ANDREW HUGHES, MARCO BIANCHI AND LOTS OF OTHERS – 15TH JULY 2025

Modelling groundwater at the British mainland scale – how data (hydrological and other) has helped its development

BGS British Geological Survey

British Geological Survey (BGS)

- BGS is world's oldest national geological survey and UK's premier centre for geological information and expertise.
- Responsible for advising UK government and providing impartial geological advice to industry, academia and the public
- Extensive programme of overseas research, surveying and monitoring, including major institutional strengthening programmes in the developing world
- A major global geological survey with a staff of around 650 and a turnover of £60 million
- Part of UK Research and Innovation (UKRI)

Other national groundwater modelling initiatives

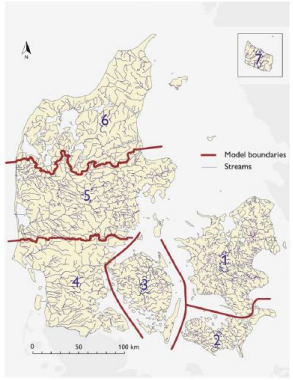
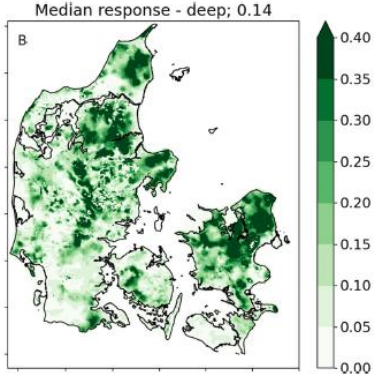


Fig. 1. The seven sub-domains of the DK-model.



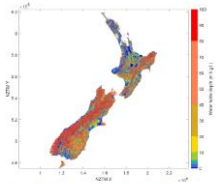
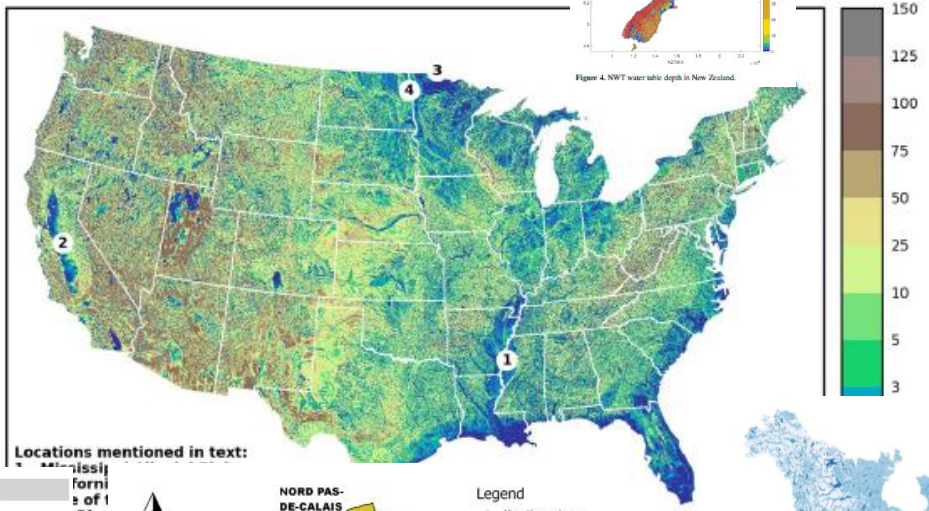
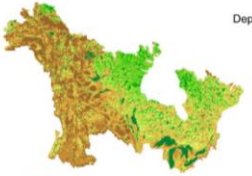
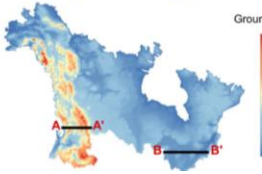


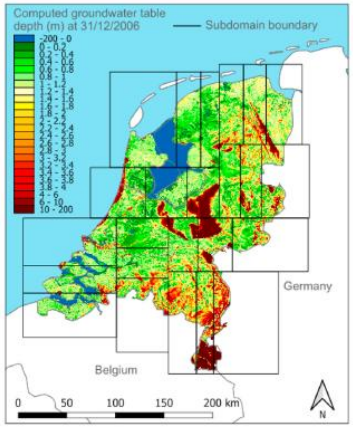
Figure 4. NWT water table depth in New Zealand.

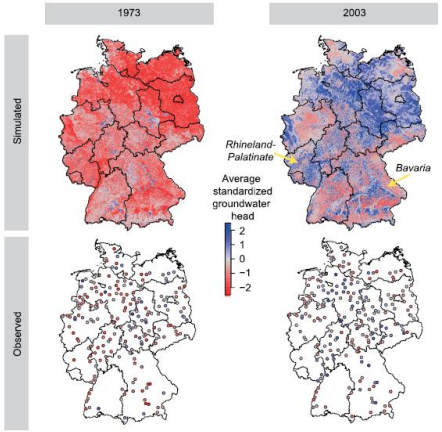


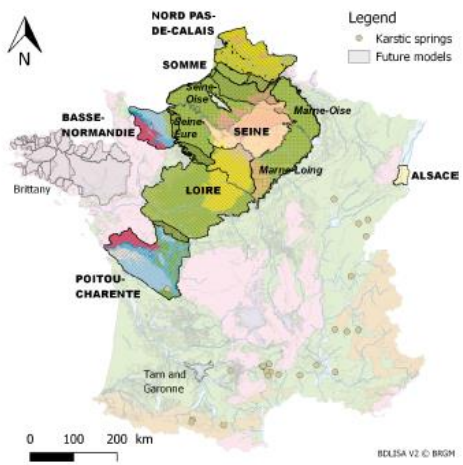
mulated Depth to Water (m)

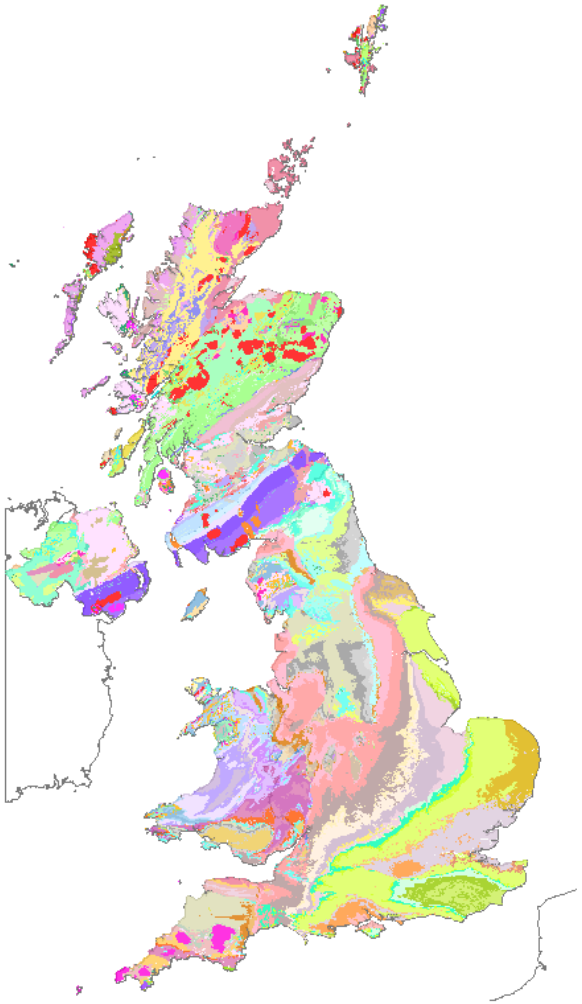


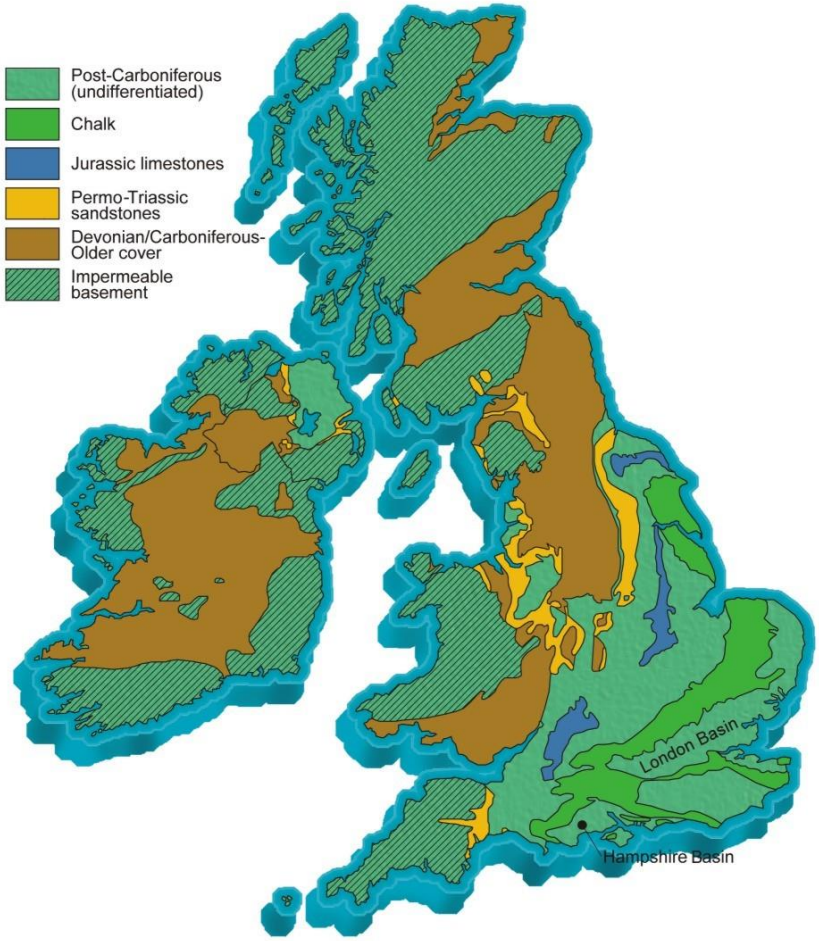


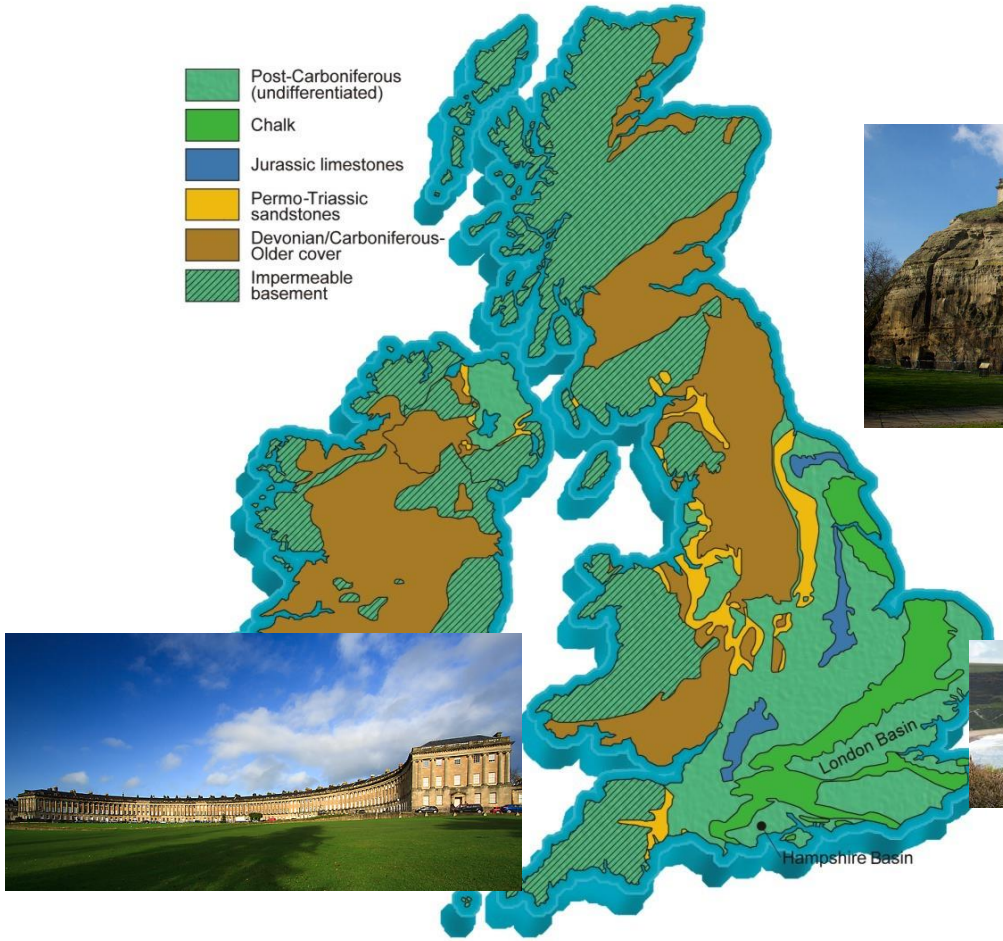









Post-Carboniferous (undifferentiated)
Chalk
Jurassic limestones
Permo-Triassic sandstones
Devonian/Carboniferous-Older cover
Impermeable basement
London Basin
Hampshire Basin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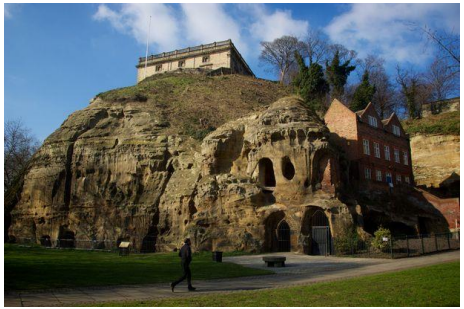
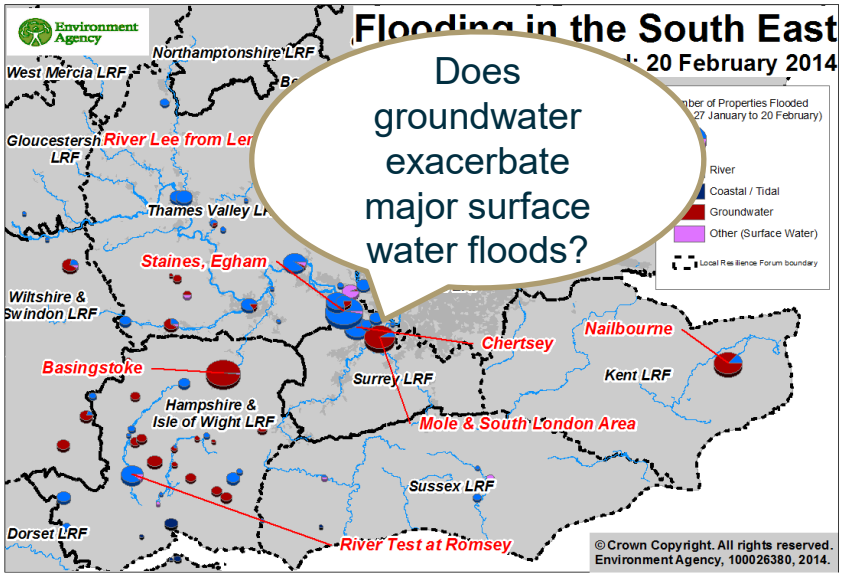
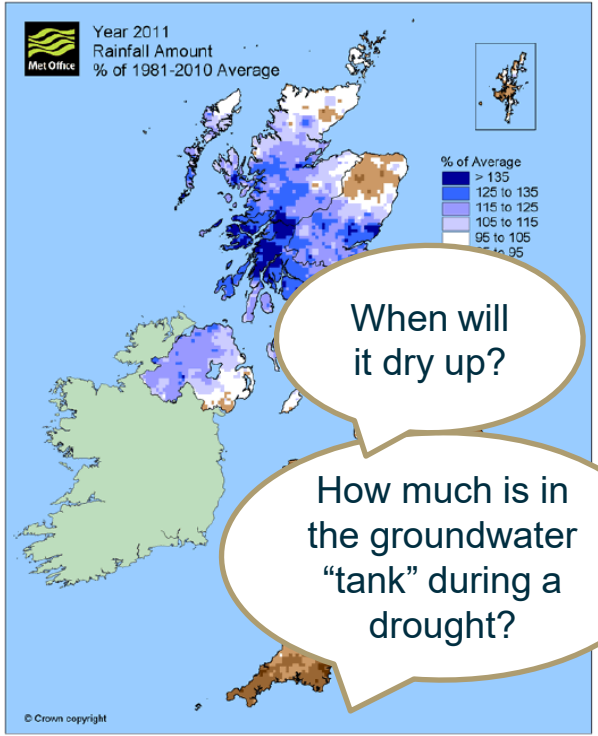
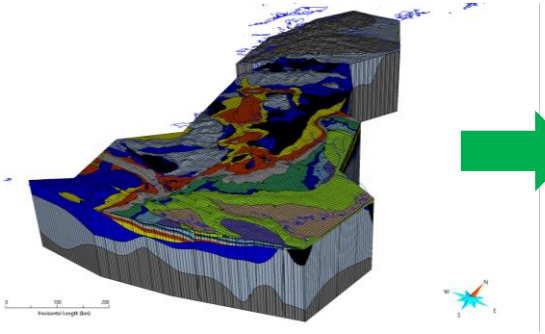


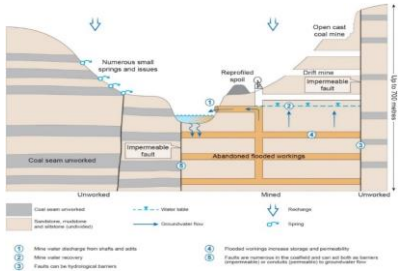
Questions…

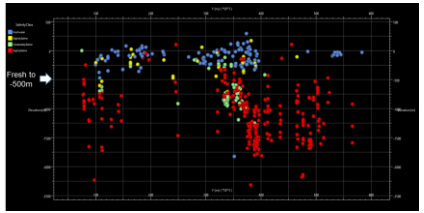

Environment Agency
Flooding in the South East
20 February 2014
Northamptonshire LRF
West Mercia LRF
Gloucestershire LRF
River Lee from Ler
Thames Valley LR
Staines, Egham
Wiltshire & Swindon LRF
Basingstoke
Hampshire & Isle of Wight LRF
Chertsey
Nailbourne
Surrey LRF
Kent LRF
Mole & South London Area
Sussex LRF
Dorset LRF
River Test at Romsey
River
Coastal / Tidal
Groundwater
Other (Surface Water)
Does groundwater exacerbate major surface water floods?
© Crown Copyright. All rights reserved. Environment Agency, 100026380, 2014.

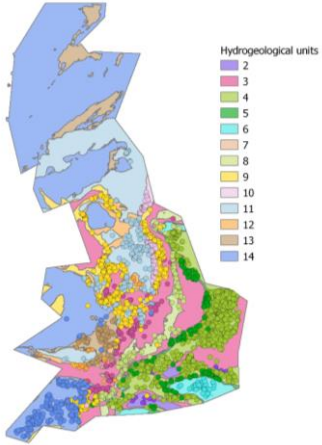

Met Office
Year 2011
Rainfall Amount
% of 1981-2010 Average
% of Average
> 135
125 to 135
115 to 125
105 to 115
95 to 105
When will it dry up?
How much is in the groundwater "tank" during a drought?
© Crown copyright

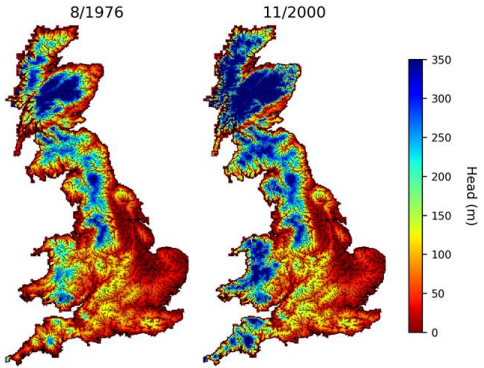
?




Open cast coal mine
Numerous small springs and issues
Reprofiled spoil
Drift mine
impermeable fault
impermeable fault
Coal seam unworked
Abandoned flooded workings
Unworked
Mined
Unworked


Fresh to -500m


Hydrogeological units
2
3
4
5
6
7
8
9
10
11
12
13
14


8/1976
11/2000
350
300
250
200
150
100
50
0
Head (m)

British Mainland Groundwater Model (BGWM)

Taylor & Francis

Hydrological Sciences Journal

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/thsj20

Simulation of national-scale groundwater dynamics in geologically complex aquifer systems: an example from Great Britain

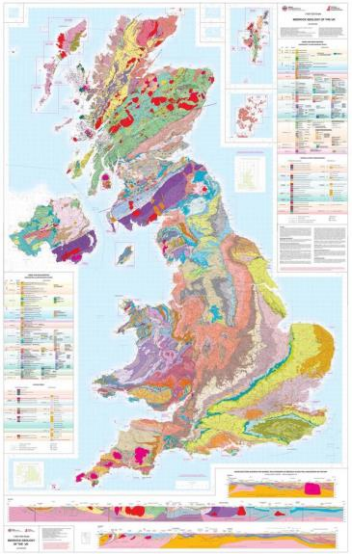
Marco Bianchi, Johanna Scheidegger, Andrew Hughes, Christopher Jackson, Jonathan Lee, Melinda Lewis, Majdi Mansour, Andrew Newell, Brighid O'Dochartaigh, Ashley Patton & Simon Dadson

To cite this article: Marco Bianchi, Johanna Scheidegger, Andrew Hughes, Christopher Jackson, Jonathan Lee, Melinda Lewis, Majdi Mansour, Andrew Newell, Brighid O'Dochartaigh, Ashley Patton & Simon Dadson (10 Apr 2024): Simulation of national-scale groundwater dynamics in geologically complex aquifer systems: an example from Great Britain, Hydrological Sciences Journal, DOI: 10.1080/02626667.2024.2320847

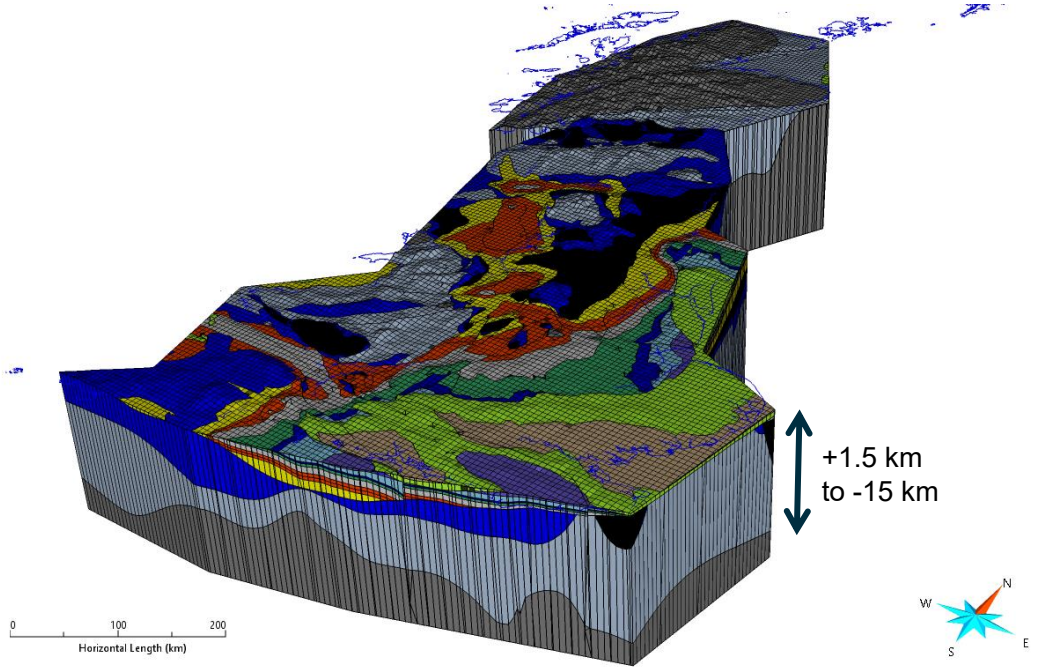
To link to this article: https://doi.org/10.1080/02626667.2024.2320847

Simulation of national-scale groundwater dynamics in geologically complex aquifer systems: an example from Great Britain - NERC Open Research Archive

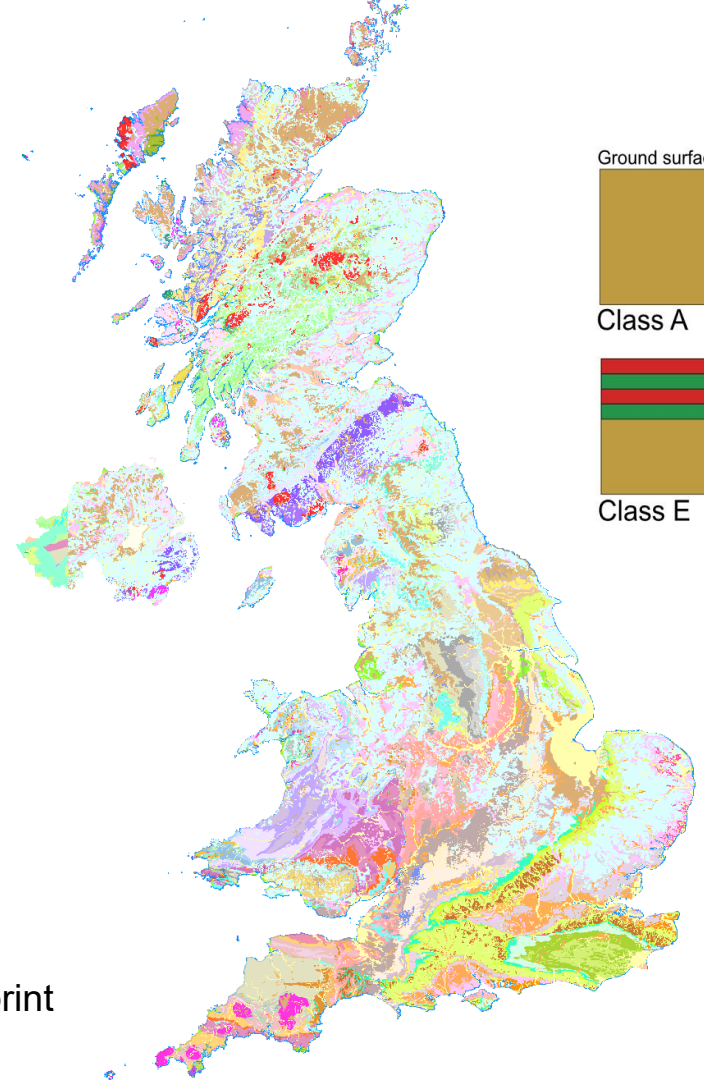
Improving the geological representation: 3D framework model

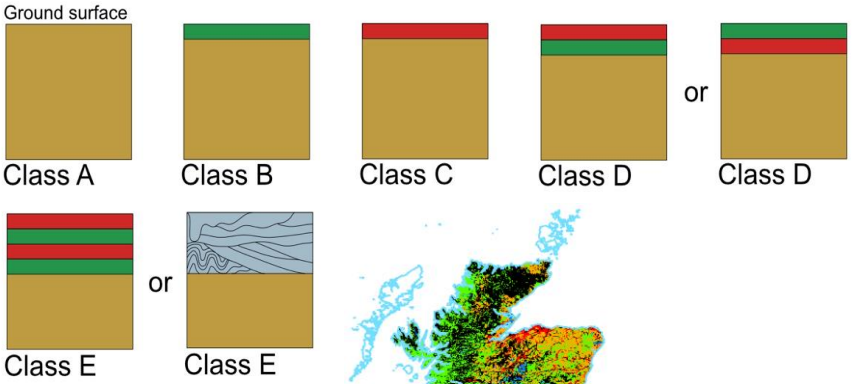


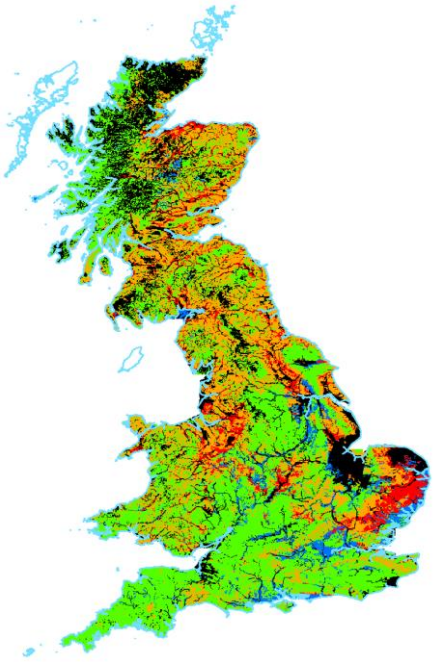
1:625,000 scale mapping



Quaternary processes





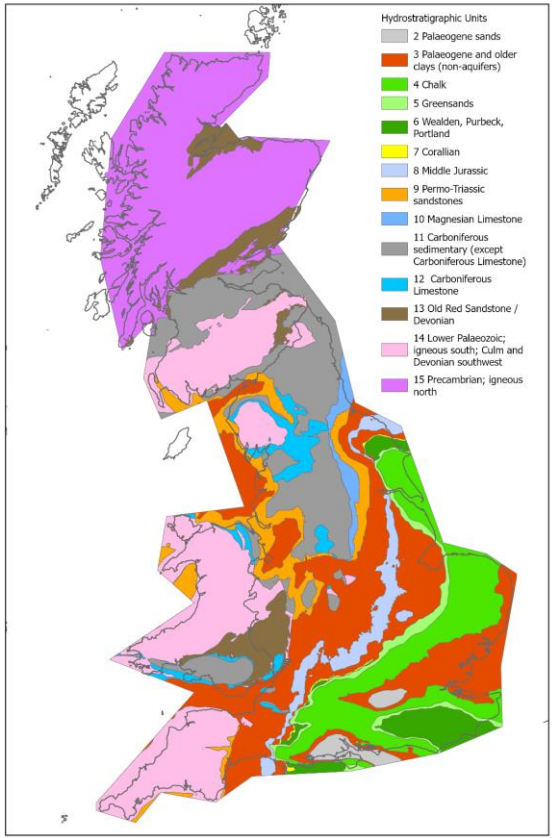


nora.nerc.ac.uk/id/eprint/532926/

Jon Lee

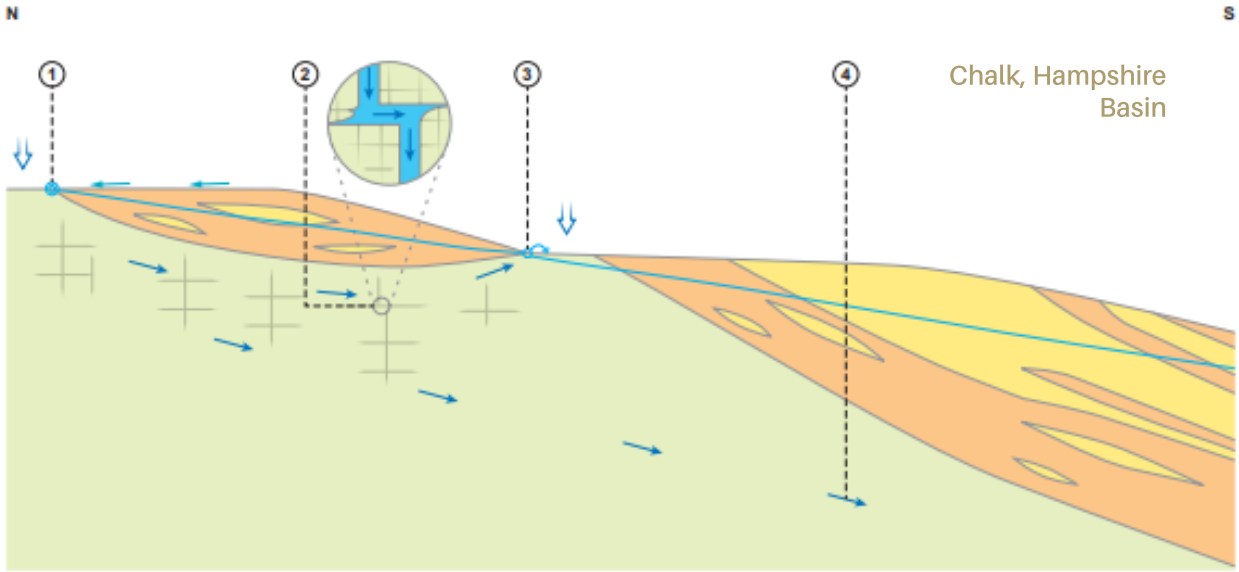
Defined 15 hydrostratigraphic units:

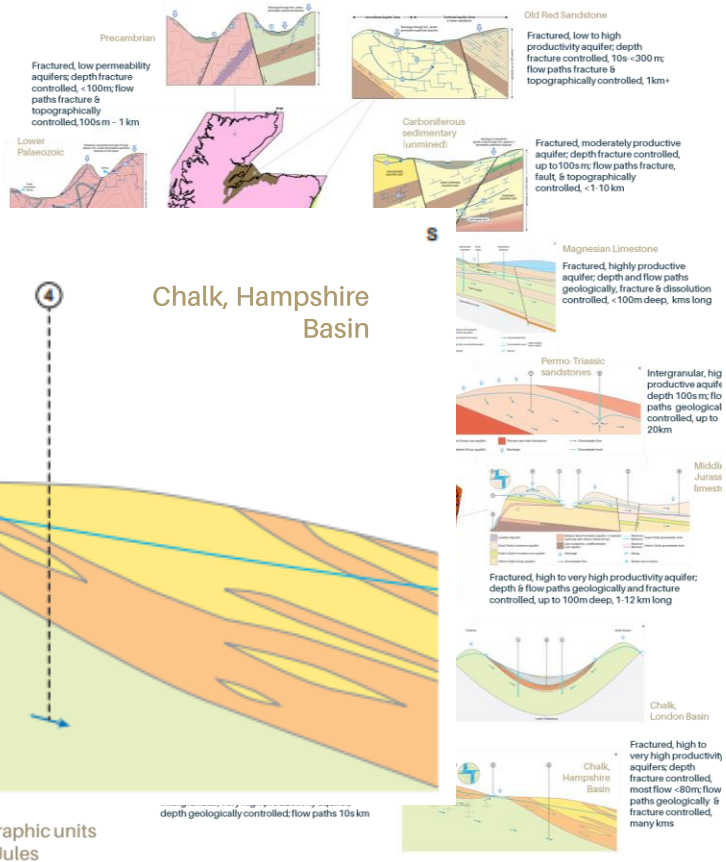
Hydro-stratigraphic unit code	Section in this report	Geological subdivisions within unit
HU1	2. Superficial aquifers (incl. Crag)	Superficial aquifers (not included in the current Hydr JULES British mainland model)
HU2	3. Palaeogene sands	Palaeogene, predominantly unconsolidated sand ac
HU3	4. Palaeogene & older clays (non-aquifers)	Predominantly clay or mudstone, Mesozoic or youn (non aquifer)
HU4	5. Chalk	Chalk
HU5	6. Greensands	Upper Greensand Formation, Gault Formation and L Greensand Group
HU6	7. Wealden, Purbeck, Portland	Wealden Group, Purbeck Formation, Portland Grou
HU7	8. Corallian	Corallian Group
HU8	9. Middle Jurassic	Middle Jurassic
HU9	10. Permo-Triassic sandstones	Permo-Triassic sandstone formations (except North Wales – HU13) and Scotland (HU14 and HU15)
HU10	11. Magnesian Limestone	Zechstein Group
HU11	12. Carboniferous sedimentary (except Carboniferous Limestone)	Dominantly Carboniferous sedimentary rocks (excep Carboniferous Limestone – HU 13; – and Culm – HU including Carboniferous Basinal Shales (very small present at depth). Also includes Carboniferous volca rocks and small areas of intrusive igneous rocks
HU12	13. Carboniferous Limestone	Dominantly Carboniferous Limestone Group; also P Triassic sandstone basins in North Wales
HU13	14. Old Red Sandstone / Devonian	Dominantly Devonian Old Red Sandstone rocks (ex in southwest England – HU14); also small areas of volcanic and intrusive igneous rocks, mostly of Devo age
HU14	15. Lower Palaeozoic; igneous south; Culm & Devonian southwest	Lower Palaeozoic across Britain; intrusive igneous a volcanic rocks south of the Southern Uplands Fault; Permo-Triassic sandstone basins in southern Scotla Culm and Devonian rocks in southwest England
HU15	16. Precambrian; igneous north	Precambrian across Britain; intrusive and volcanic r and Permo-Triassic sandstone basins north of approximately the geological boundary between Carboniferous and Devonian rocks; some Carbonife igneous intrusive rocks just south of this line; and tw small areas mapped on the 1:625,000 scale geolog as Triassic Mercia Mudstone Group, near Leicester, Carboniferous Warwickshire Group, near Nuneaton

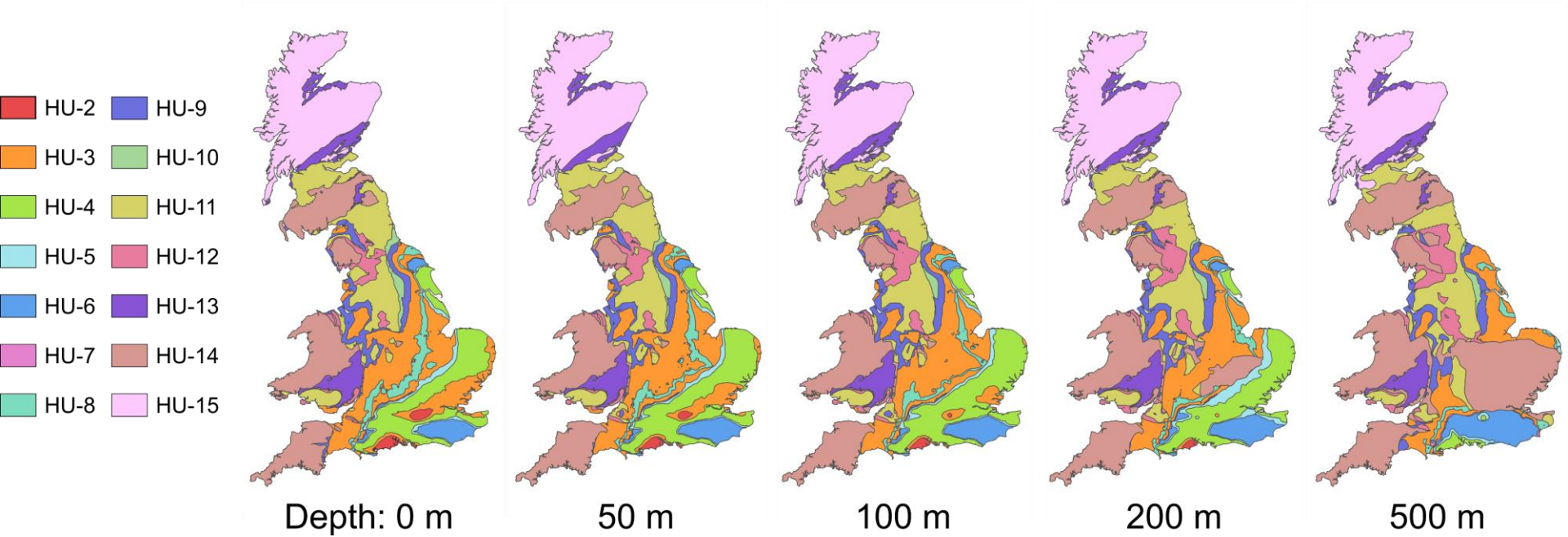


Conceptual understanding

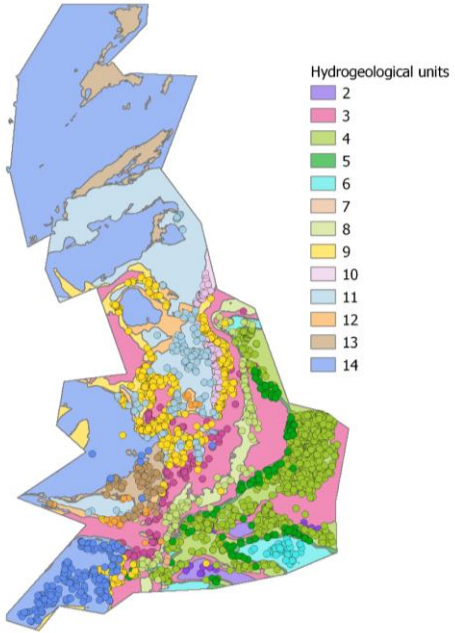
- How doe groundwater flow?
- How doe
- Need to
  break GB
- 15 Hydro
  (Quaterr
- Leading
  complex

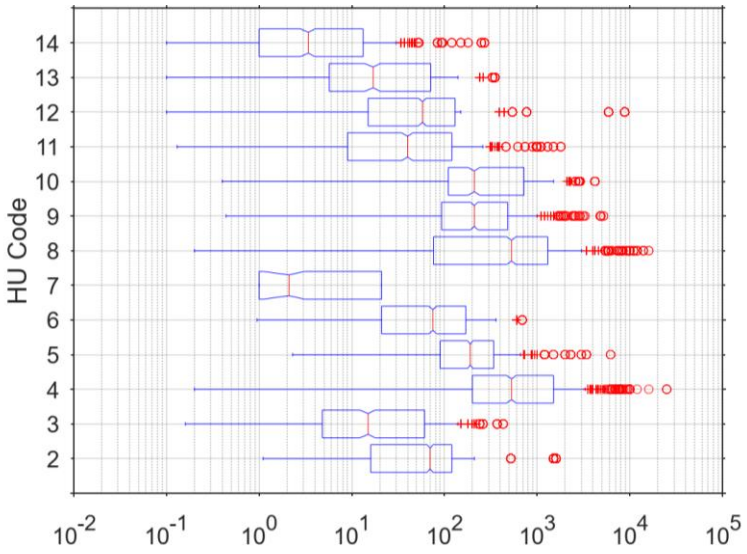





HU-2
HU-3
HU-4
HU-5
HU-6
HU-7
HU-8
HU-9
HU-10
HU-11
HU-12
HU-13
HU-14
HU-15
Depth: 0 m
50 m
100 m
200 m
500 m

Hydrostratigraphic units and Transmissivity distribution



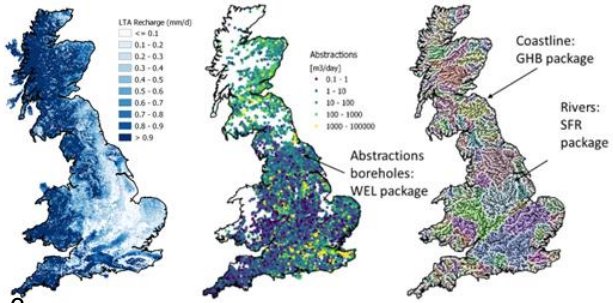


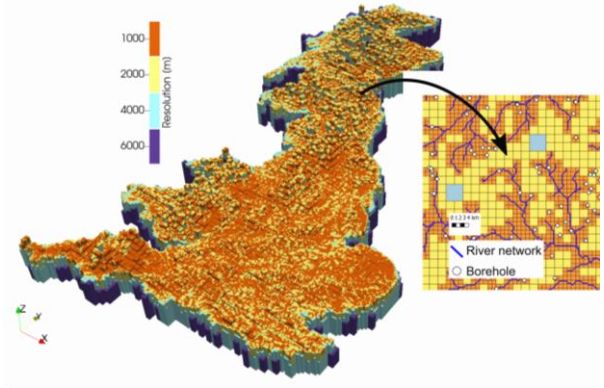
- Hydrostratigraphic units and borehole locations
- Transmissivity distribution for each hydrostratigraphic unit

The model: key info

The BGWM implemented in MODFLOW 6 simulates 3-D transient groundwater dynamics in the major and minor aquifers of Great Britain

The unstructured grid has a minimum resolution of 1 km in in the horizontal plane and 50 m along the vertical direction.

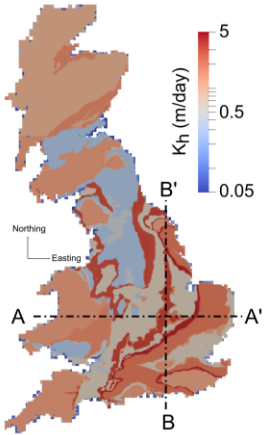


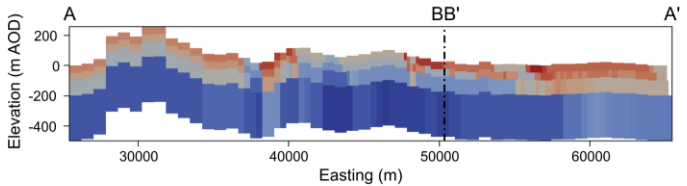


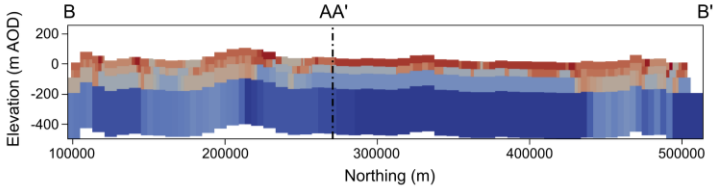
Hydrogeological parameterisation based on a 3-D geological model

Boundary conditions include:

- groundwater abstractions;
- groundwater discharge to the sea;
- river-aquifer interactions;
- distributed net recharge

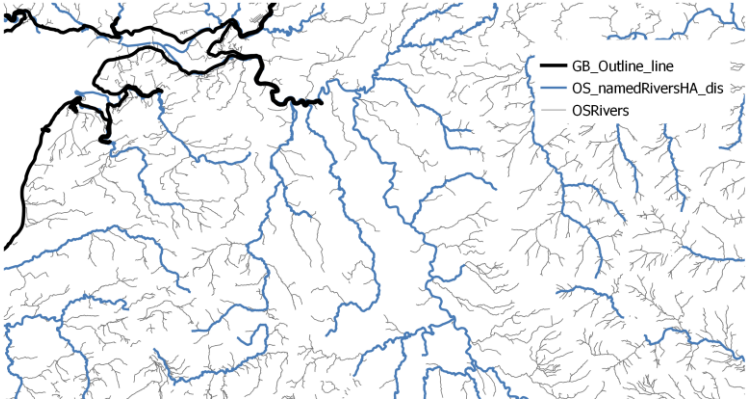


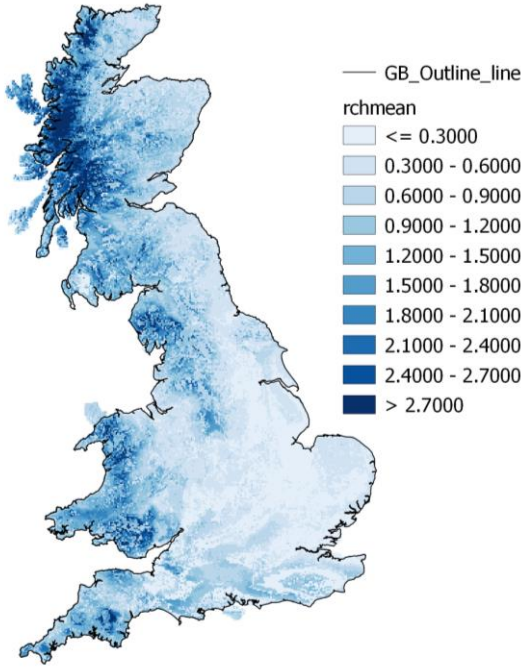




Boundary conditions

- Coastline: CHD package
- Rivers: RIV/SFR package
- Recharge: RCH package
- Abstractions: WEL package





Groundwater recharge

- BGWM is currently driven by monthly distributed potential recharge rates estimated with a national scale model (2 km resolution) implemented with the code ZOODRM

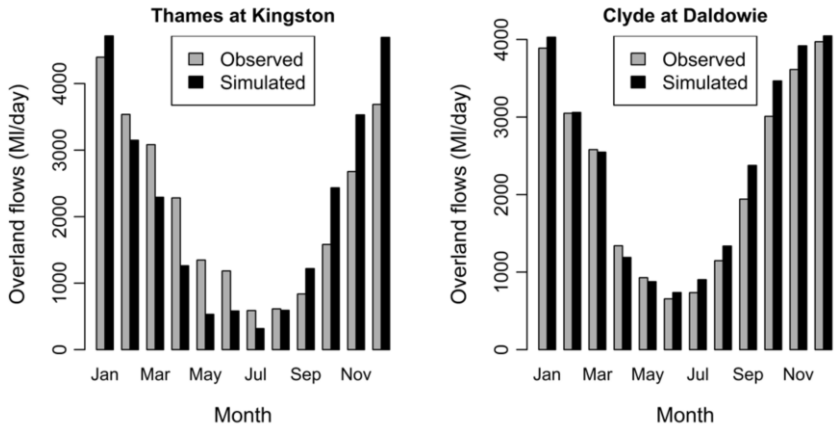
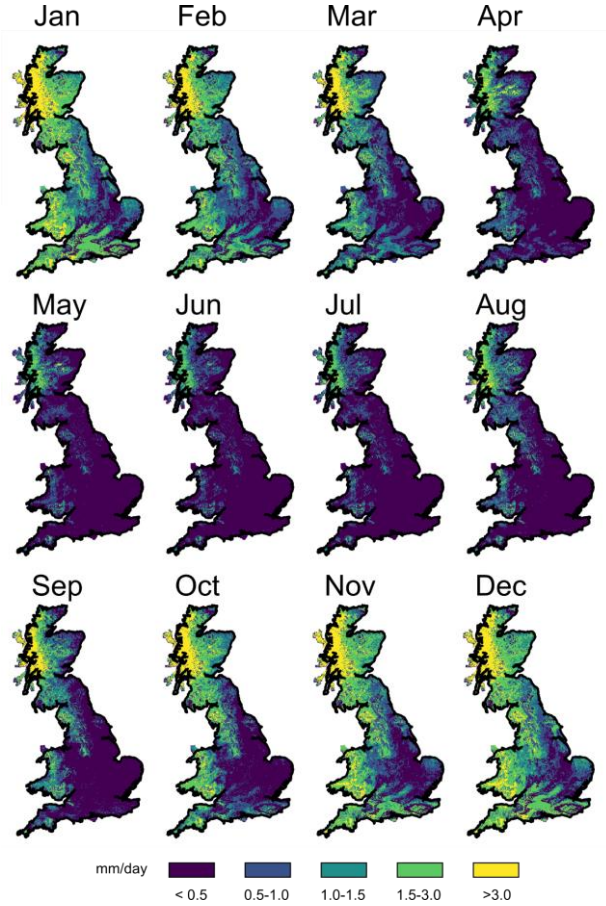
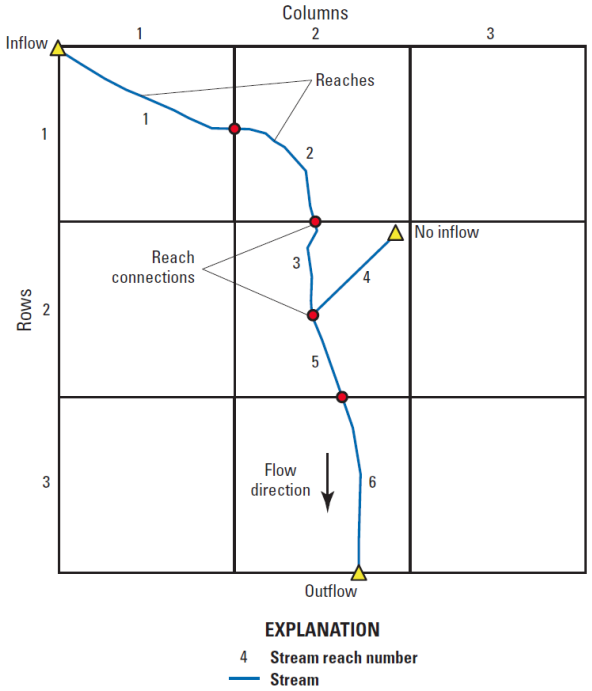


Fig. 8. Comparison between the simulated and observed monthly average run-off at the gauging stations represented by red circles shown in Figure 1.

Estimation of spatially distributed groundwater potential recharge for the United Kingdom - NERC Open Research Archive

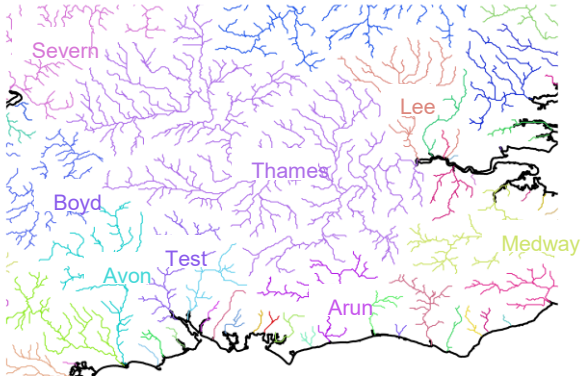


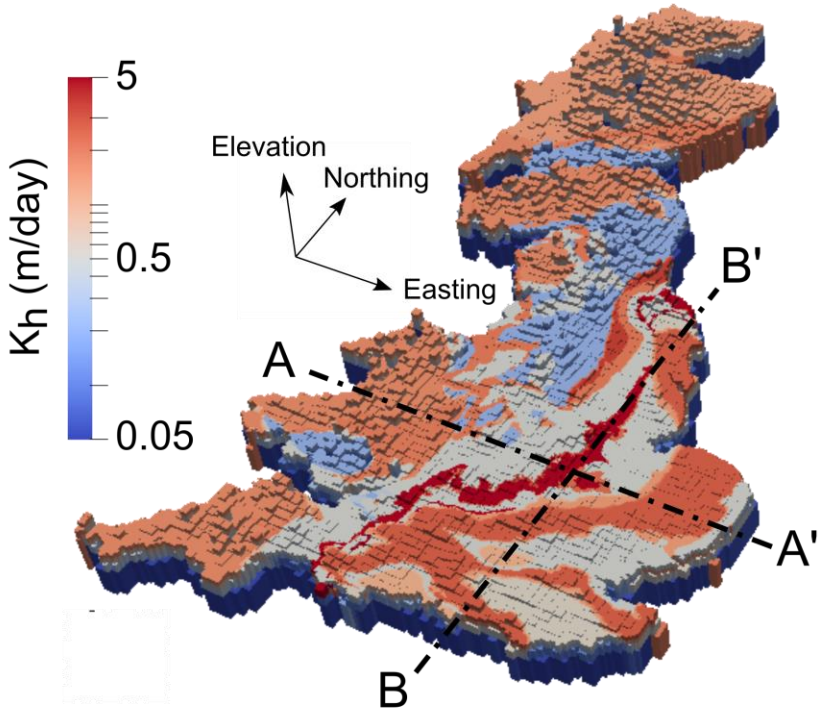
Streamflow-Routing Package

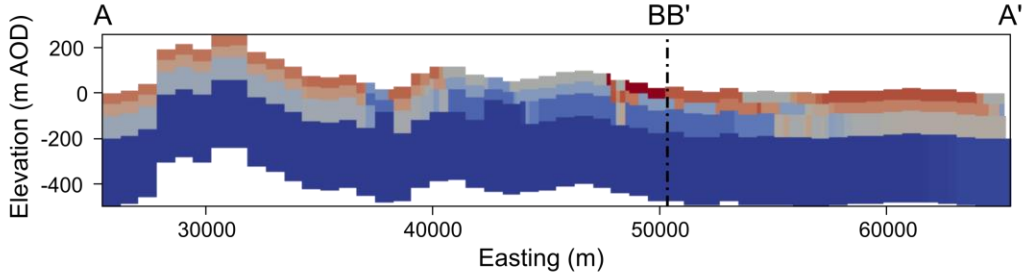


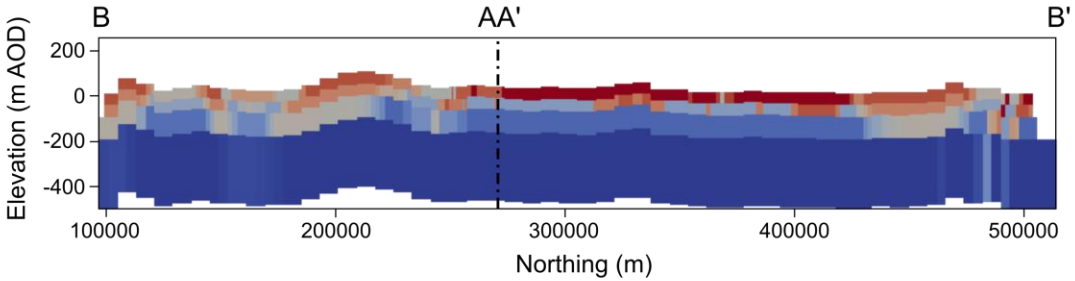
Prudic et al. (2004)

- Simulation of stream/aquifer interactions
- River network (D8 algorithm) based on the CEH Integrated Hydrological Digital Terrain Model [IHDTM]
- > 900 catchments and > 84000 reaches
- Channel width estimated with empirical formula of Bell et al. (2009)




5
0.5
0.05
K_h (m/day)
Elevation
Northing
Easting
A
A'
B
B'

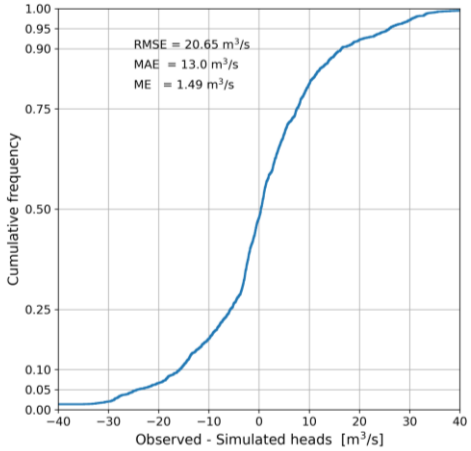

A
BB'
A'
200
0
-200
-400
Elevation (m AOD)
30000
40000
50000
60000
Easting (m)

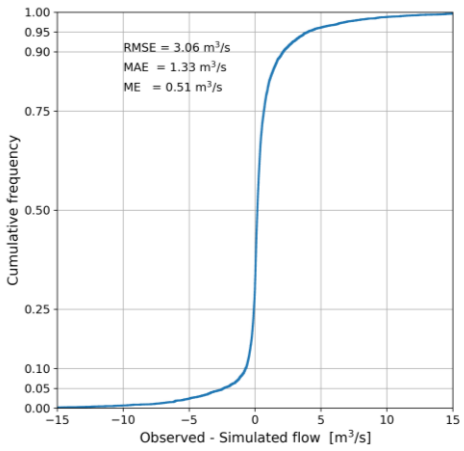

B
AA'
B'
200
0
-200
-400
Elevation (m AOD)
100000
200000
300000
400000
500000
Northing (m)

Calibration, accuracy, and predictability

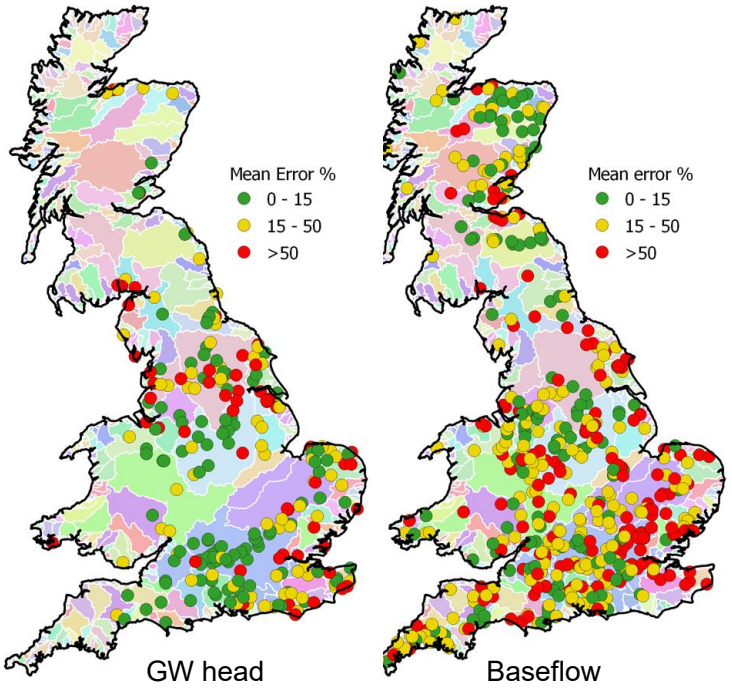
Model input parameters were calibrated using the **automated parameter estimation** (PEST) to minimise the residuals between simulated and observed **groundwater heads** (266 monitoring boreholes) **and baseflow** estimates (552 gauging stations)

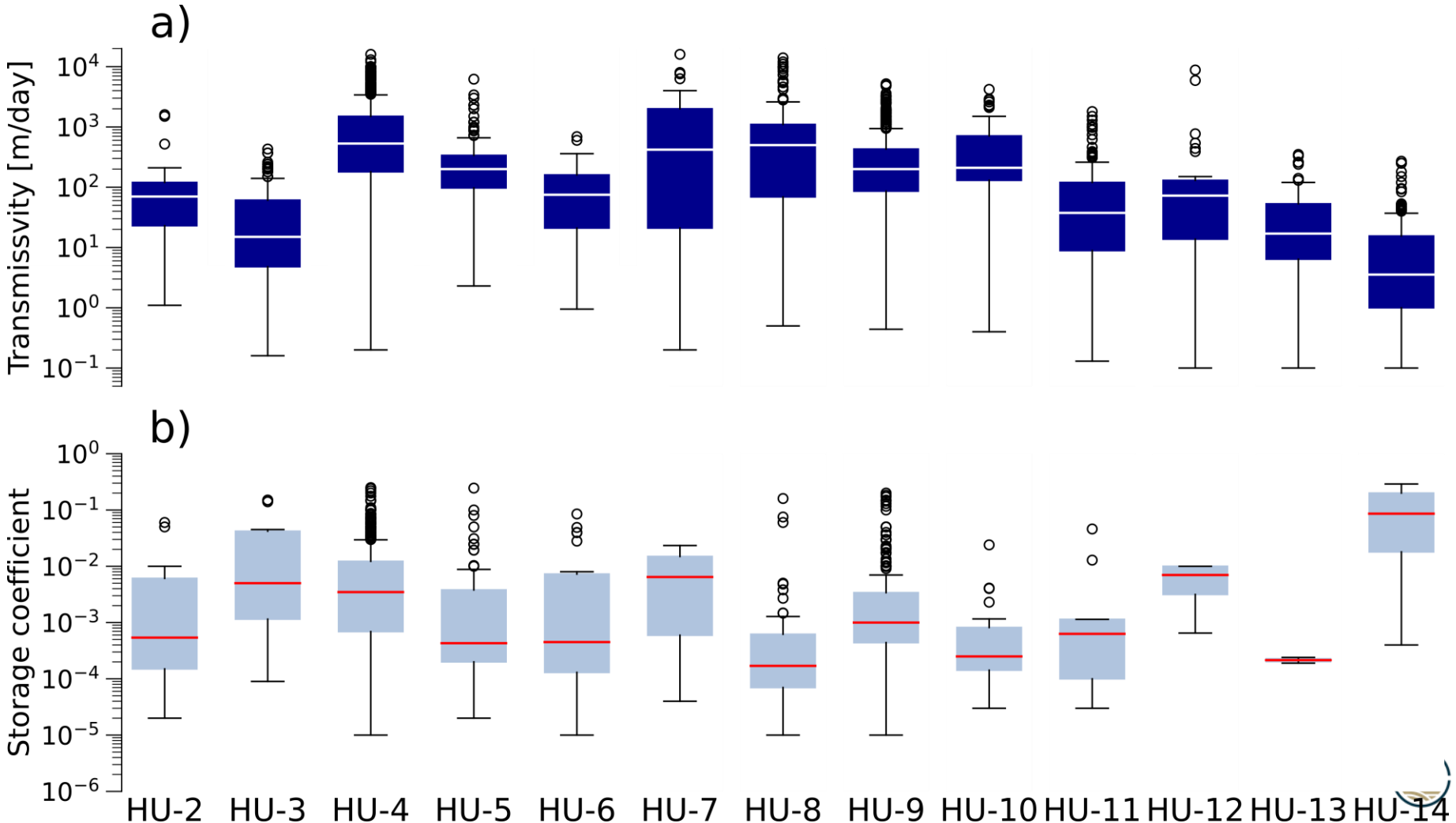
The full set of observations for the period 1970 – 2018 were compared the predictions from the BGWM to assess predictability





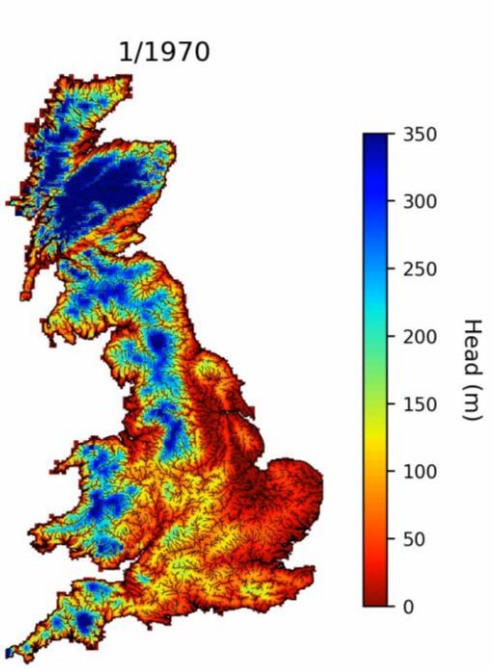
Prediction errors

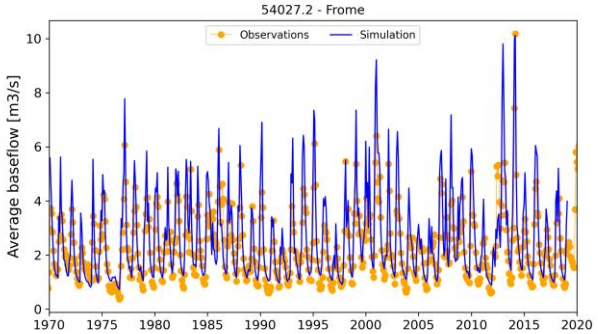


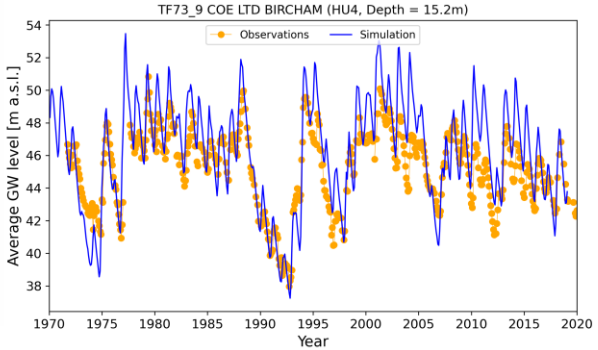

a)
Transmissvity [m/day]
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
b)
Storage coefficient
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
HU-2
HU-3
HU-4
HU-5
HU-6
HU-7
HU-8
HU-9
HU-10
HU-11
HU-12
HU-13
HU-14

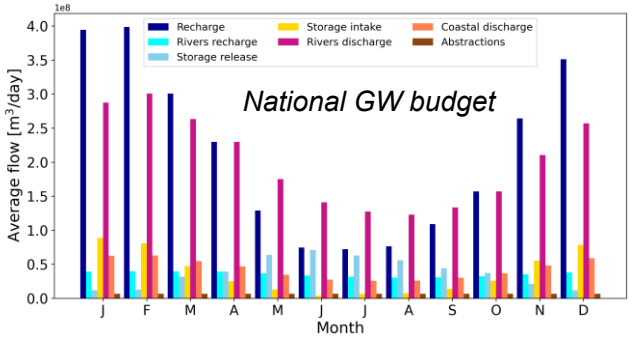
Simulation outputs

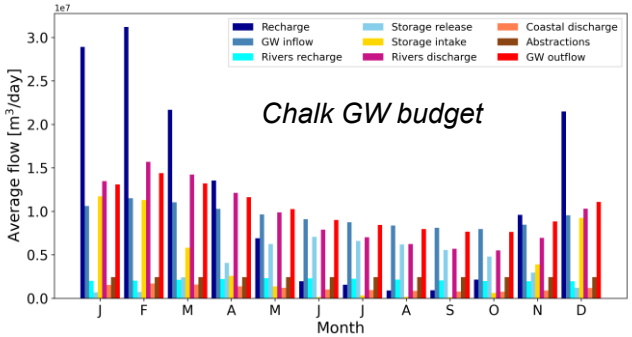
The BGWM simulates time-varying 3-D groundwater head distributions, groundwater depths, baseflows, and budgets

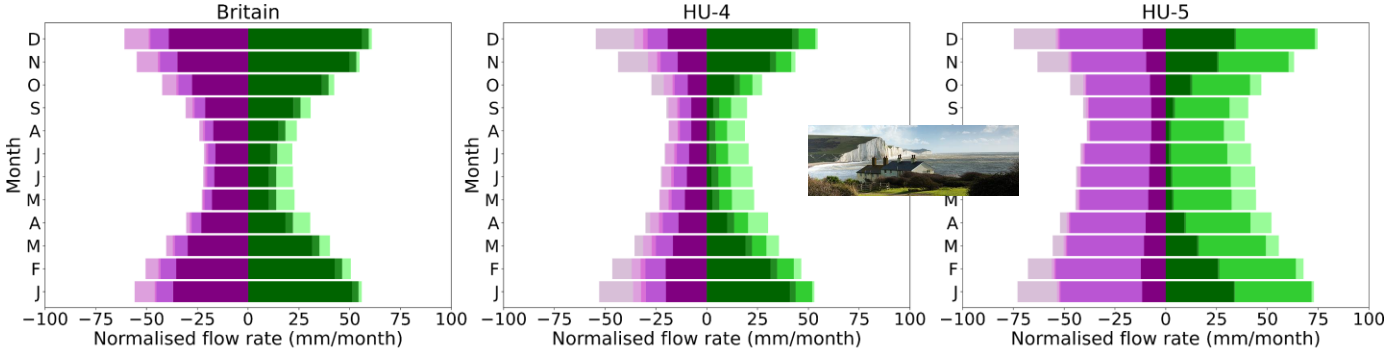


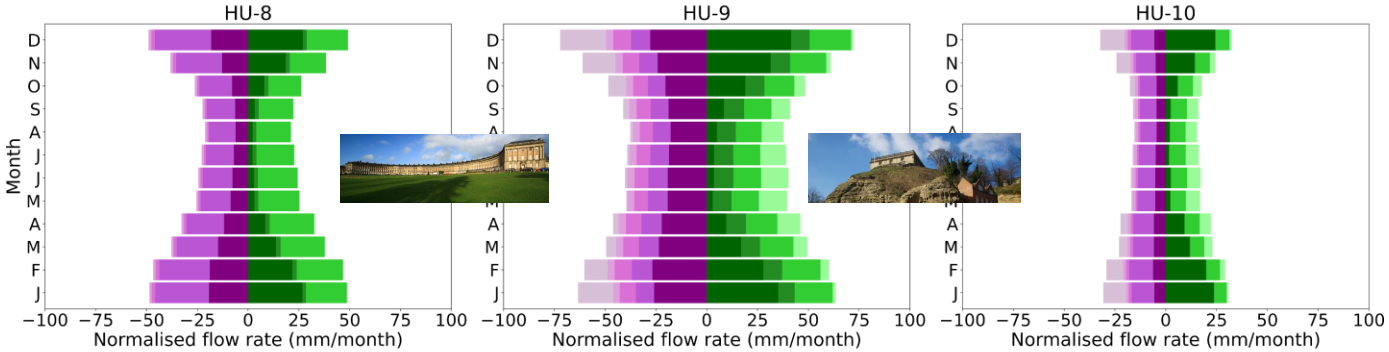


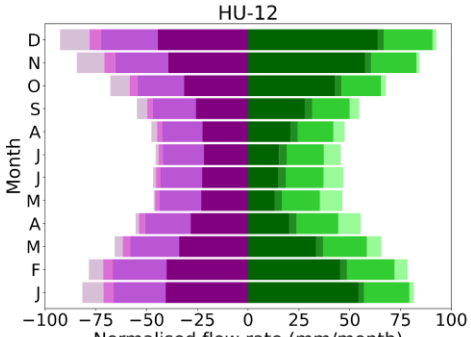


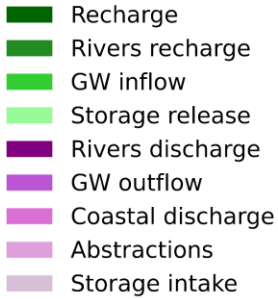


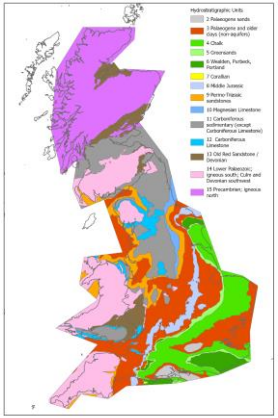


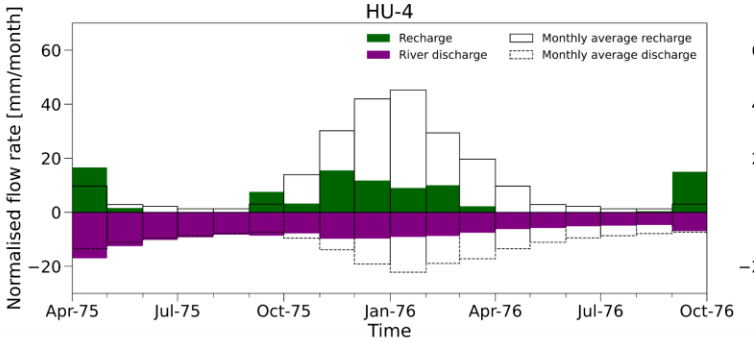

Britain
HU-4
HU-5
Month
D
N
O
S
A
J
J
M
A
M
F
J
−100 −75 −50 −25 0 25 50 75 100
Normalised flow rate (mm/month)

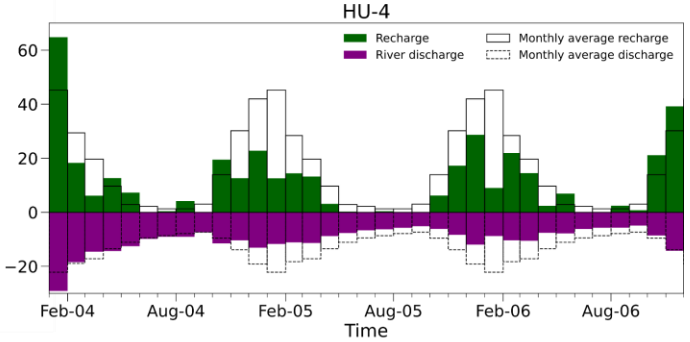

HU-8
HU-9
HU-10
Month
D
N
O
S
A
J
J
M
A
M
F
J
−100 −75 −50 −25 0 25 50 75 100
Normalised flow rate (mm/month)

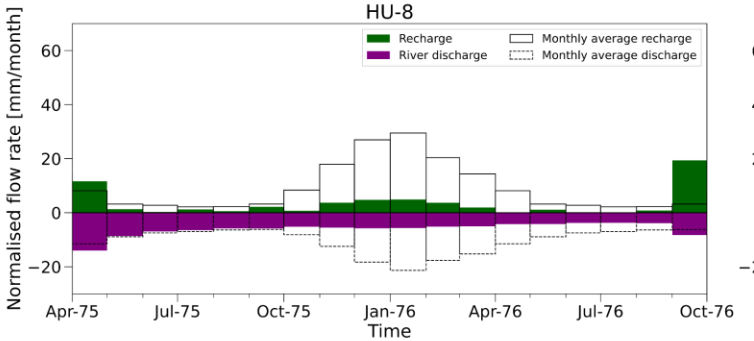

HU-12
Month
D
N
O
S
A
J
J
M
A
M
F
J
−100 −75 −50 −25 0 25 50 75 100
Normalised flow rate (mm/month)

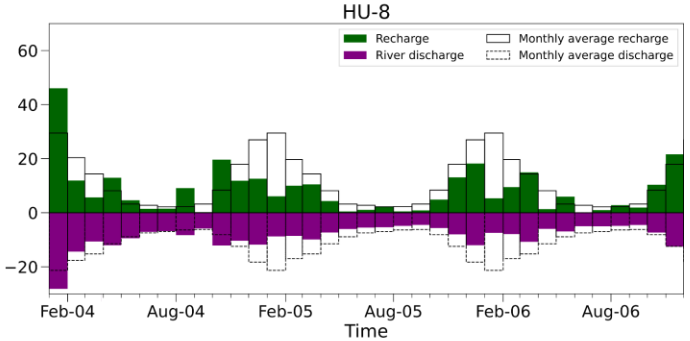

Recharge
Rivers recharge
GW inflow
Storage release
Rivers discharge
GW outflow
Coastal discharge
Abstractions
Storage intake

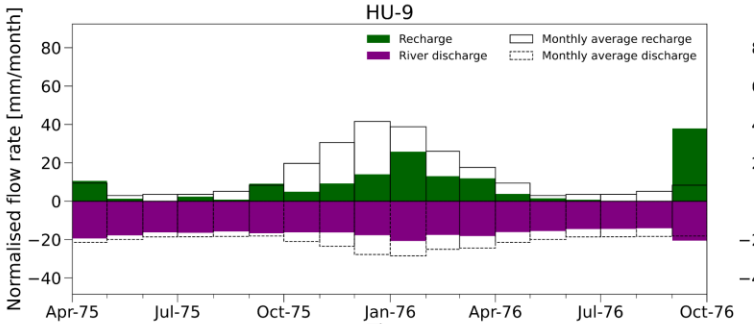


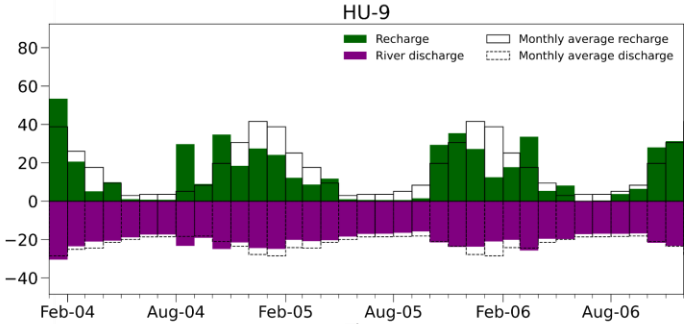

HU-4
Recharge
River discharge
Monthly average recharge
Monthly average discharge
Normalised flow rate [mm/month]
60
40
20
0
−20
Apr-75
Jul-75
Oct-75
Jan-76
Apr-76
Jul-76
Oct-76
Time


HU-4
Recharge
River discharge
Monthly average recharge
Monthly average discharge
60
40
20
0
−20
Feb-04
Aug-04
Feb-05
Aug-05
Feb-06
Aug-06
Time


HU-8
Recharge
River discharge
Monthly average recharge
Monthly average discharge
Normalised flow rate [mm/month]
60
40
20
0
−20
Apr-75
Jul-75
Oct-75
Jan-76
Apr-76
Jul-76
Oct-76
Time

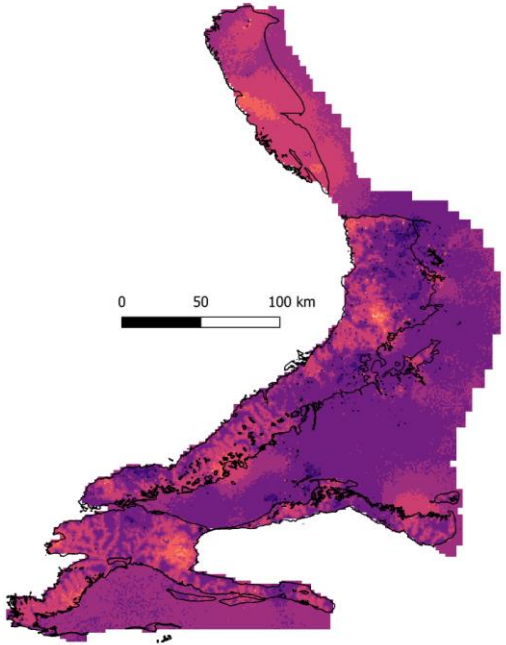

HU-8
Recharge
River discharge
Monthly average recharge
Monthly average discharge
60
40
20
0
−20
Feb-04
Aug-04
Feb-05
Aug-05
Feb-06
Aug-06
Time


HU-9
Recharge
River discharge
Monthly average recharge
Monthly average discharge
Normalised flow rate [mm/month]
80
60
40
20
0
−20
−40
Apr-75
Jul-75
Oct-75
Jan-76
Apr-76
Jul-76
Oct-76
Time


HU-9
Recharge
River discharge
Monthly average recharge
Monthly average discharge
80
60
40
20
0
−20
−40
Feb-04
Aug-04
Feb-05
Aug-05
Feb-06
Aug-06
Time

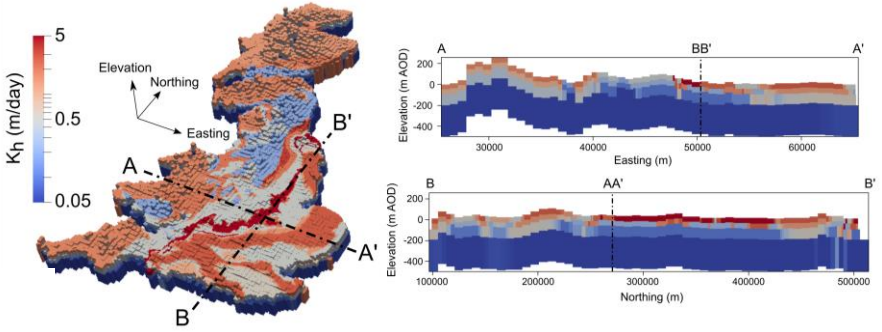
What next for the BGWM? MODFLOW6 enhancements

- Low permeability aquifers typically found in upland Britain – develop model structures to represent short groundwater flow pathways in these groundwater systems.
- Improved parametrisation – voxel based, stochastic and incorporating BGS databases.
- Coastal processes – extending groundwater flows beyond the coast.
- Inclusion of quaternary aquifers.

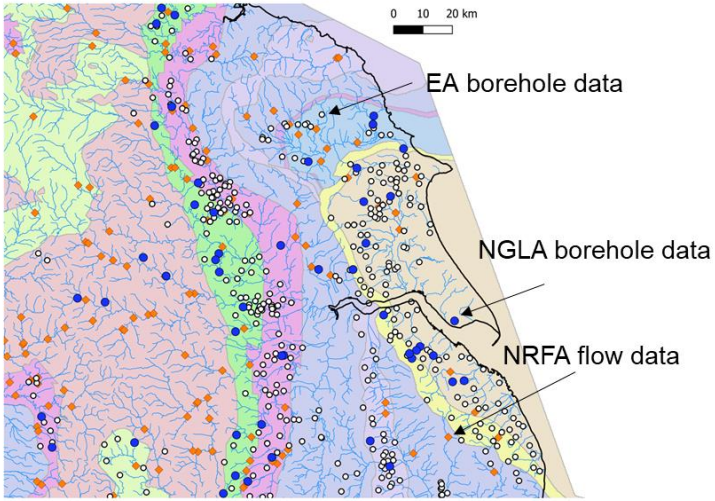


Parameterisation

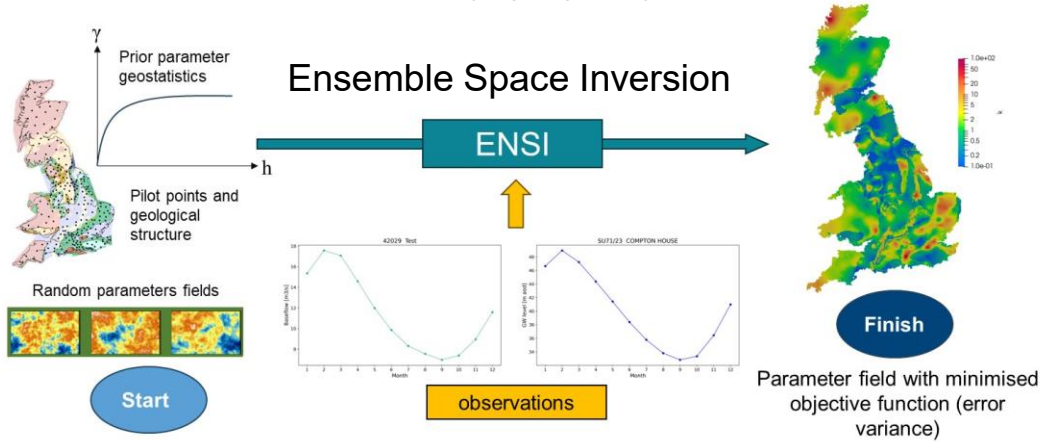
Current parametrisation after history matching



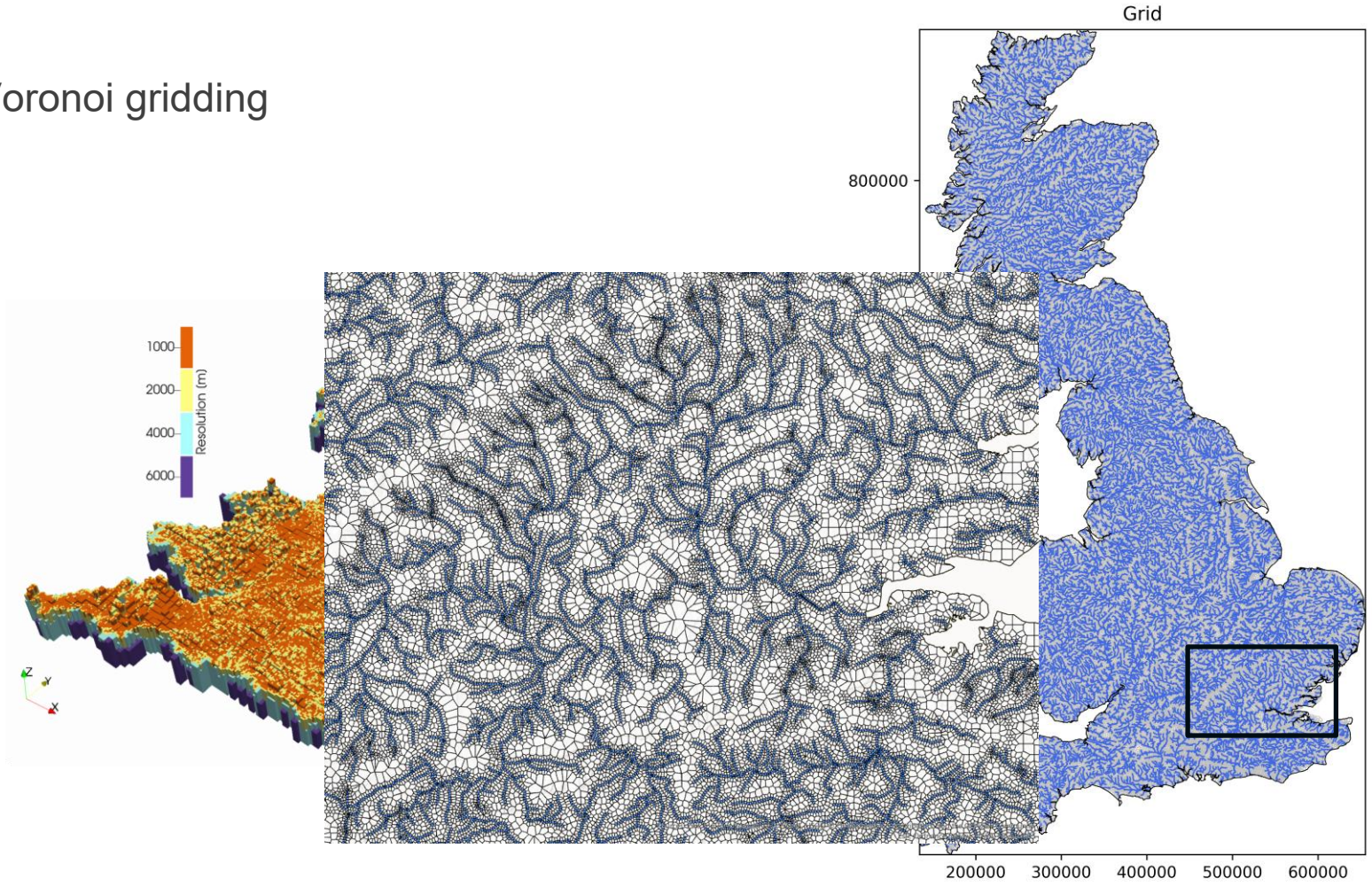
Data for history matching

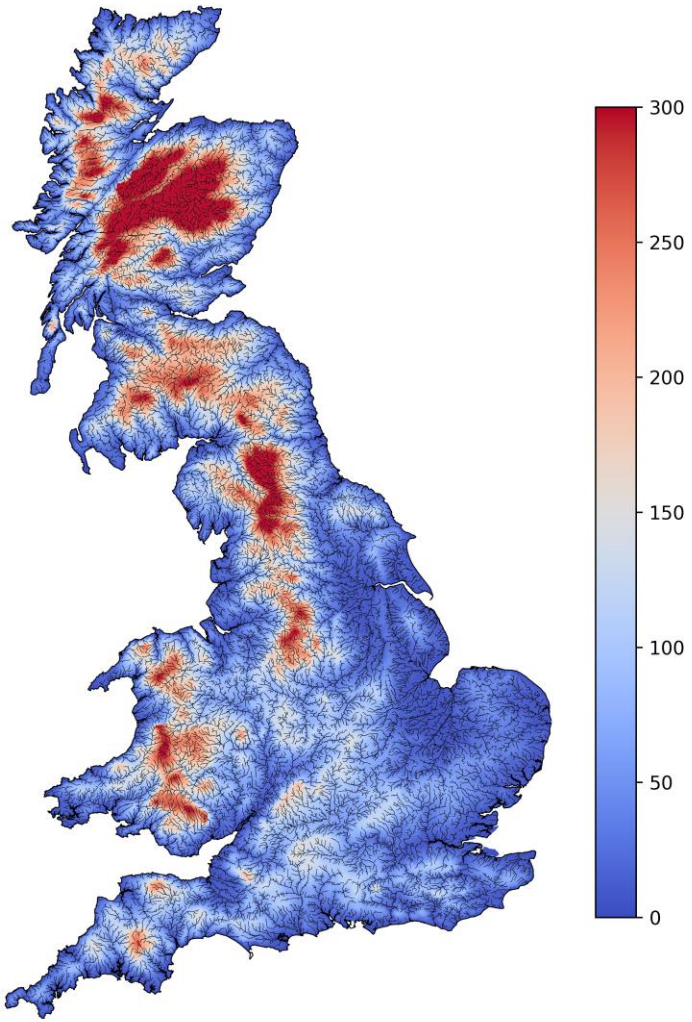


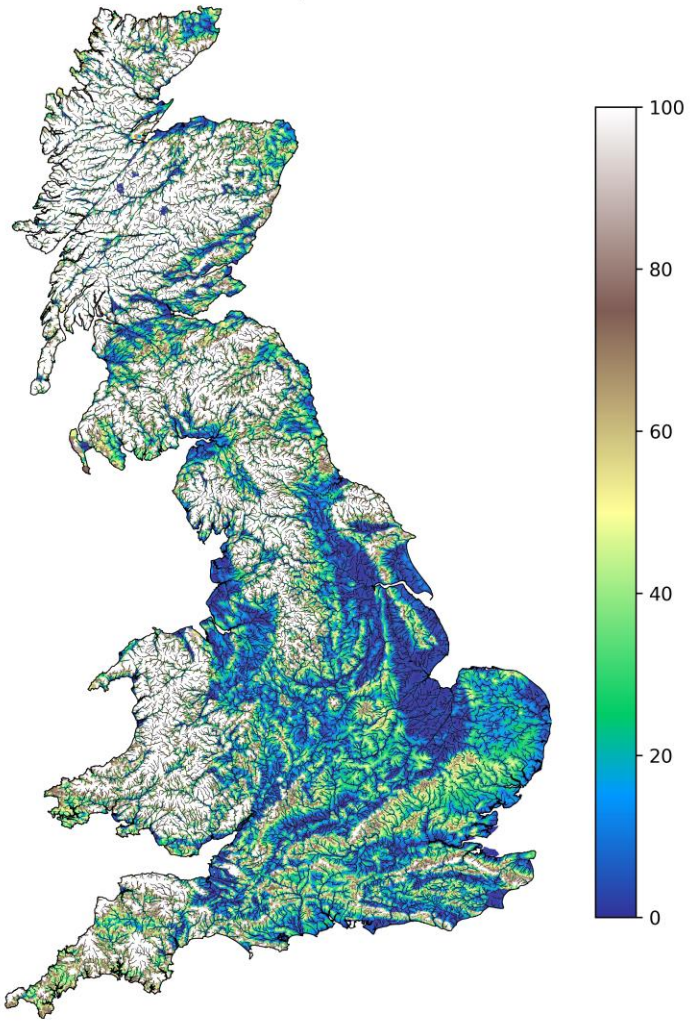
Future calibration approach (ongoing work)

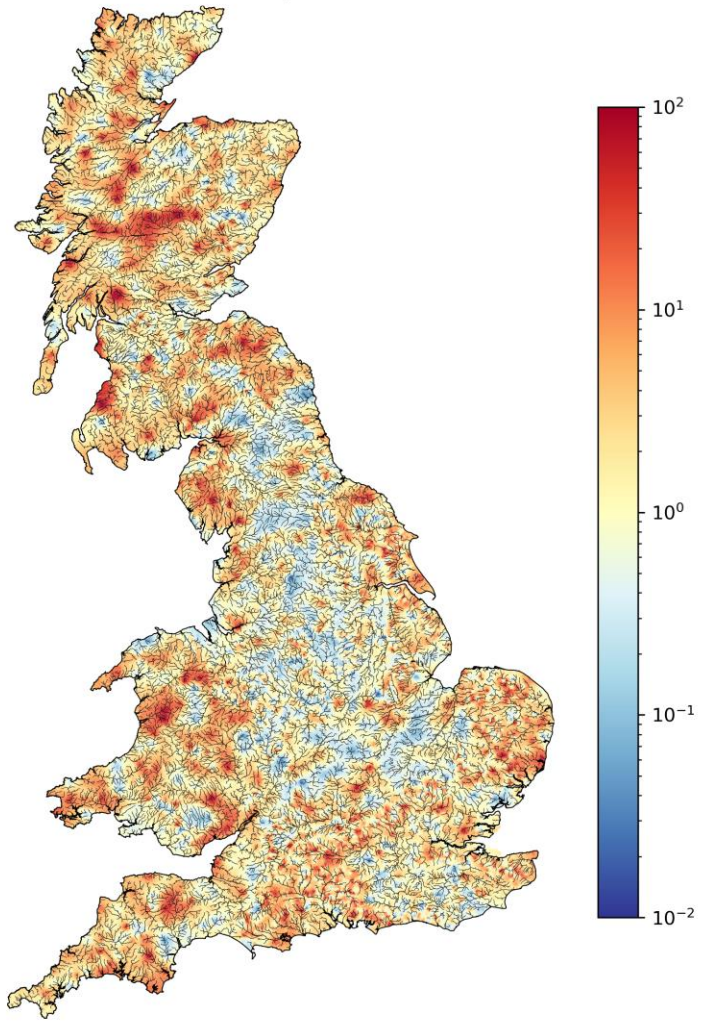


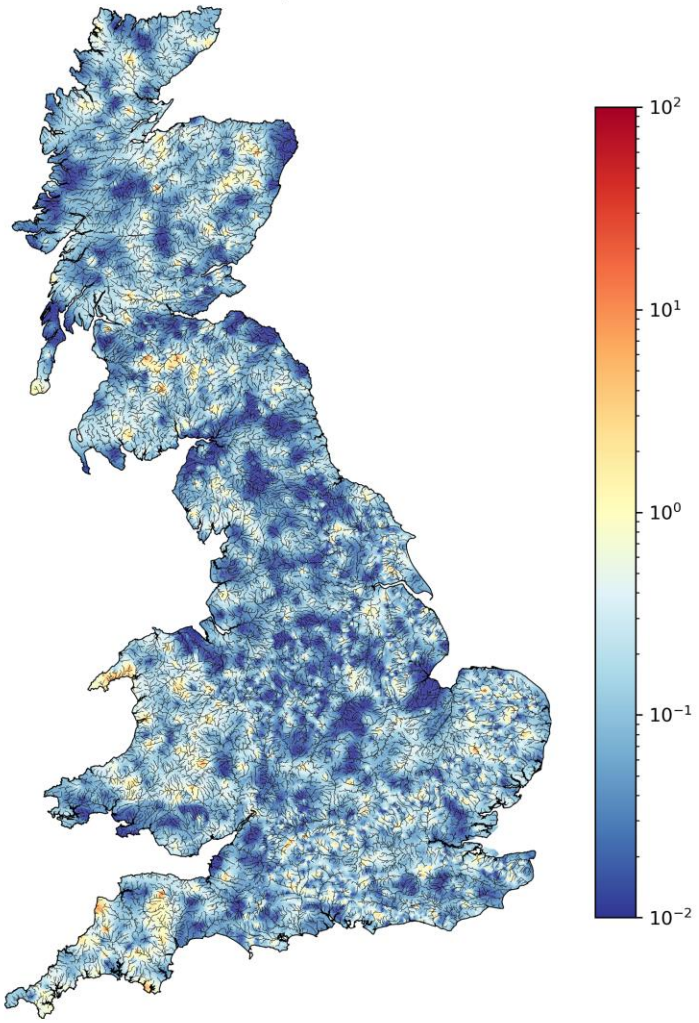
Voronoi gridding

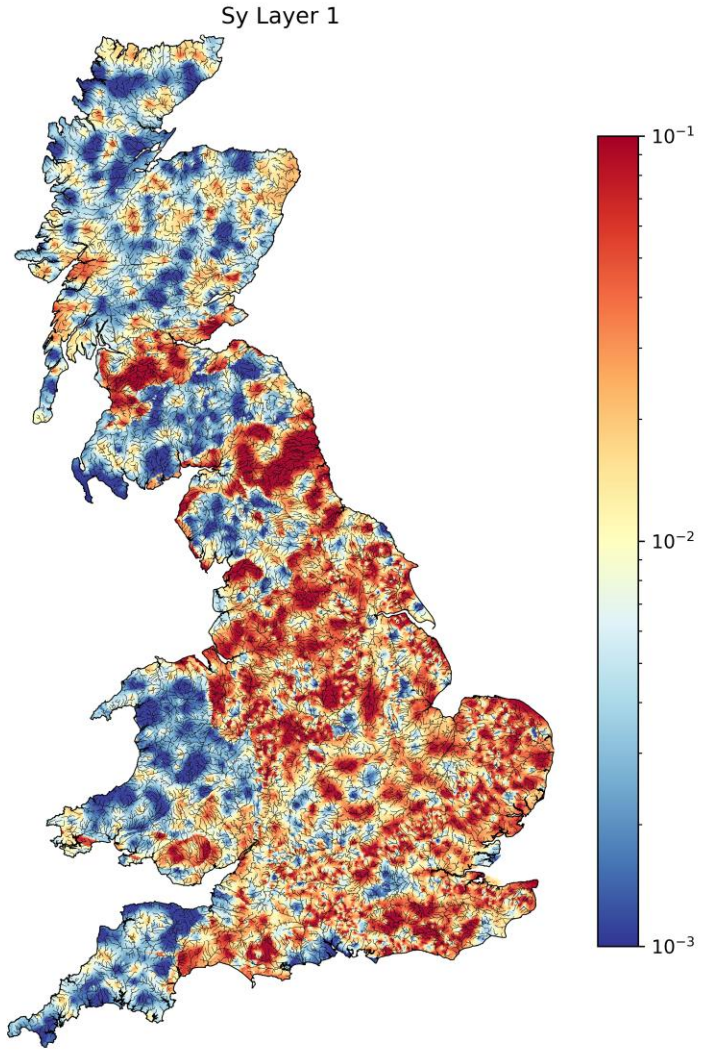


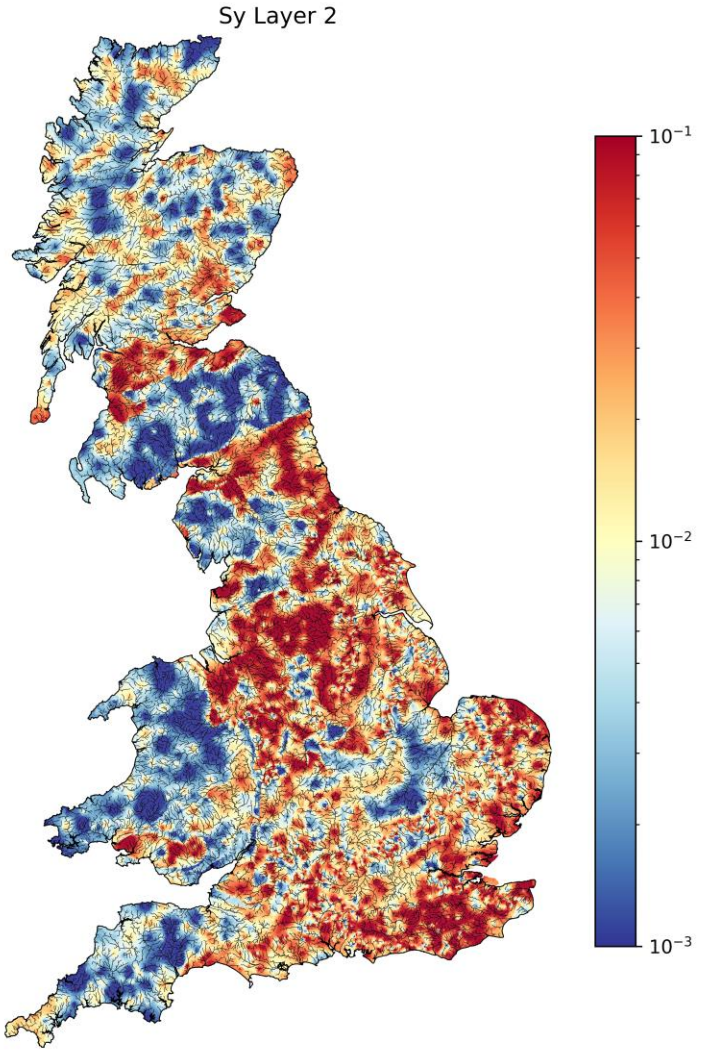

SS Head
300
250
200
150
100
50
0


GW depth
100
80
60
40
20
0

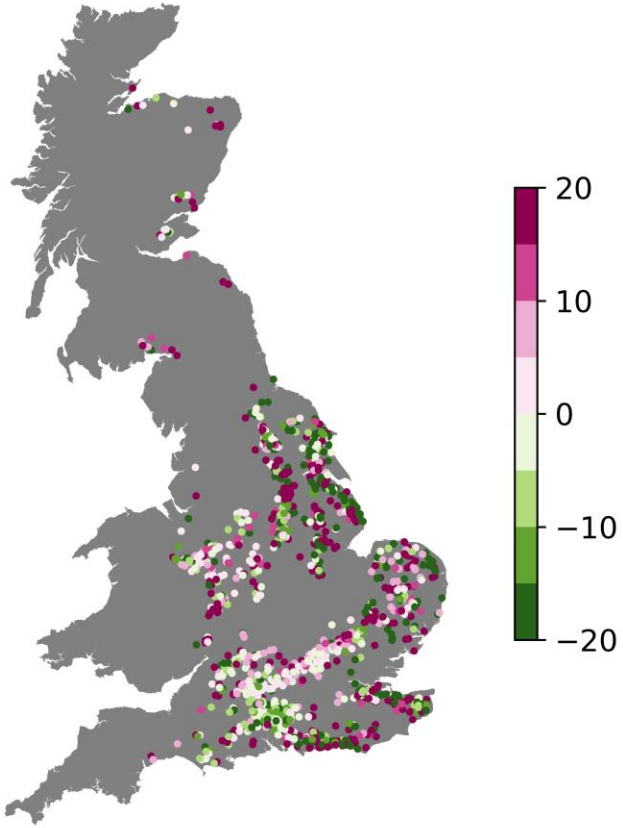

Kh Layer 1
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}


Kh Layer 2
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}

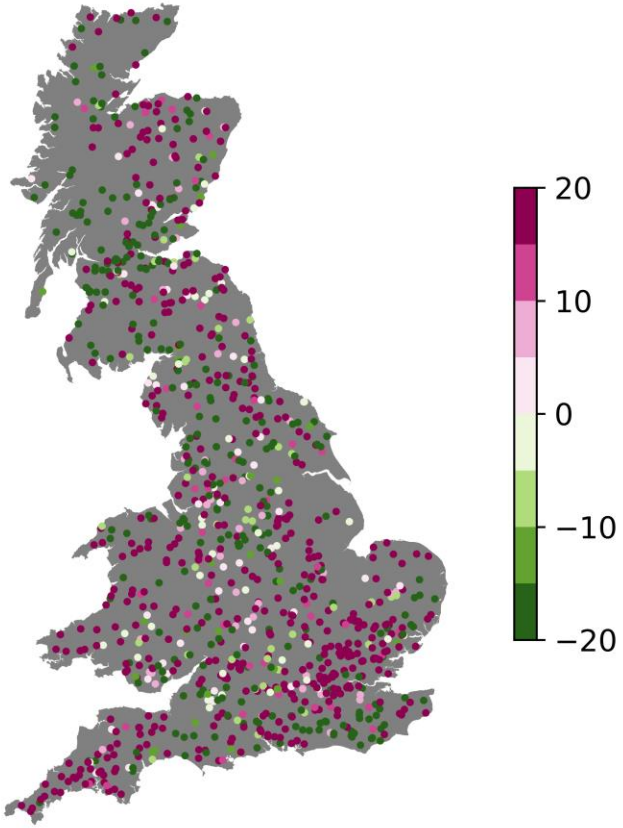

Sy Layer 1
10^{-1}
10^{-2}
10^{-3}


Sy Layer 2
10^{-1}
10^{-2}
10^{-3}

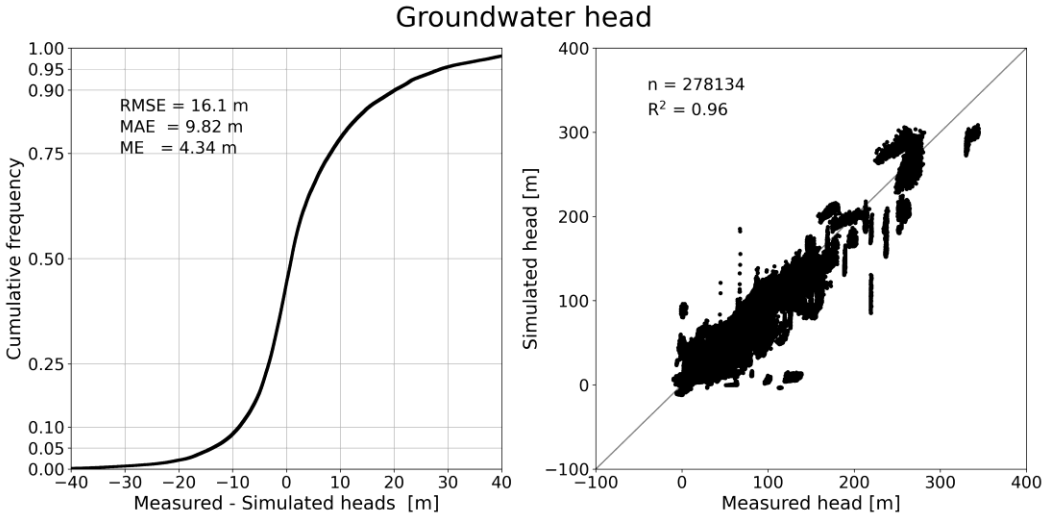
MPE error (%)
-overstimation; +underestimation



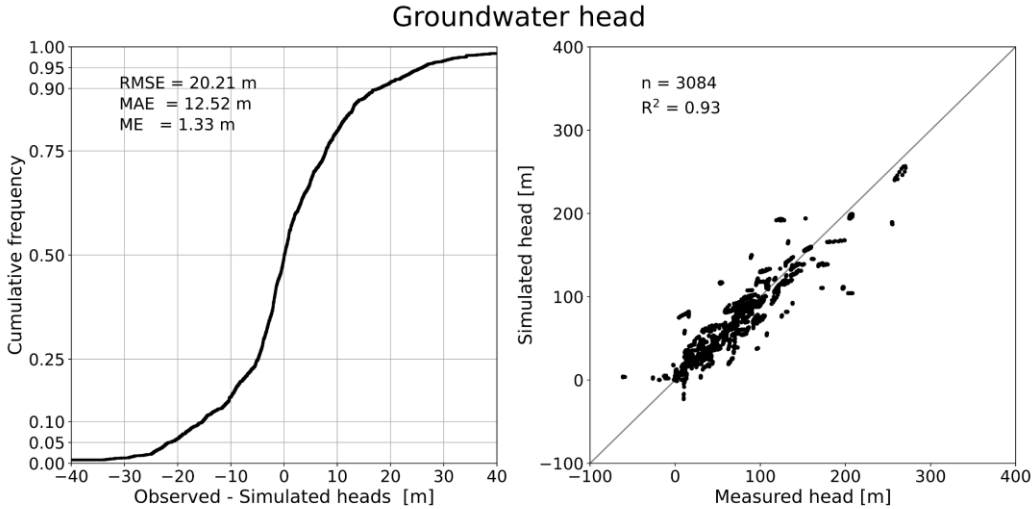
MPE baseflow (%)
-overstimation; +underestimation



Voronoi model

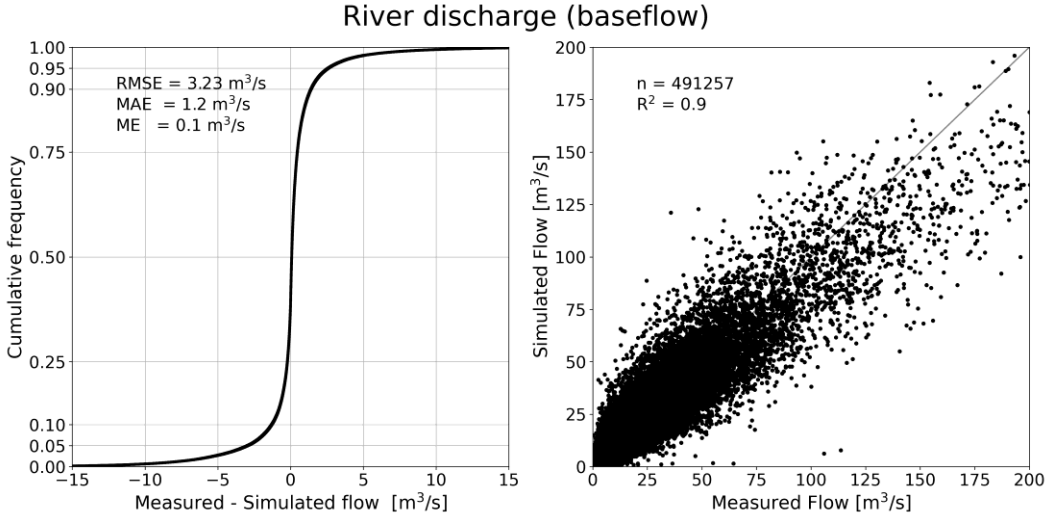


Old model

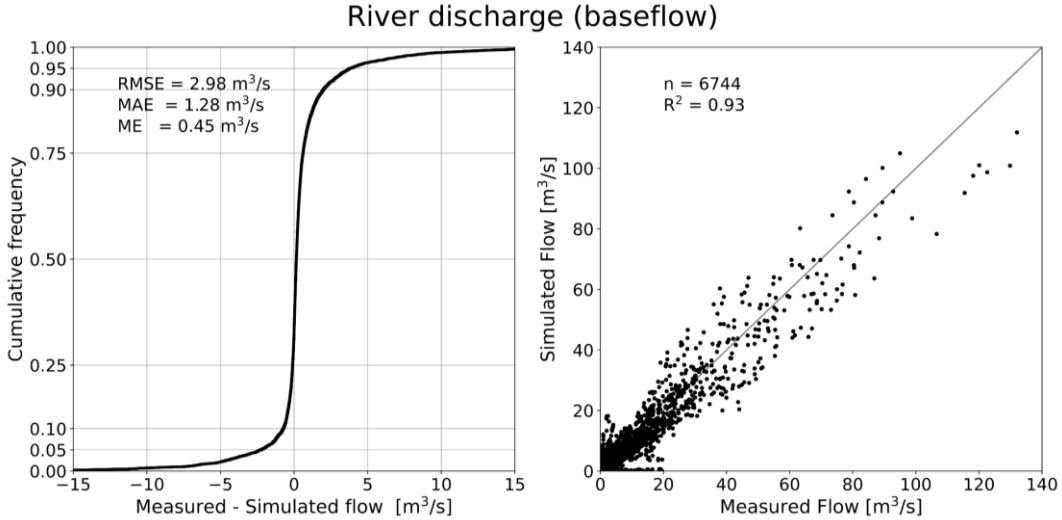


Setareh Nagheli

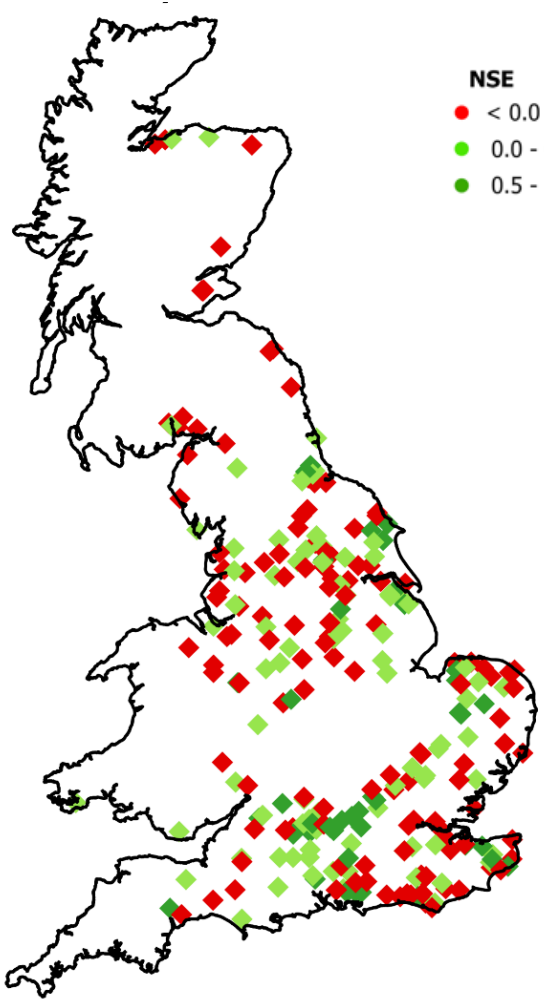
Voronoi model



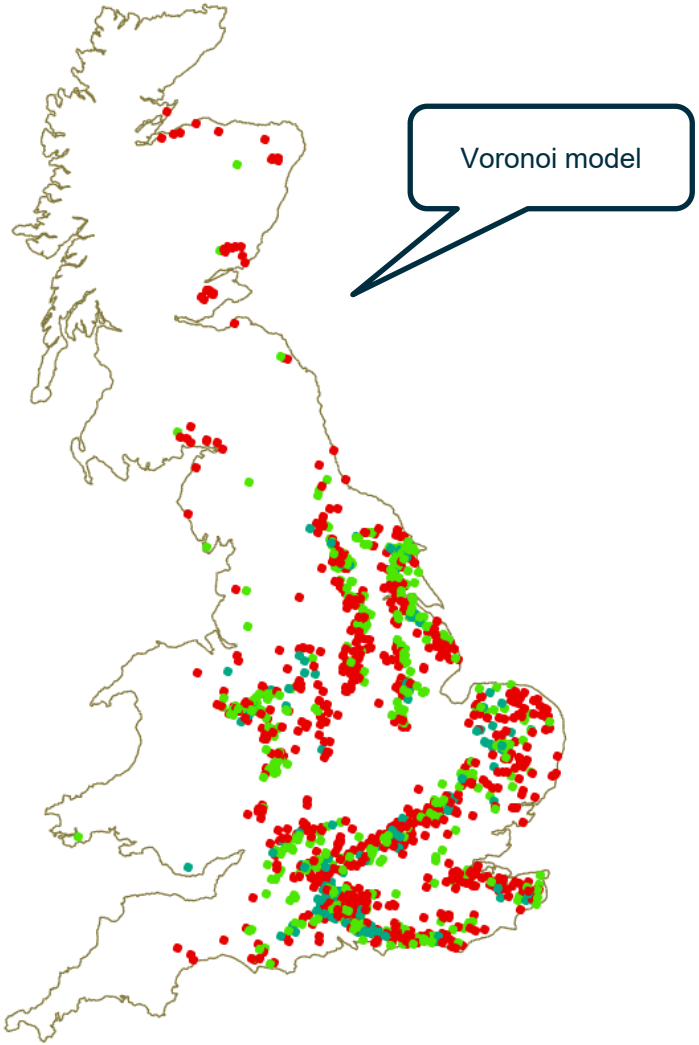
Old model



Old model

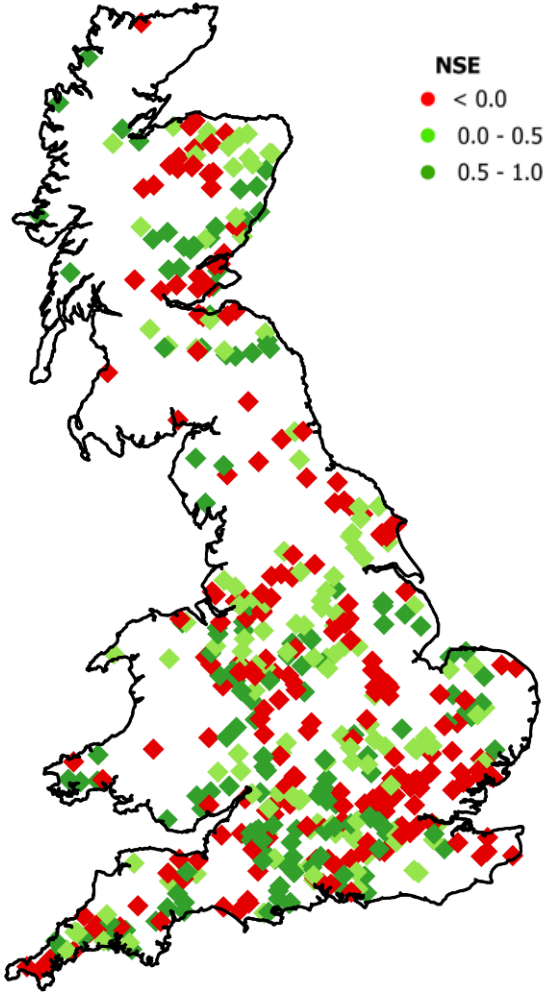


Voronoi model

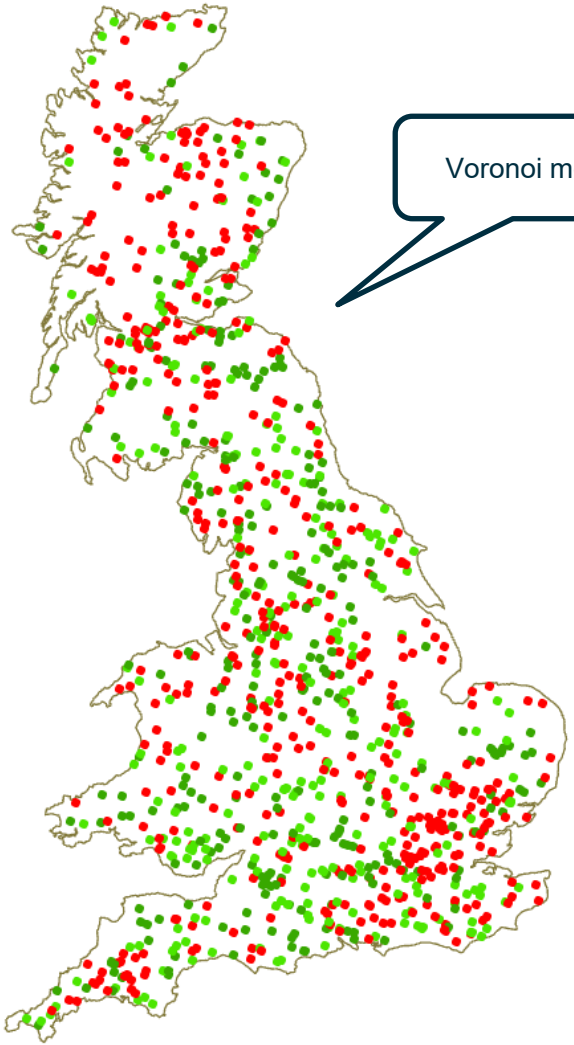


NSE = 0 same predictive skill as median of variable; NSE = 1 perfect model

Old model

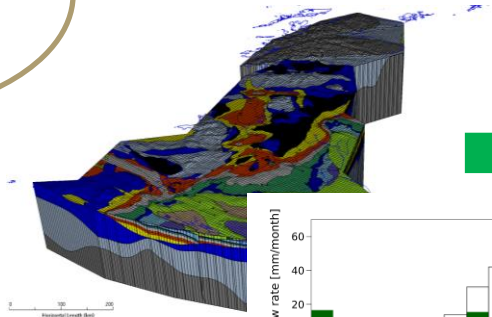


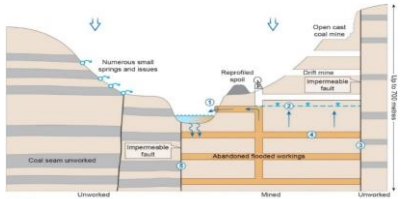
Voronoi model

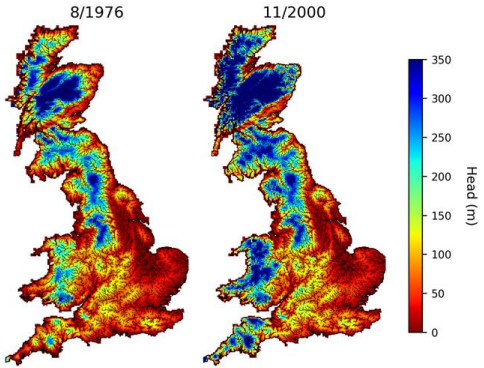


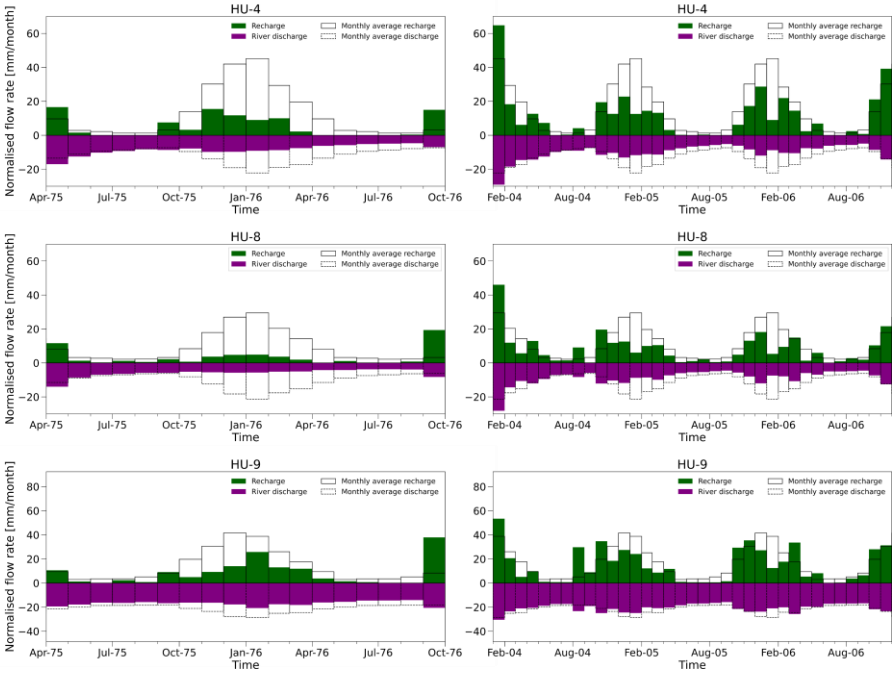
How much is in the groundwater “tank” during a drought?

When will it dry up?









ANY QUESTIONS

Thank-you