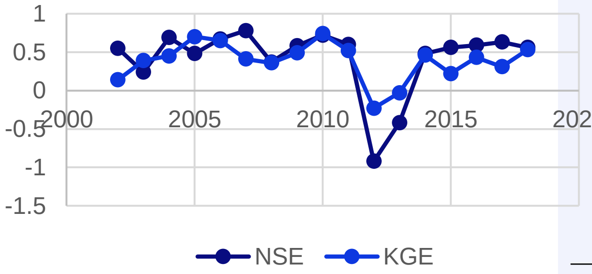
USGS 01053500 Androscoggin River at Errol, NH



USGS 01052500 Diamond River near Wentworth Location, NH



USGS 01055500 Nezinscot River at Turner Center, Maine



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Conclusions

wflow_sbm derived with the Deltares wflow_sbm global setup seem to give reasonable results for many places

However (and not surprising) sensitive to

- rainfall forcing (CHIRPS in Africa, ERA5 in Scandinavia, EOBS/ERA5, NIWA dataset New Zealand)
- rooting depth (especially Africa ⇔ often needs adjustments seem to agree with Yang et al 2016 WRR)
- lateral hydraulic conductivity (ksathorfrac often in order 1-100)
- human activity (hydropower)
- underlying global datasets (for instance landuse as used for effective rooting depth)

wflow_sbm & wflow_sbm global setup improvements:

- a priori reservoir parameters seem to give reasonable estimates (Errol, Lake Victoria, Harrsele KRV)
- wetlands, lakes (not well modelled yet)
- rooting depth approach (fractions)
- better routing for flat rivers
- update global datasets

Avoiding calibration makes forcing datasets more comparable, however further sensitivity analysis needed especially for ksathorfrac (no PTF) and effective rooting depth.