Groundwater interactions with the land surface fluxes. Introduction of a Dynamic GroundWater Scheme into the JULES LSM

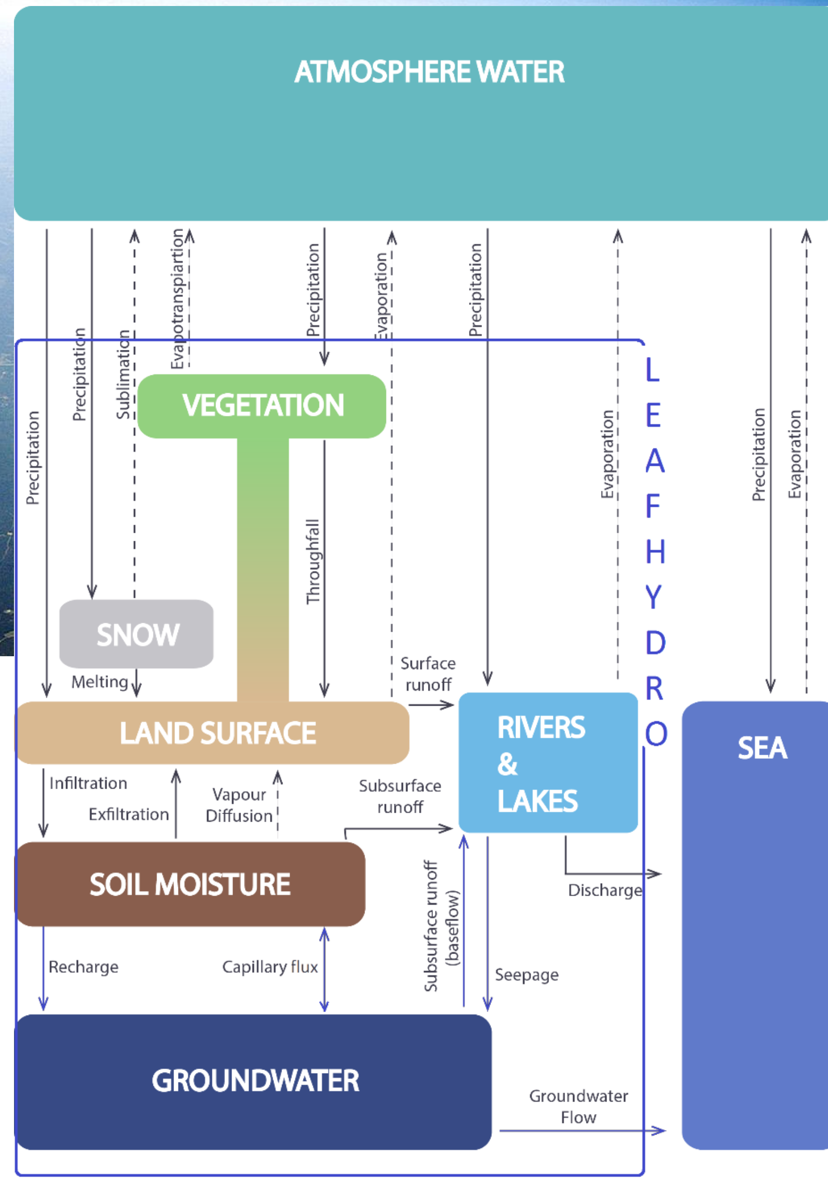

Photo : iStockPhoto

Alberto Martínez-de la Torre (UKCEH),
Sarah Collins (BGS),
Andrew Hughes (BGS)

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Hydro-JULES

Dynamic Groundwater Scheme

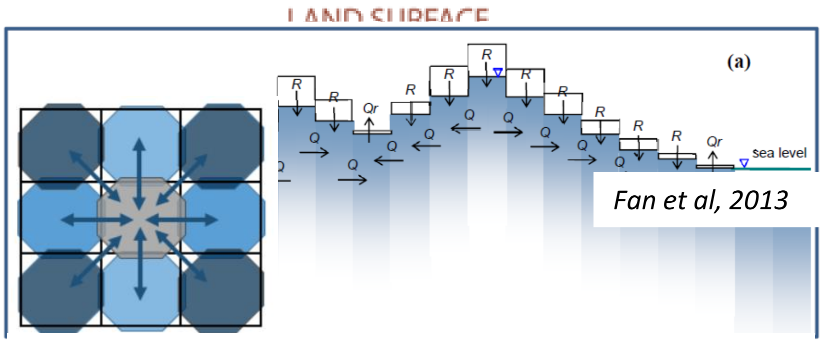
The LEAFHYDRO dynamic groundwater scheme was first presented in *Fan et al.* (2007) and *Miguez-Macho et al.* (2007). Initial condition EWTD calculated as the long-term balance between vertical recharge (P-E-Qr) and the topographically driven lateral flow (Fan et al., 2007, 2013)
Dynamical behaviour of the groundwater reservoir and its interactions with the land-atmosphere system:

- **Groundwater recharge**: Water flux between the groundwater reservoir and the soil. Depending on the soil wetness and the atmosphere demands, the recharge can be downwards, causing the water table to rise, or upwards, causing the water table to deepen.

- **Lateral groundwater flow**: Water flux to or from neighbour cells within the saturated groundwater reservoir. This flux is governed by topography and the water table head elevation in the cells.

- **Groundwater-river flow**: It can occur as groundwater discharge (subsurface runoff) into the streams when the water table head is above the river bed, maintaining the streams baseflow, or as river infiltration to the groundwater reservoir when the water table head is below the river bed.

$$\frac{dS_G}{dt} = \Delta x \Delta y R + \sum_{n=1}^{8} Q_n - Q_r$$

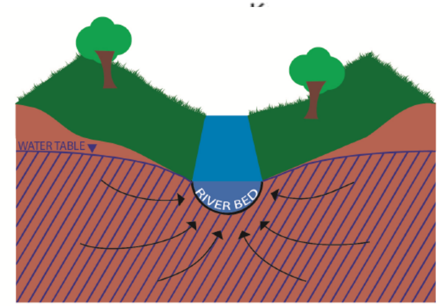


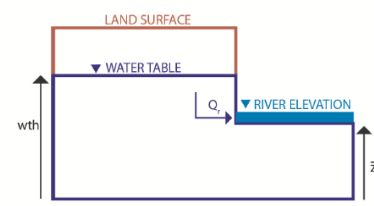
Fan et al, 2013

Aquifer hydraulic conductivity can either…

decrease exponentially with depth (as in LeafHydro)

or remain constant with depth (as in most groundwater models)





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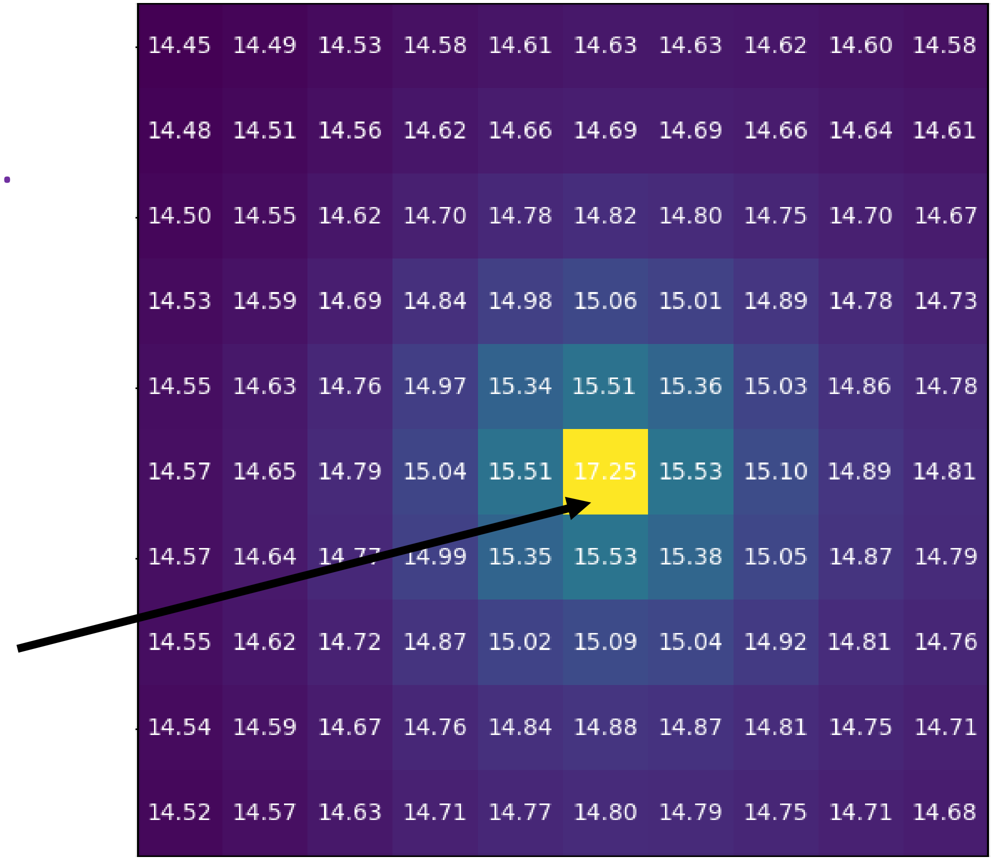
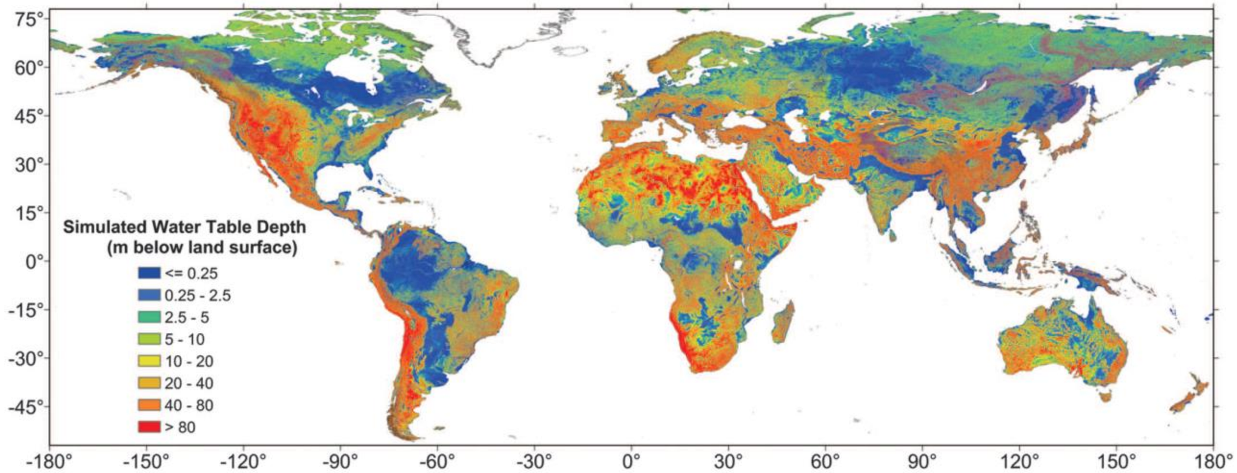
Abstraction

Groundwater pumping can be introduced as prescribed data (i.e. time dependent)
New development by BGS

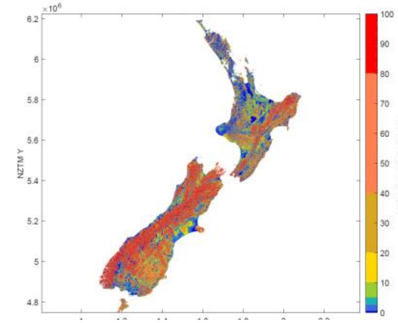
Depth to groundwater (m)



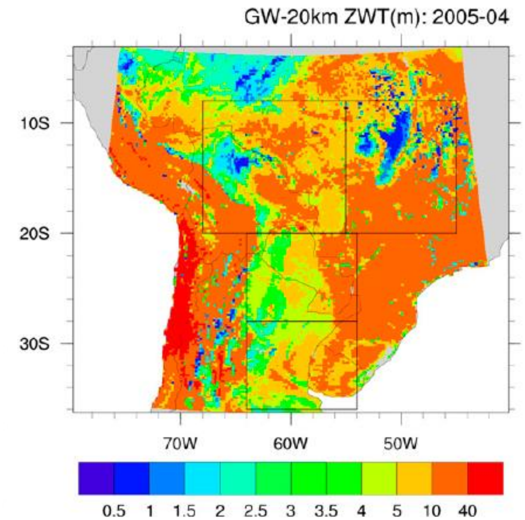
Applications (out of HJ)

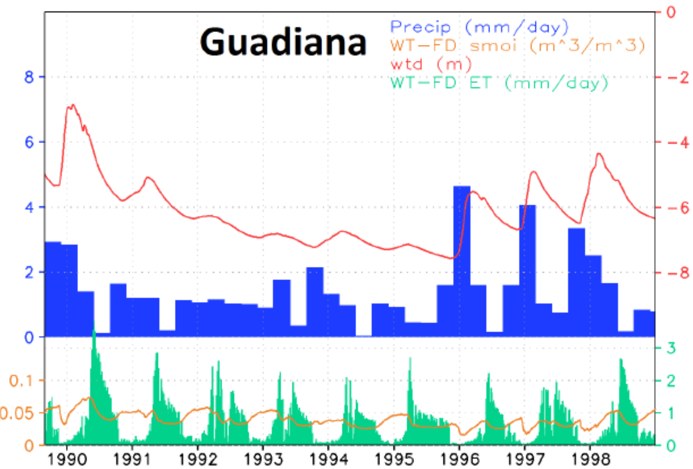


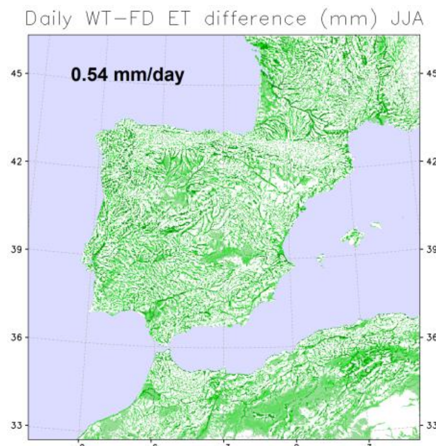
Fan et al, 2013 *(Science)*: global patterns at ~1km resolution

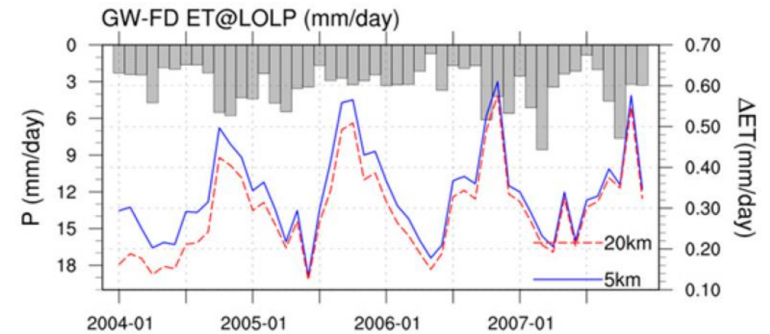


Westerhoff et al, 2019 (*GMD*): high res application for New Zealand EWTD









Martínez-de la Torre and Miguez-Macho, 2019 (*HESS*): full LEAFHYDRO integration over IP at 2.5 km resolution
https://hess.copernicus.org/articles/23/4909/2019/hess-23-4909-2019.html

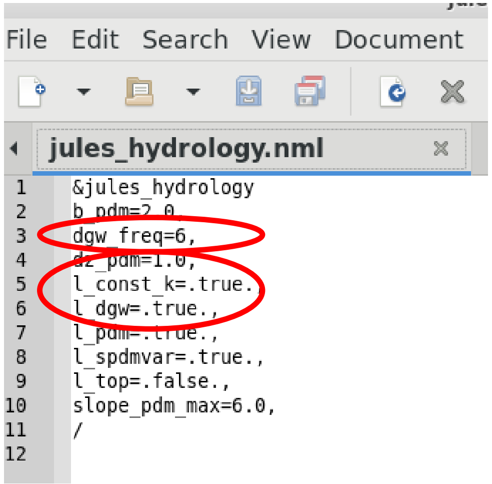
Martínez, 2016 (*Journal of Hydrometeorology*): full integration with the DGW scheme into Noah-MP over Southern SA at 5/20km resolution

Implementation into JULES

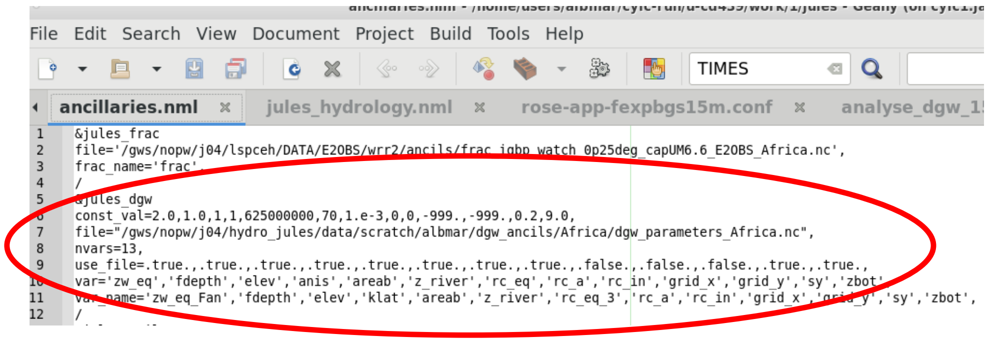
Opened ticket #532 to implement the Dynamic GroundWater scheme from LEAFHYDRO in JULES.

Branch:
https://code.metoffice.gov.uk/trac/jules/browser/main/branches/dev/albertomartinez/vn5.2_dgw_leafhydro_bgs

- New flag **l_dgw** to activate the scheme, new flag **l_const_k** and new variable **dgw_freq** in jules_hydrology.nml



- Read in zw_eq_gb, fdepth_gb and other ancillary datasets from a gridded file or as constant values in a new namelist **jules_dgw** in the ancillaries.nml file



- Added **zwd, gwrech, qlat** to possible **outputs**

Working with Doug Clark (UCKCEH) to improve the code and make it to the trunk (already in v6.3)

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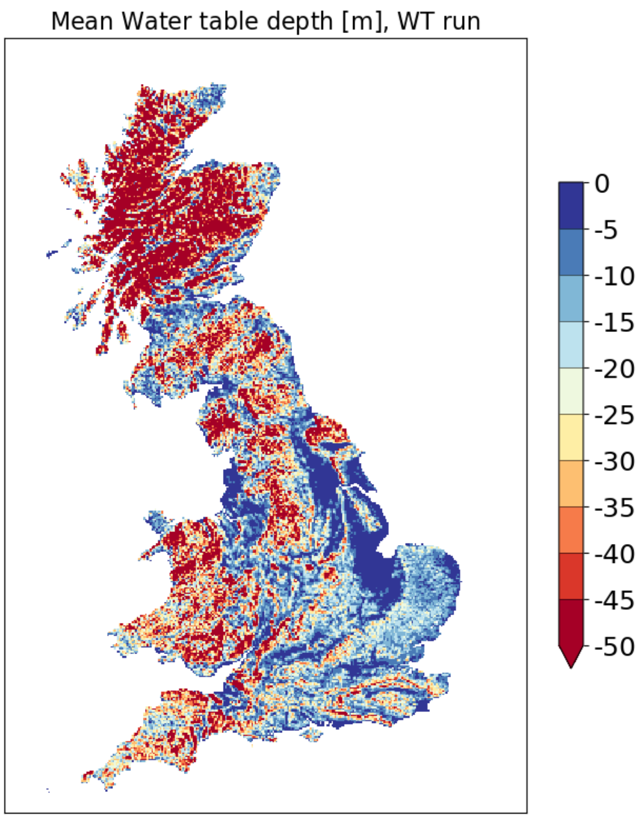
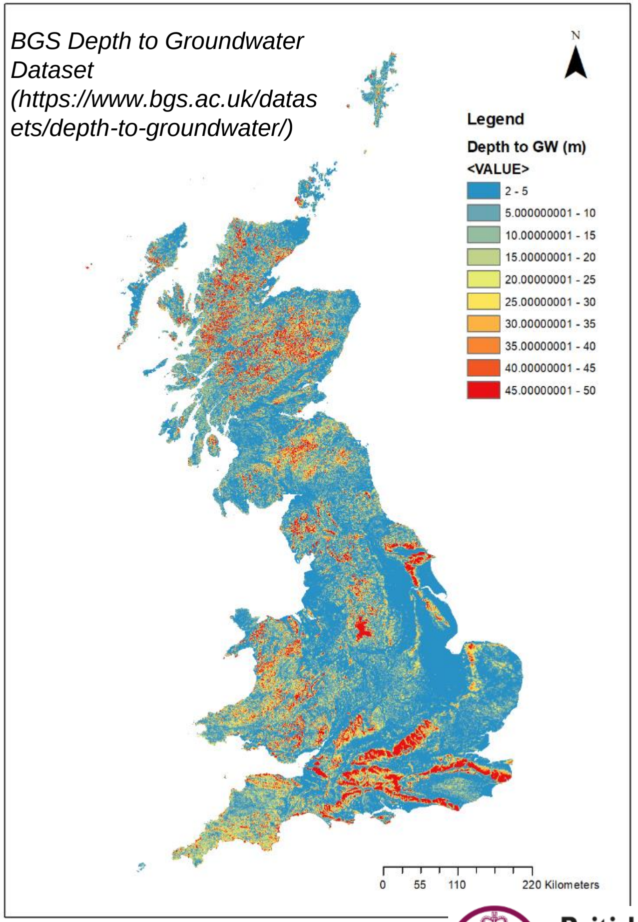
First regional test (REP project)

- Improved hydrology for Reginal Environment Prediction (MetOffice)
- Rose suite: https://code.metoffice.gov.uk/trac/roses-u/browser/c/k/0/8/5
- Closed collaboration with BGS colleagues to provide ancillaries datasets
- 2007-2012 6-years simulations over GB





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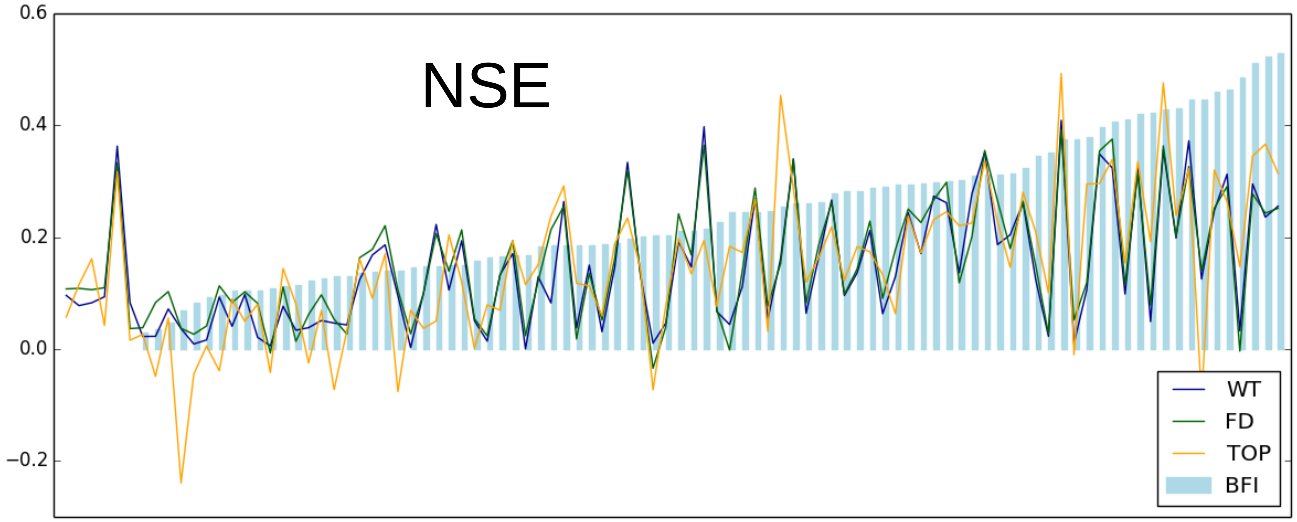
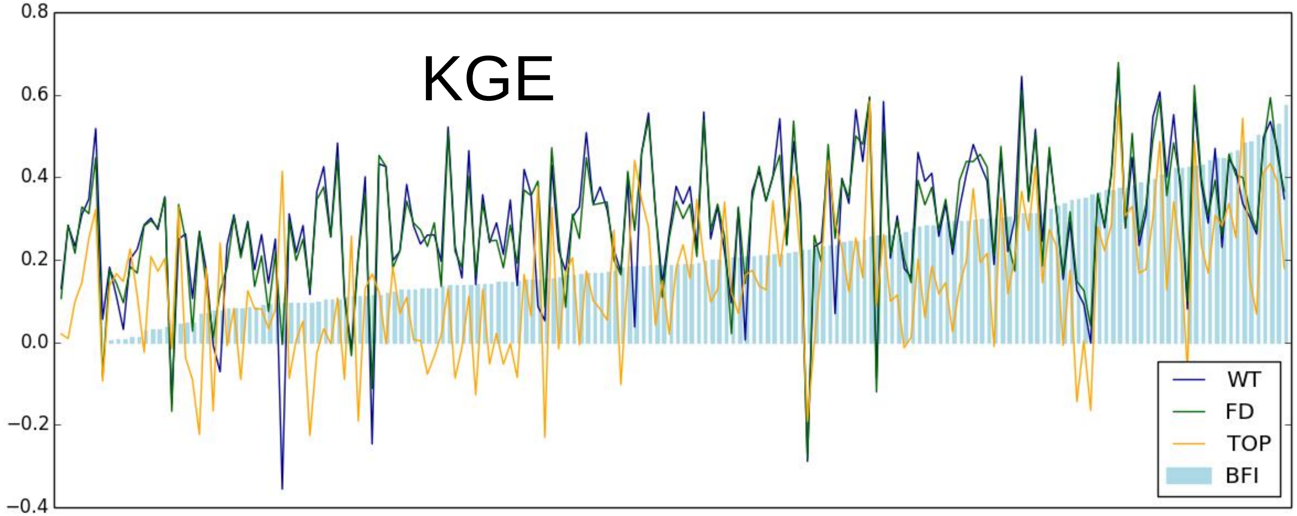
REP project: River flow metrics



50% catchments



93% catchments

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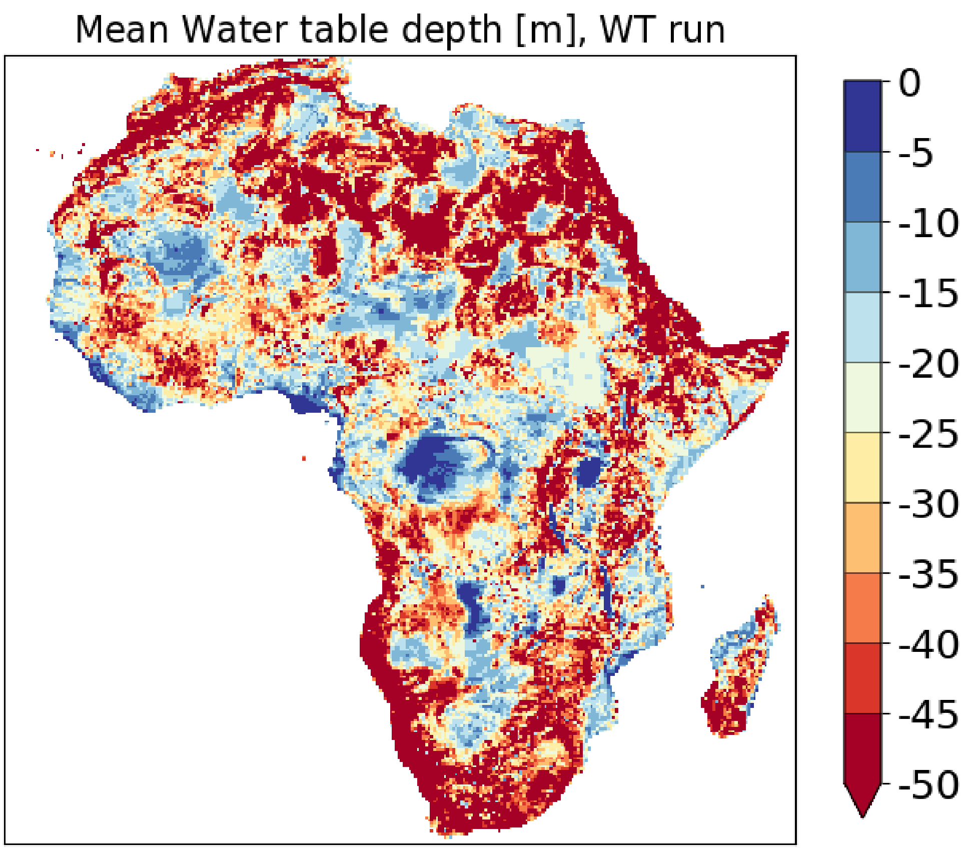
Africa instance: HydroJULES task 4.2

- Rose suite: https://code.metoffice.gov.uk/trac/roses-u/browser/c/d/4/3/9
- Closed collaboration with BGS colleagues to provide ancillaries datasets
- 2000-2015 15-years simulations at 0.25deg resolution
- Drivers from eartH2Observe (WFDI + MSWEP)



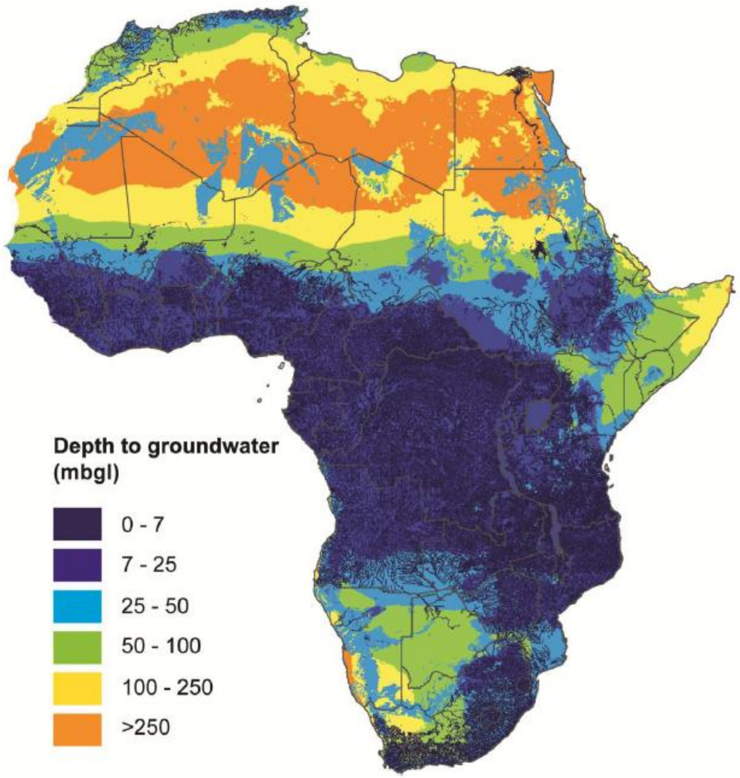


Fig. 4 – An initial estimate of depth to groundwater in Africa.

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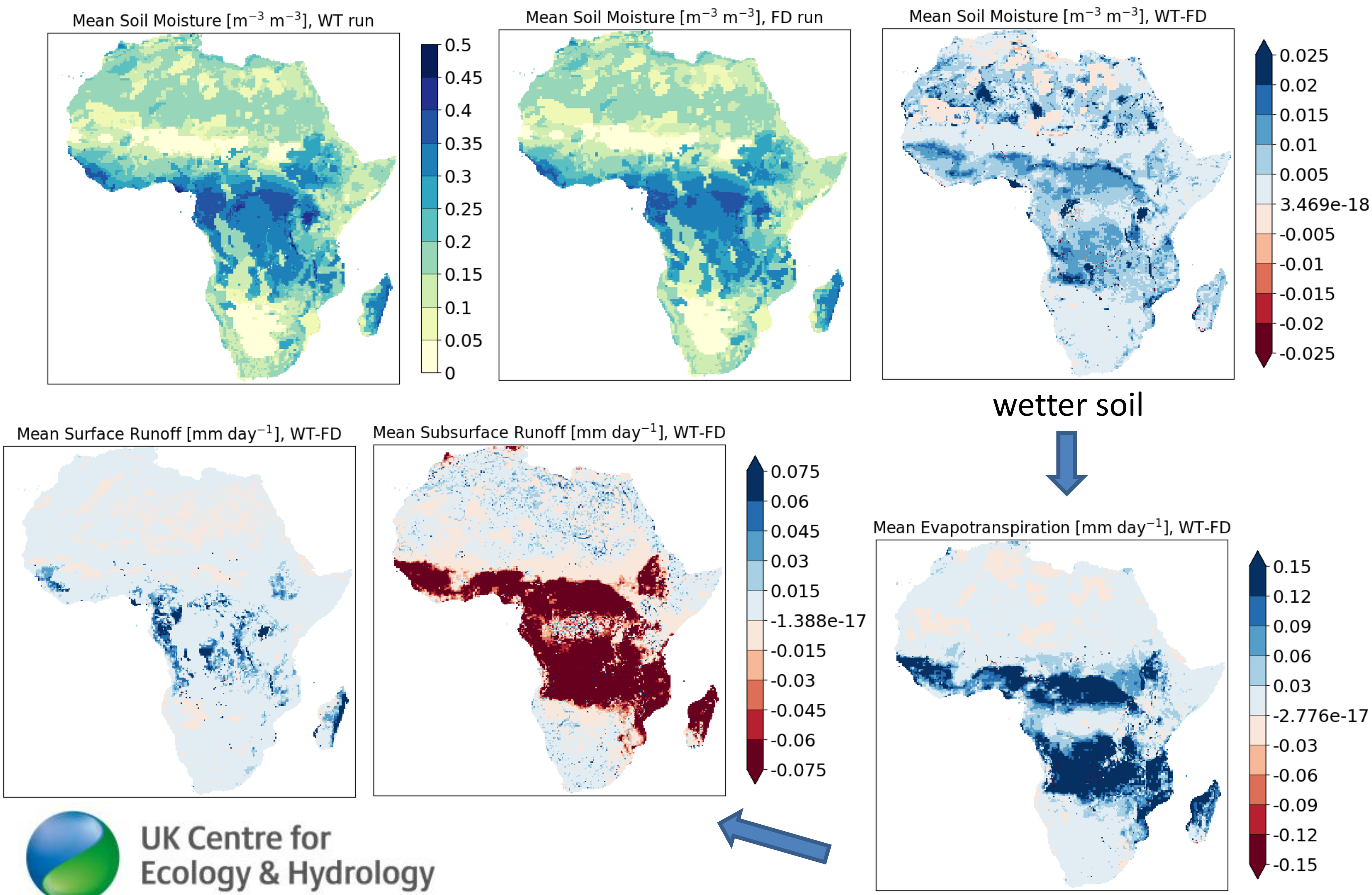
Africa instance: HydroJULES task 4.2



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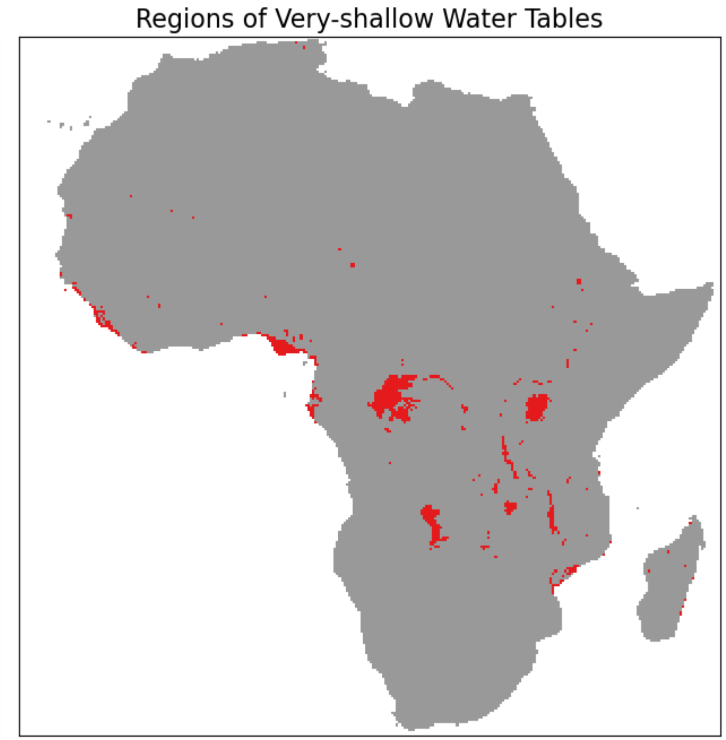
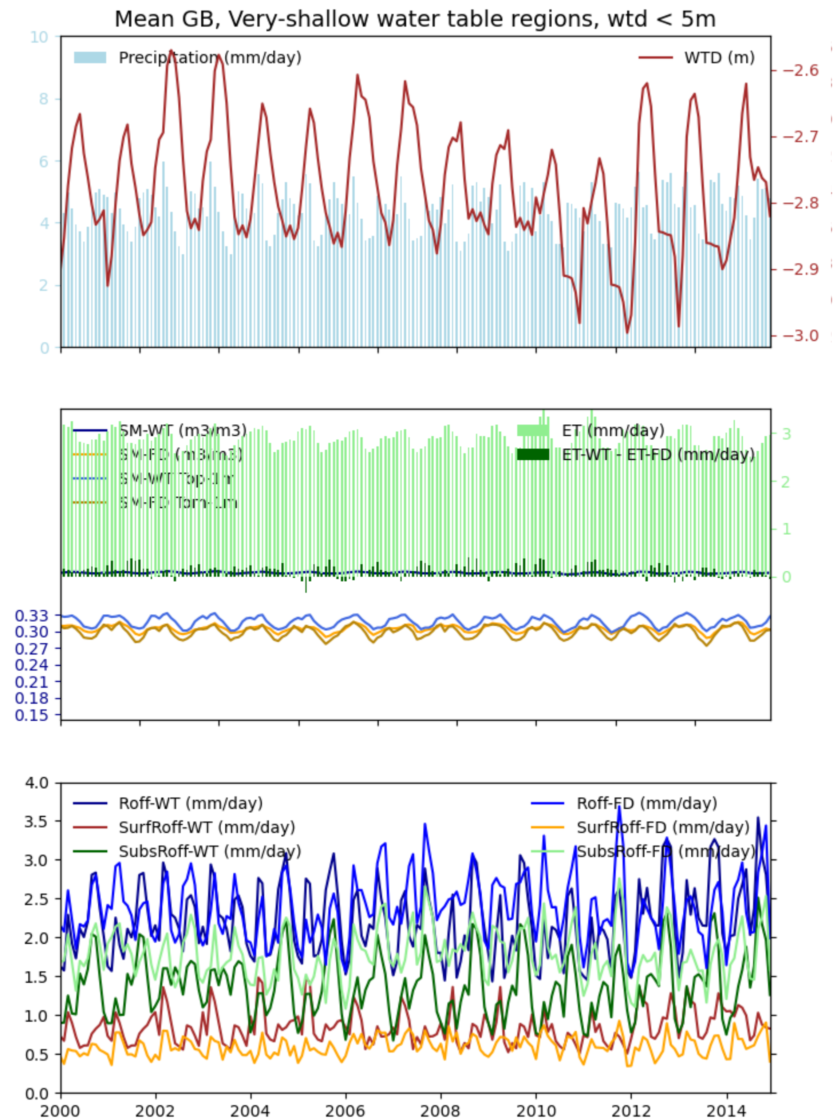
Africa instance: HydroJULES task 4.2



wtd < 5m, 2%



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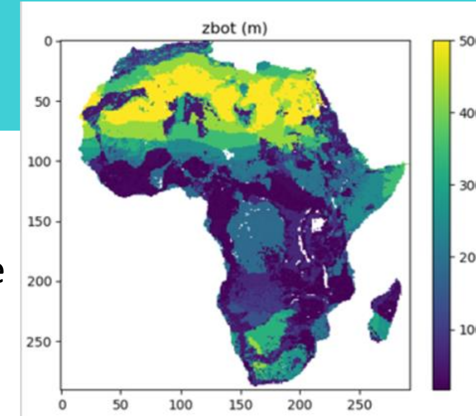
Summary and future work

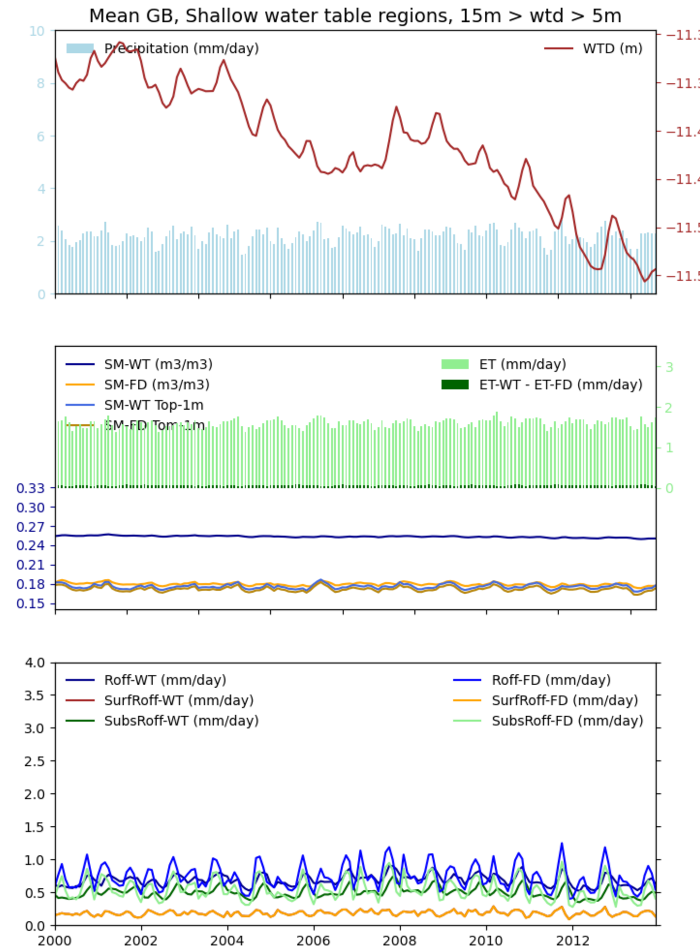
We have presented the first continental scale simulations using JULES-DGW.

- The initial results showed here are encouraging, with the DGW scheme connecting groundwater to the JULES surface hydrology over a large part of the domain.
- Groundwater is maintaining baseflow.
- Wetter soil results in altered ET fluxes.



Next steps:

- Validation of the position and time evolution of the modelled water table depth using observations from BGS data (collaboration with TerraFIRMA project).
- Further study of seasonal variations in different catchments.
- Study the impact and behaviour of the lateral flows of groundwater.
- Assess the impact of different configurations (ZBOT).
- Validate the river runoff outputs using river flow observations.
- Validation of changes in ET shown here using in situ measurements from flux towers or continental scale ET estimations.



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THANKS

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Groundwater Recharge (within resolved soil layers)

- Assume equilibrium (no vertical flux) between saturated portion of layer 1 and saturated layer 2

$$\frac{\partial(\Psi + z)}{\partial z} = 0 \quad \Longrightarrow \quad \Psi_1 - \Psi_2 = z_2 - z_1$$

- Applying Brooks & Corey $\Psi = \Psi_f \left(\frac{\eta_f}{\eta}\right)^b$ and provided that layer 2 is saturated

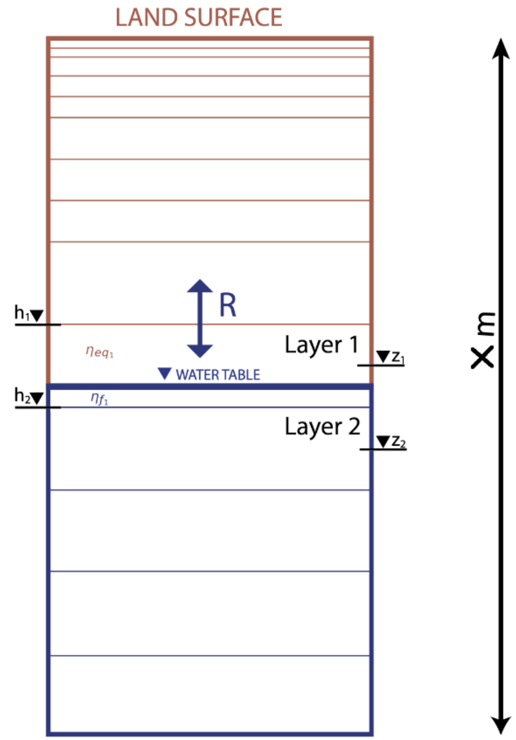
$$\eta_{eq_1} = \eta_{f_1}\left(\frac{\Psi_{f_1}}{\Psi_{f_2} + z_2 - z_1}\right)^{1/b_1}$$

- Now distributing evenly the soil moisture in layer 1 from the soil fluxes subroutine

$$\eta_1 = \eta_{eq_1}\left(\frac{h_1 - wtd}{h_1 - h_2}\right) + \eta_{f_1}\left(\frac{wtd - h_2}{h_1 - h_2}\right)$$

$$wtd = \frac{\eta_{f_1} h_2 - \eta_{eq_1} h_1 + \eta_1 (h_1 - h_2)}{\eta_{f_1} - \eta_{eq_1}}$$

- Move the water table Δwt from the previous position, and calculate the recharge as the water needed to fill or drain the pore space between saturation and present equilibrium water content in the unsaturated portion of the layer after the water table movement



$$R = \Delta wt(\eta_{f_1} - \eta_{eq_1})$$

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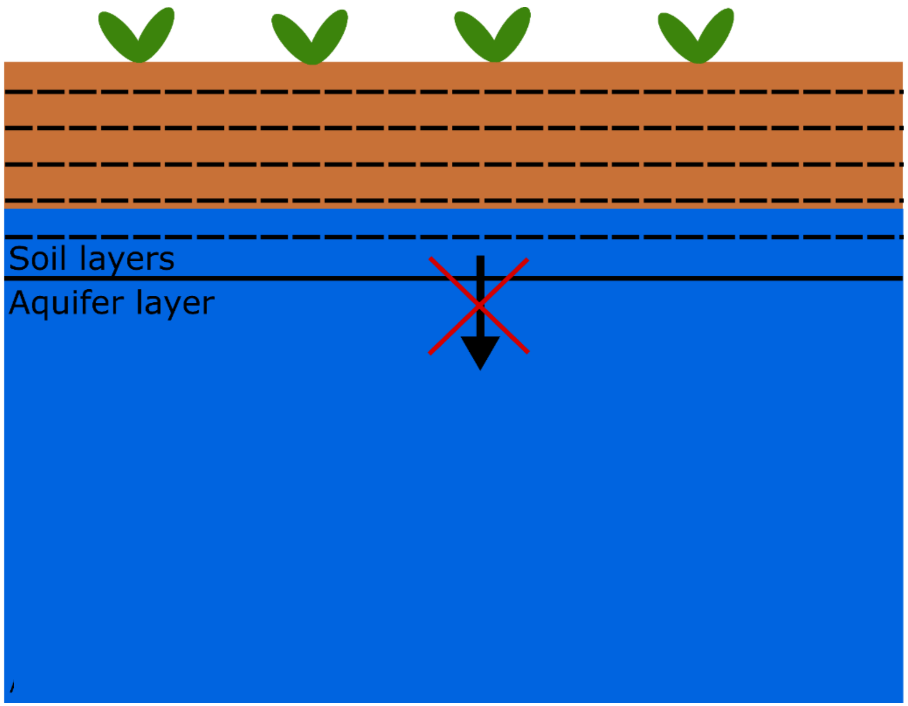
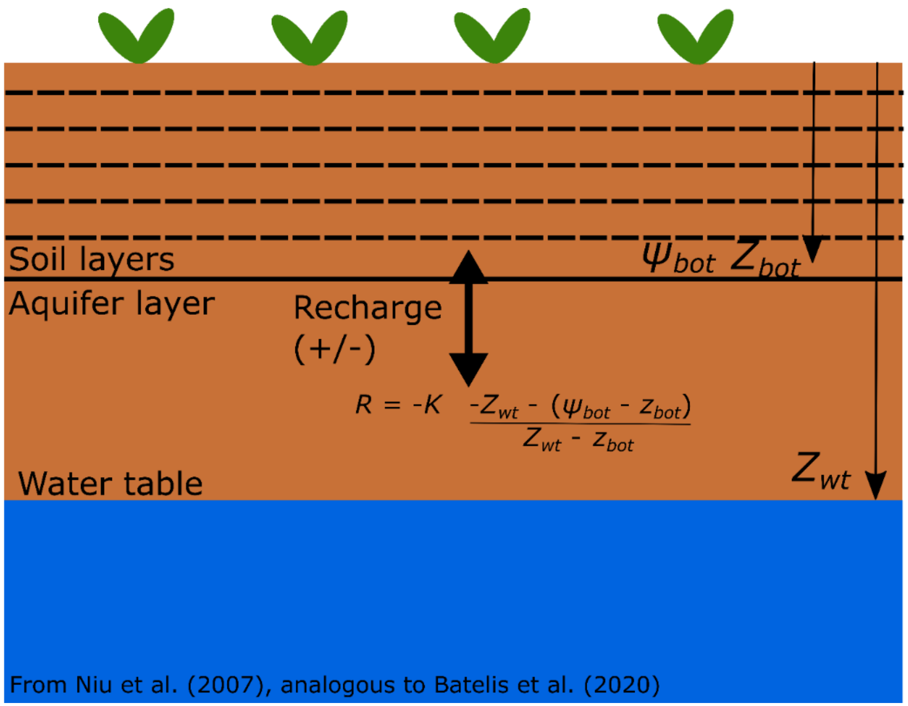
Groundwater Recharge

Water table within soil layers



Water table below soil layers



From Niu et al. (2007), not in the original LEAFHYDRO, recently introduced by BGS

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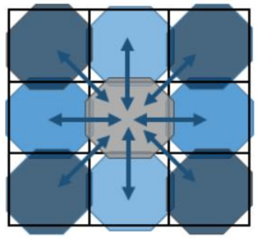
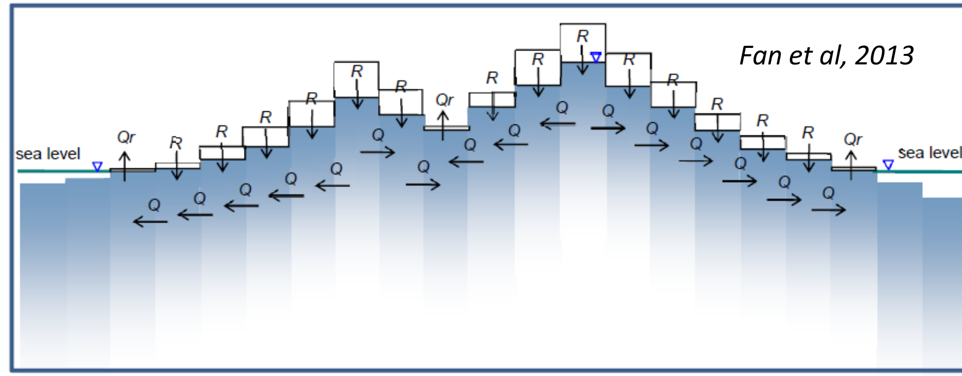
Groundwater Lateral flow

- Lateral flow from the nth neighbour applying Darcy's law

$$Q_n = cT\left(\frac{wtd_n - wtd}{l}\right)$$





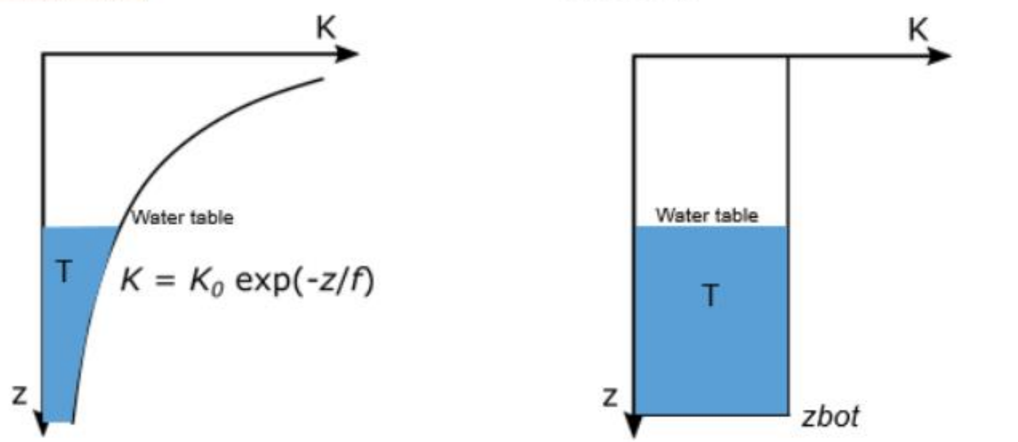
- Flow transmissivity $T = \int_{-wtd}^{\infty} K_{L_f}\, dz'$

- The model uses the anisotropy ratio $\alpha = K_{Lsat} / K_{Vsat}$, and exponential decrease with depth for K_{Vsat}

Aquifer hydraulic conductivity can either…

decrease exponentially with depth (as in LeafHydro)

or remain constant with depth (as in most groundwater models)



We can use an estimation of the bottom of the aquifer as a parameter if we have it

New development by BGS

Groundwater-river flow

- Gaining streams, applying Darcy's law

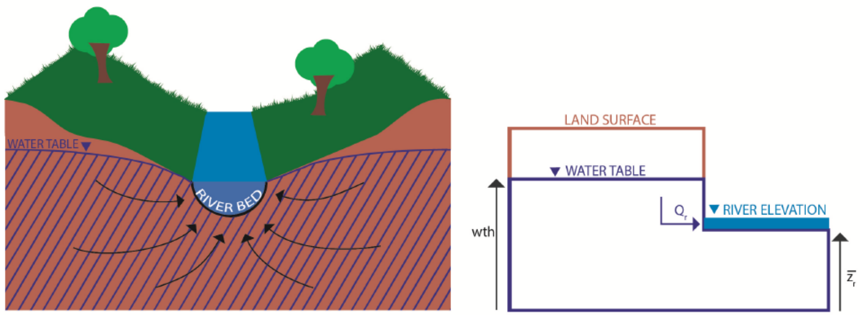
$$Q_r = \left(\frac{\bar{K}_{rb}}{\bar{b}_{rb}}\right)\left(\bar{w}_r \sum L_r\right)(wth - \bar{z}_r)$$

- Define river conductance $\Longrightarrow$ $RC = \dfrac{\bar{K}_{rb}\bar{w}_r \sum L_r}{\bar{b}_{rb}}$

- RC parametrized as $RC = ERC \cdot F(wtd - ewtd)$

- The ERC represent the long-term hydraulic connection rivers-groundwater in a cell, so in an equilibrium situation:

$$Q_r = \Delta x \Delta y R + \sum_{n=1}^{8} Q_n \longrightarrow ERC = \frac{\Delta x \Delta y R_{lt} + \sum_{n=1}^{8} Q_n}{ewtd - \bar{z}_r}$$



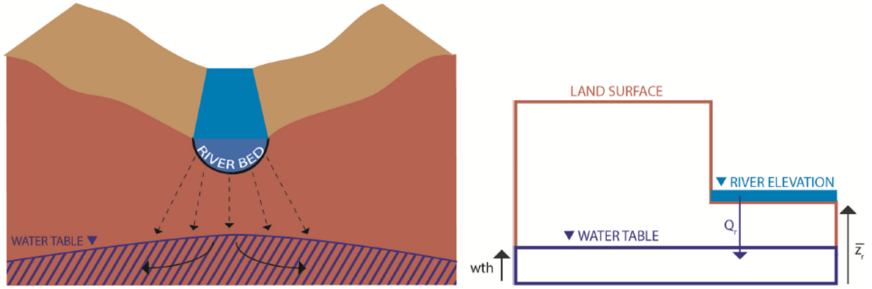
- *F* (*wtd* - *ewtd*) represents the *RC* deviation from equilibrium as a response to the channels expansions and contractions caused by seasonal hydrological changes

$$F(wtd - ewtd) = \exp[a(wtd - ewtd)]$$

where *a* = 0 in steep terrain, and *a* = 1 where the terrain slope β satisfies $\beta < 0.2$

- Losing streams, b_{rb} and the distance between riverbed and water table cancel each other:

$$Q_r = -K_{rb}\bar{w}_r \sum L_r$$



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