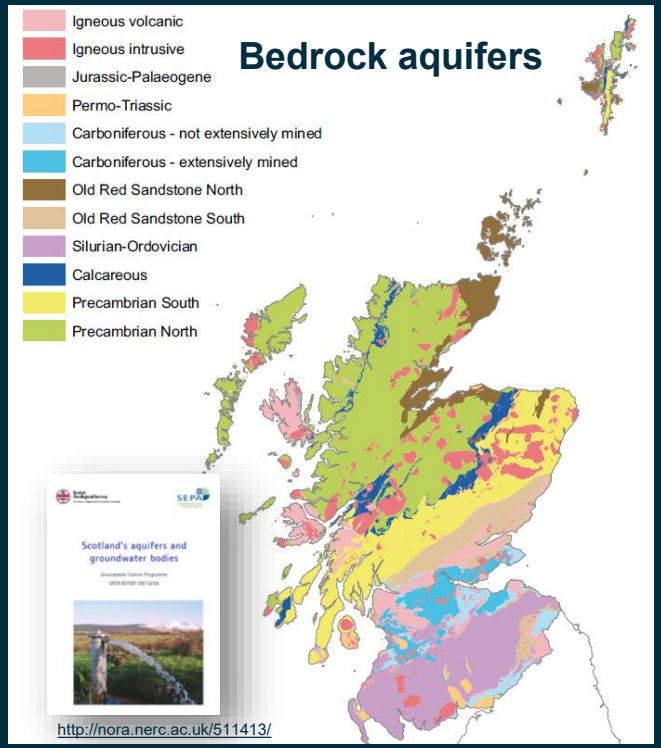


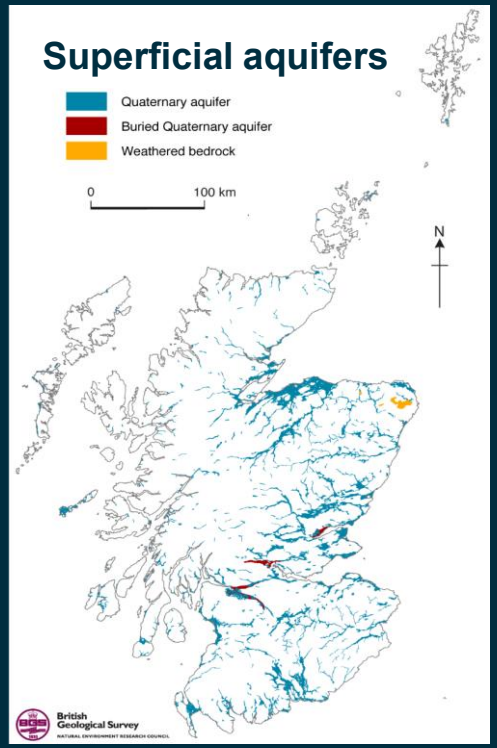
KIRSTY UPTON, FUTUREPROOFING GROUNDWATER IN SCOTLAND, MARCH 2026

Digital groundwater systems: insights into the past, present and future of Scottish groundwater

British Geological Survey

Scotland's Groundwater











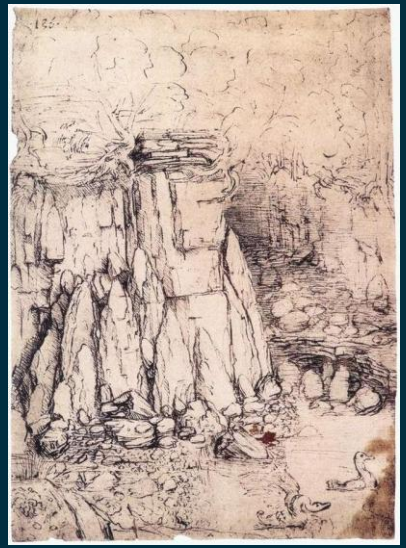




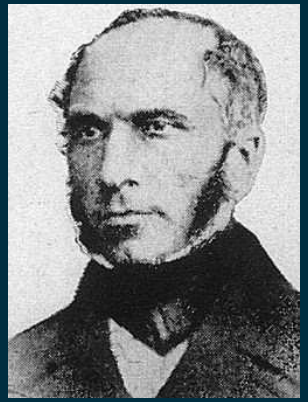


The past… regional scale, groundwater focus

The journey to numerical models



Cavern with ducks
Leonardo da Vinci c15th

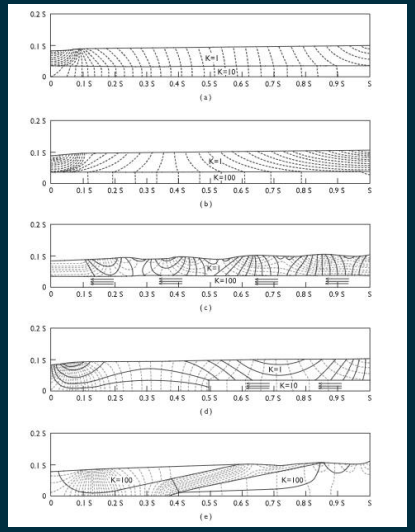


$$q = K\frac{\Delta h}{\Delta l}$$

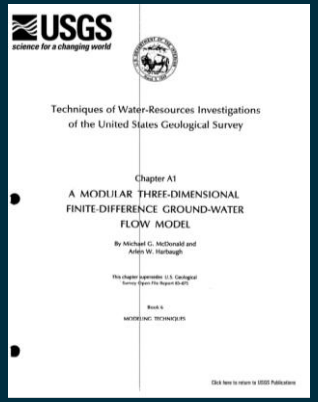
Darcy, 1856

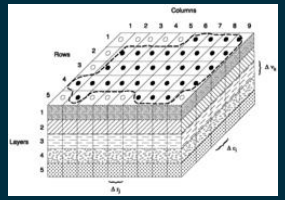


USGS, 1962



Freeze & Witherspoon
1967





MODFLOW
1988

1990s – early 2000s

BRITISH GEOLOGICAL SURVEY
Natural Environment Research Council

TECHNICAL REPORT WD/99/39
Hydrogeology Series

Technical Report WD/99/39

The Upper Devonian Sandstone Aquifer of F

Ó Dochartaigh B É, Ball D F, Browne M A E, S
MacDonald A M, Robins N S and McNeill G W

This report was prepared for
East of Scotland Water Authority,
Scottish Environment Protection Agency,
and the British Geological Survey Board

Bibliographic Reference

Ó Dochartaigh B E, Ball D F, Browne M A E, Shand P, MacDonald A M, Robins N S and McNeill G W 1999
The Upper Devonian Sandstone Aquifer of Fife
British Geological Survey Report WD/99/39

©NERC copyright 1999 British Geological Survey

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

TECHNICAL REPORT WD/00/24
Hydrogeology Series

The Permian aquifer of Dumfries: groundwater chemistry and age

A M MacDonald, D F Ball and W G Darling



NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
Murchison House
West Mains Rd
EDINBURGH
United Kingdom EH9 3LA

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Hydrogeology of the Devonian Aquifer in Strathmore

Groundwater Systems and Water Quality Progra
Internal Report IR/04/130R

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The physical properties of the Upper Devonian/Lower Carboniferous aquifer in Fife

Groundwater Systems and Water Quality Programme
Internal Report IR/04/003

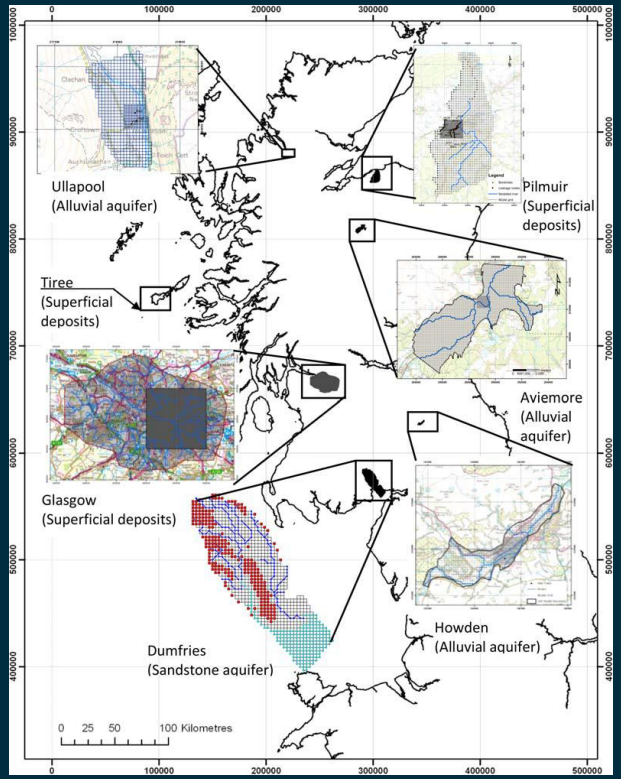
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The Dumfries Basin aquifer

Research Report RR/06/02



Mid 2000s -



Mansour et al., 2012
https://doi.org/10.1144/SP364.7

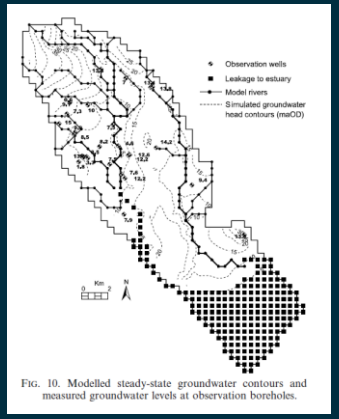
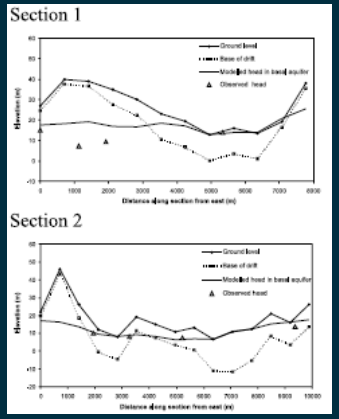
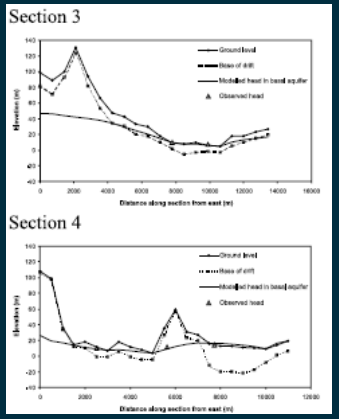


FIG. 10. Modelled steady-state groundwater contours and measured groundwater levels at observation boreholes.





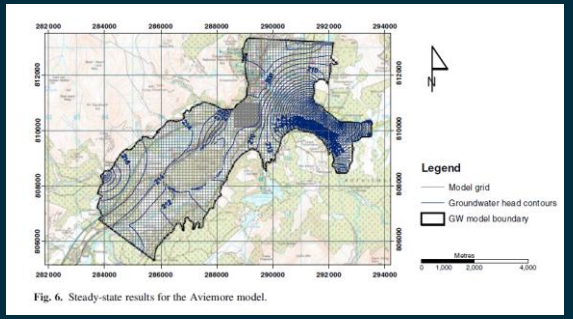
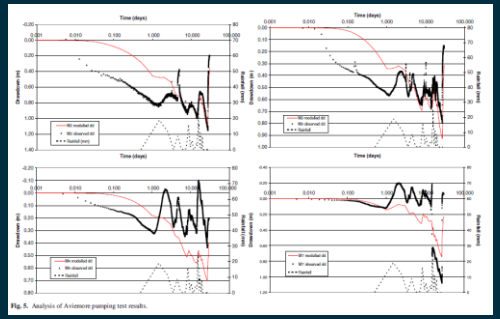


Fig. 6. Steady-state results for the Aviemore model.



Jackson et al., 2005
https://doi.org/10.1144/sjg41010051

2010s

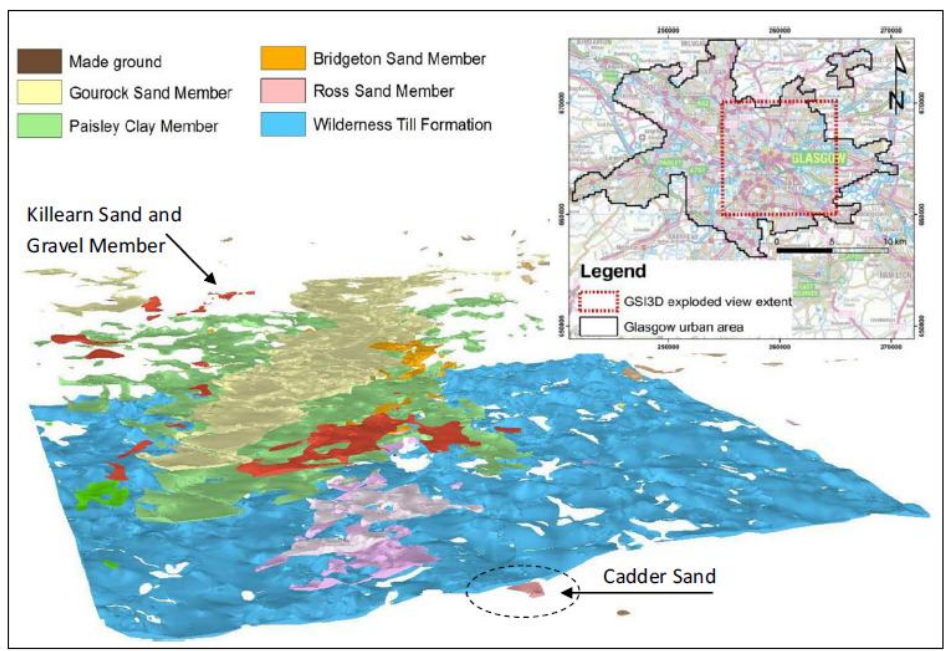


Fig. 2 Three-dimensional view of the superficial deposits using the GSI3D software "NEXTMap Britain elevation data from Intermap Technologies"

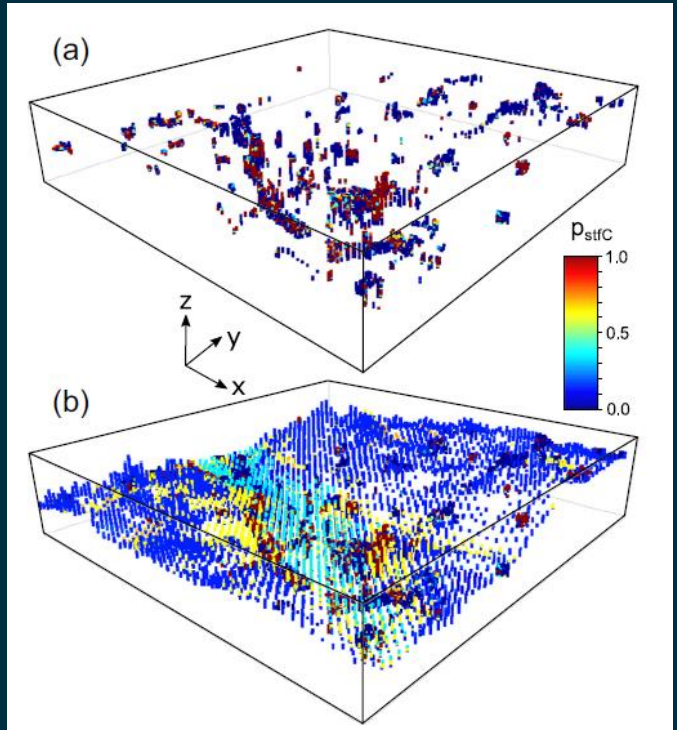


Fig. 3. Example of conditioning points for the two stochastic models M1 (a) and M2 (b). Colours correspond to probability values for lithofacies stfC. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

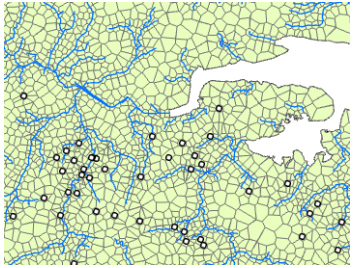
Turner et al, 2015
http://dx.doi.org/10.1007/s10040-014-1207-0

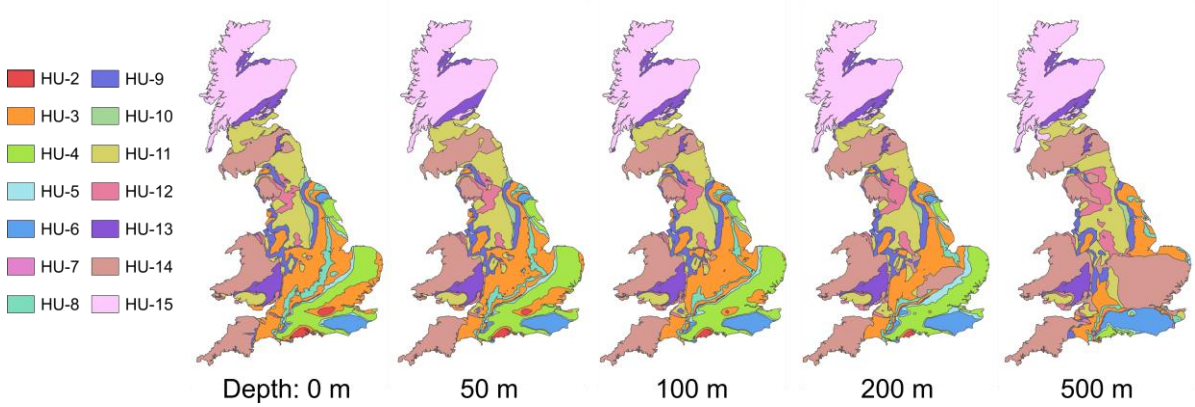
Bianchi et al, 2015
http://dx.doi.org/10.1016/j.jhydrol.2015.10.072

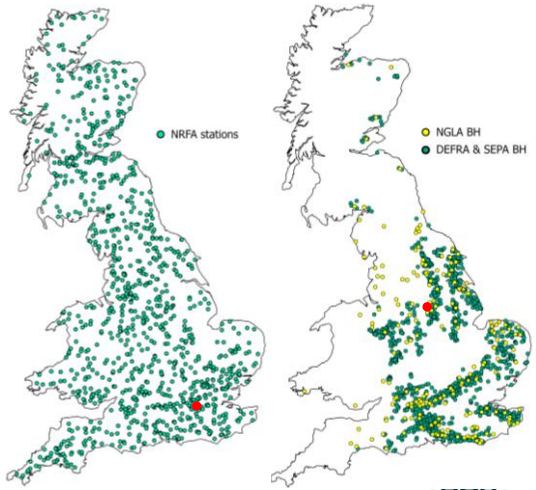
The present…
multi-scale, multi-process

HydroJULES & British Groundwater Model

- Aim to improve representation of GW in land-surface models
- MF6, unstructured grid, ~1km resolution, monthly 1970-2018
- 15 hydro-stratigraphic units
- Time-variant abstraction from EA and SEPA (~16,000 BHs)
- Calibrated using PEST against ~1000 OBHs and gauging stations



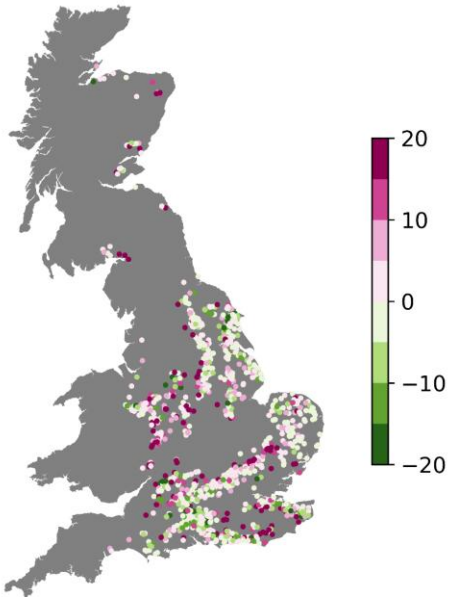




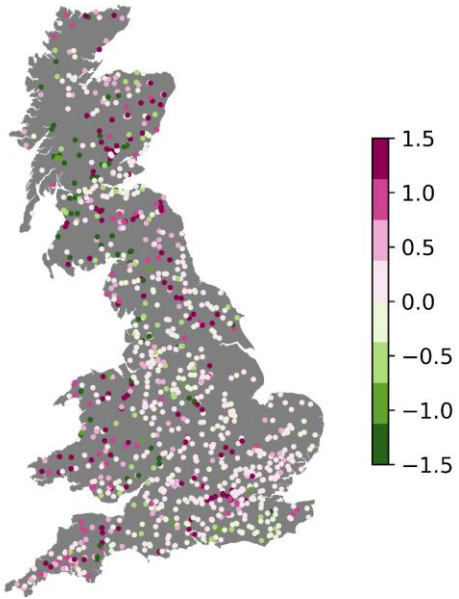
Bianchi et al, 2024
https://doi.org/10.1080/02626667.2024.2320847

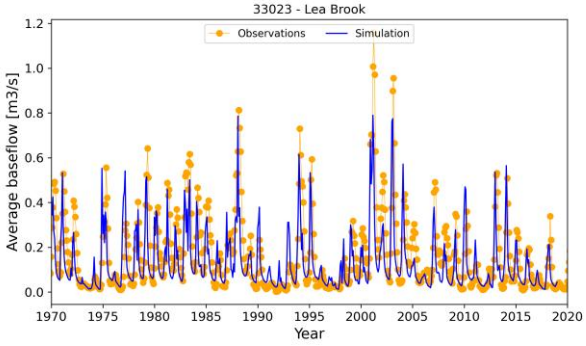
HydroJULES & British Groundwater Model

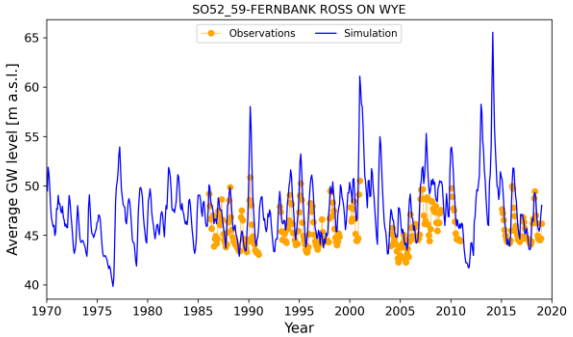
Mean head error (m)
-overstimation; +underestimation



Mean baseflow error (m3/s)
-overstimation; +underestimation

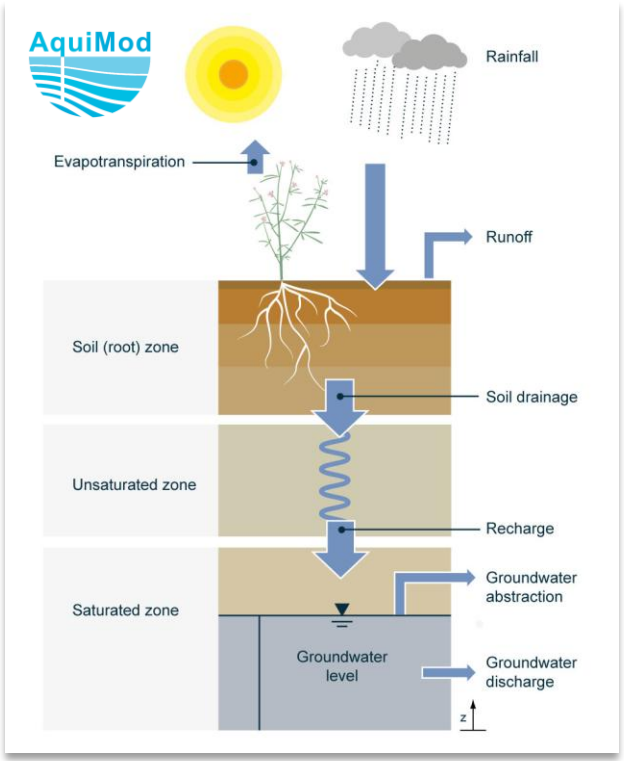






Bianchi et al, 2024
https://doi.org/10.1080/02626667.2024.2320847

Time series modelling with simple models



FLOOD FORECASTING CENTRE

A working partnership between

Environment Agency | Met Office

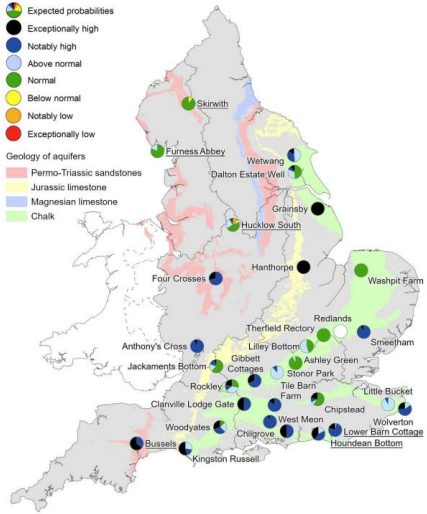
- 50 AquiMod models run daily
- 15 day forecasts
- Groundwater flood alert triggers

Research and analysis

Water situation: February 2026 summary

Updated 11 March 2026

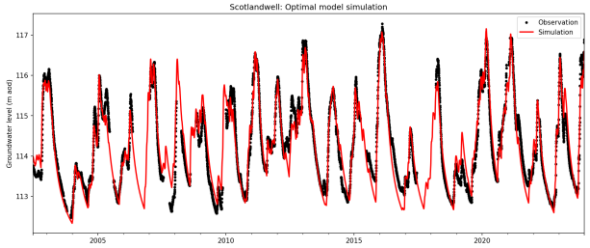
- AquiMod run monthly for 30 indicator boreholes
- 24-month probabilistic forecasts of GWLs

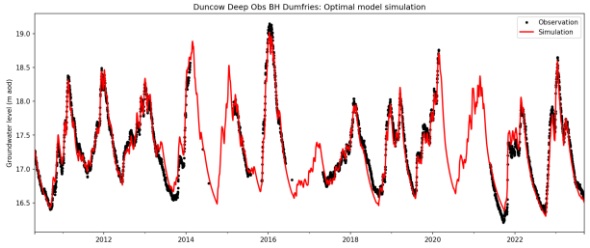


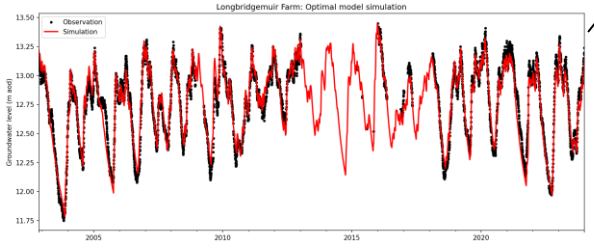
UK Hydrological Outlook

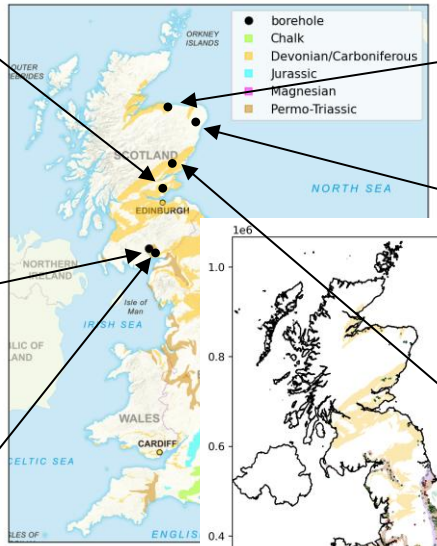
BGS

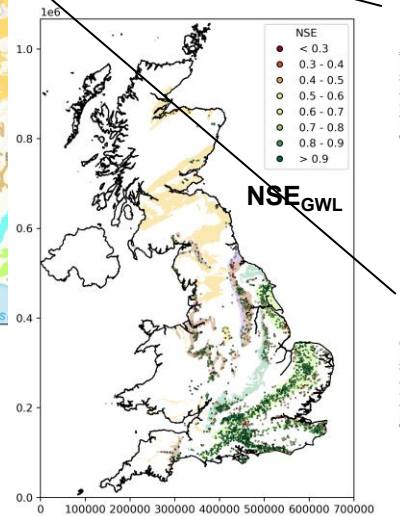
Time series modelling with simple models

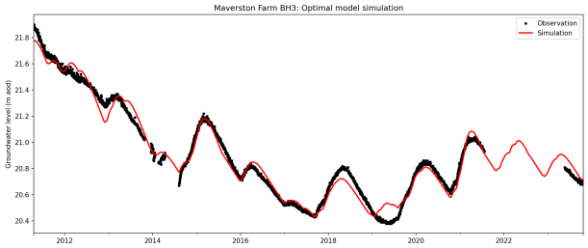


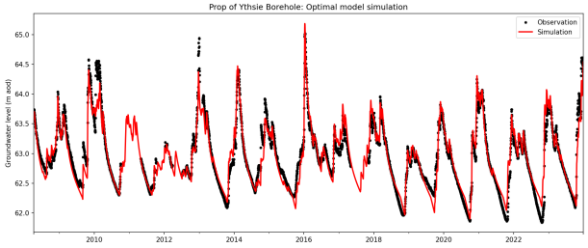


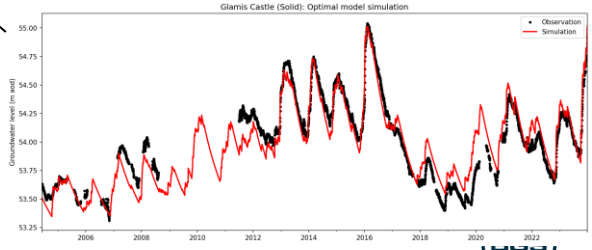










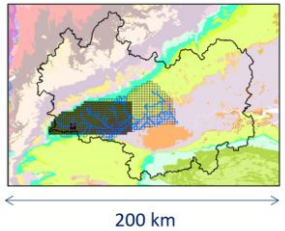


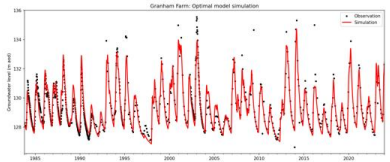
Forecasting with Machine Learning

How do we estimate the sustainable yield of groundwater supply sources in the future?

Can we forecast the performance of groundwater supply sources during a drought?

Regional Aquifer

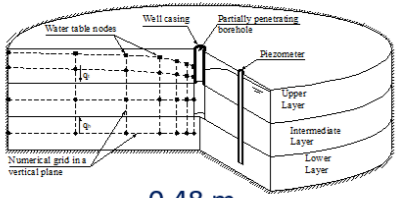




Boundary conditions

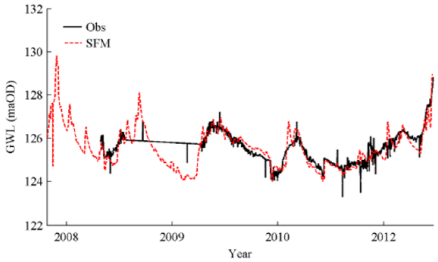
GWL + recharge

SPIDERR



0.48 m

750 m





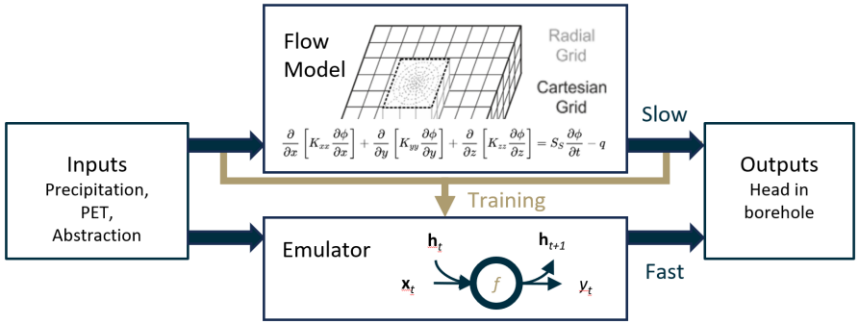
AquiMod

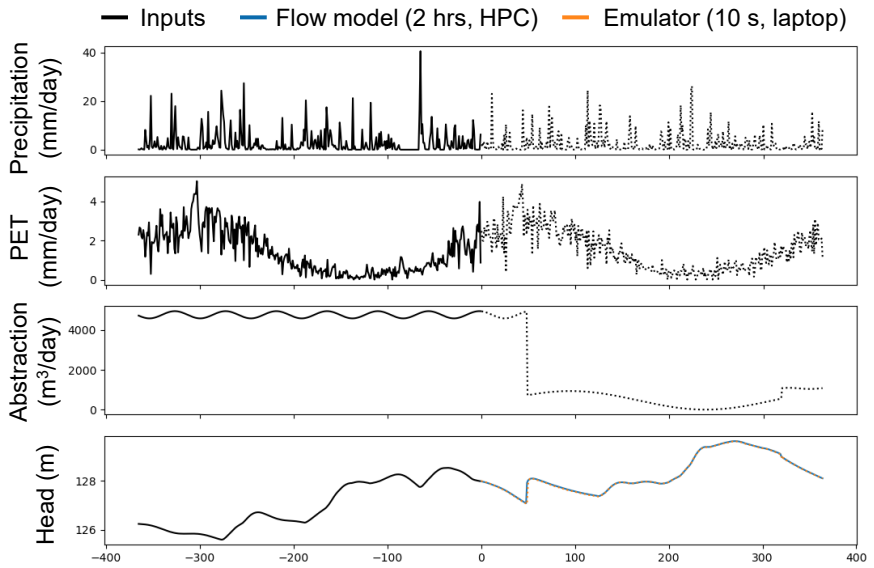
Upton et al, 2020
https://doi.org/10.1016/j.jhydrol.2020.125113

Forecasting with Machine Learning

How do we estimate the sustainable yield of groundwater supply sources in the future?

Can we forecast the performance of groundwater supply sources during a drought?





- Recurrent neural network
- Emulator trained on input-output relationship of SPIDERR-AquiMod

Upton et al, *in prep*

Forecasting with Machine Learning

How do we estimate the sustainable yield of groundwater supply sources in the future?

Can we forecast the performance of groundwater supply sources during a drought?





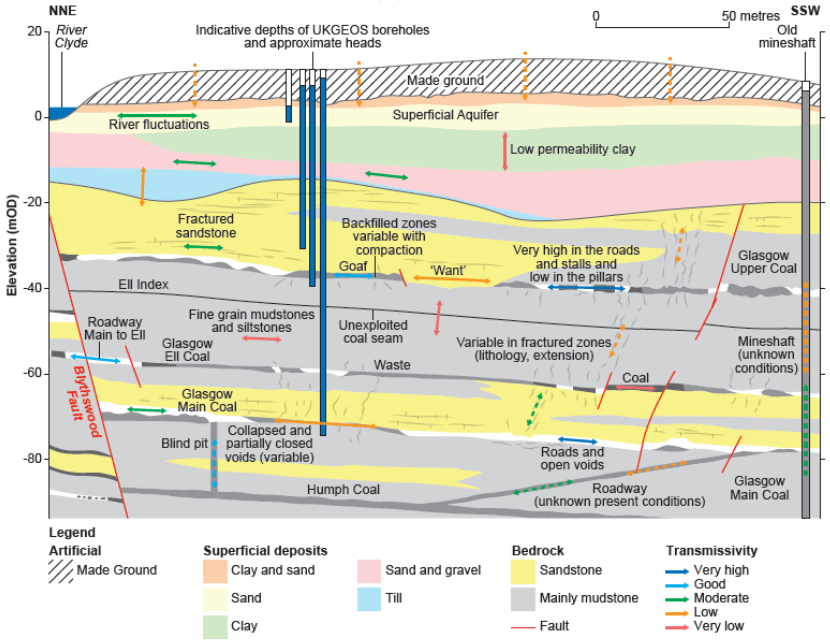
Warning: Some predictions are out of the range of the emulator's training data, making the emulator's predictions less reliable.

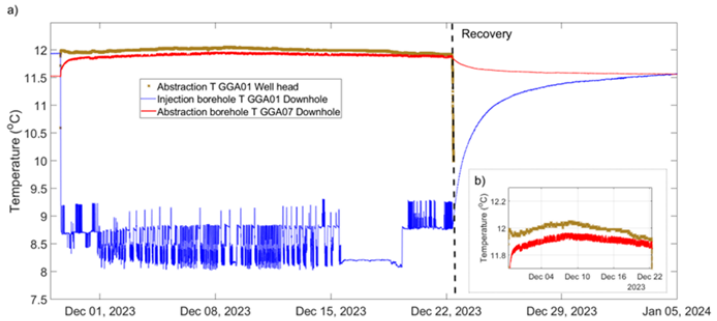
Intervals of exceedance

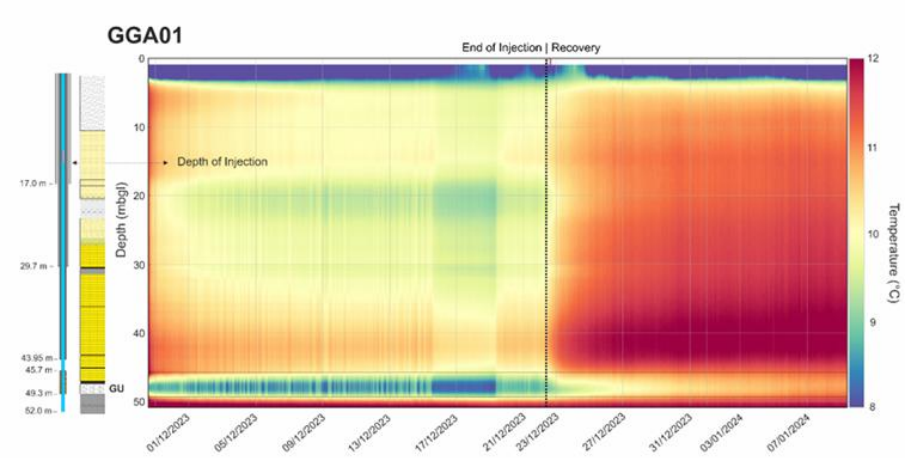
Upton et al, *in prep*

UK Geoenergy Observatory Glasgow

https://www.ukgeos.ac.uk/





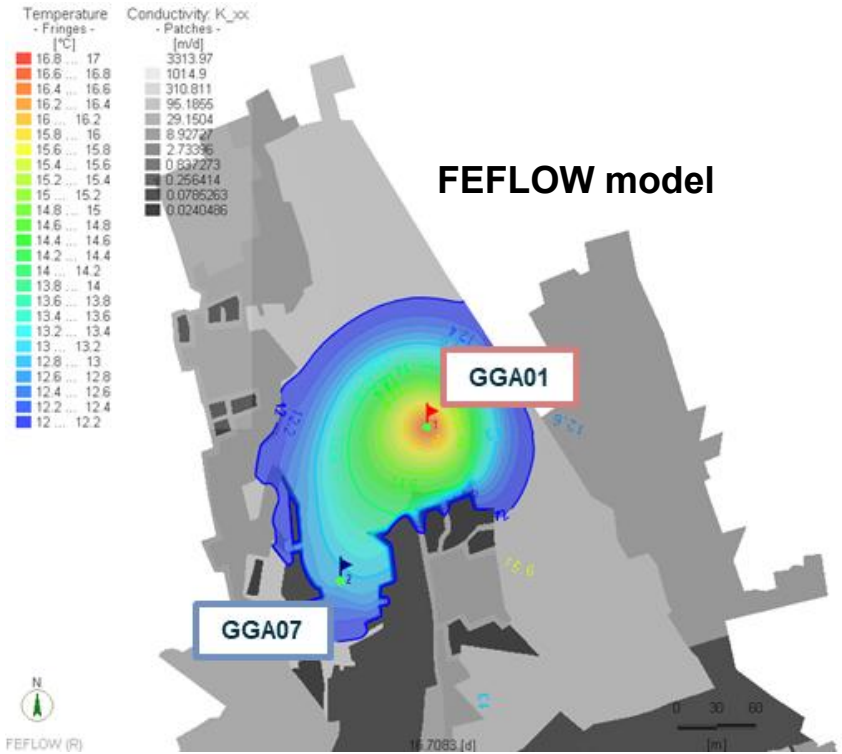


Gonzalez Quiros, 2024

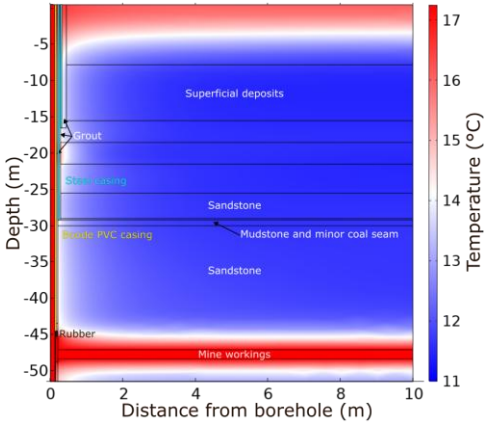
Gonzalez Quiros, 2025

UK Geoenergy Observatory Glasgow

https://www.ukgeos.ac.uk/

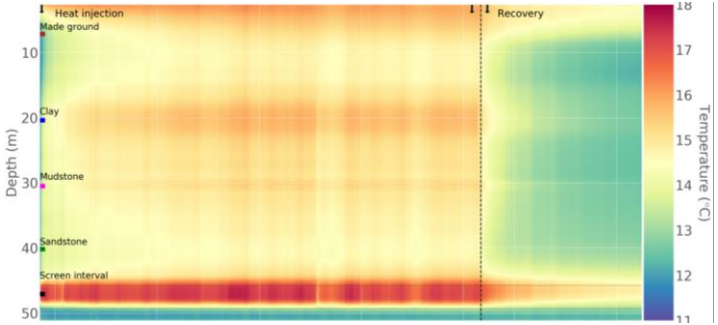


FEFLOW model



COMSOL model
(GGA01 injection well)

Temperature data
(DTS GGA01)

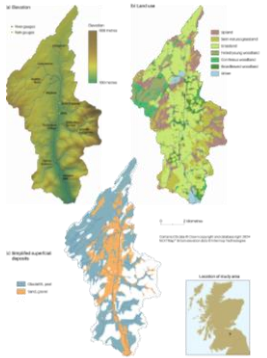


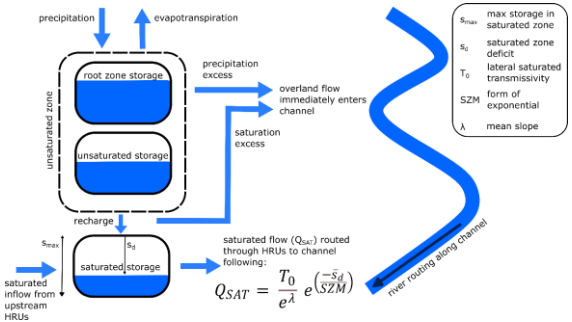
Gonzalez Quiros et al, 2025

Receveur et al., 2026

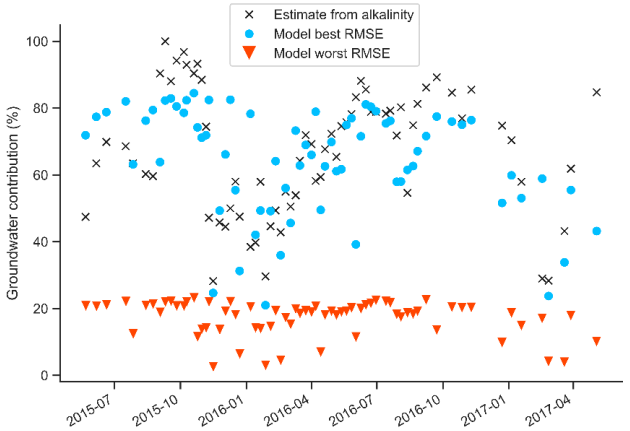
Natural Flood Management

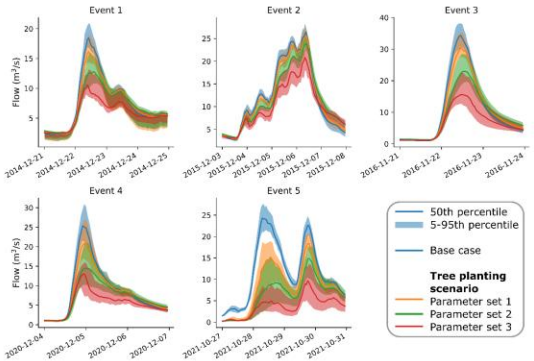
- Multi-criteria model calibration using groundwater tracers to reduce predictive uncertainty
- Parameterisation of NFM approaches in models introduces significant uncertainty





Dynamic TOPMODEL



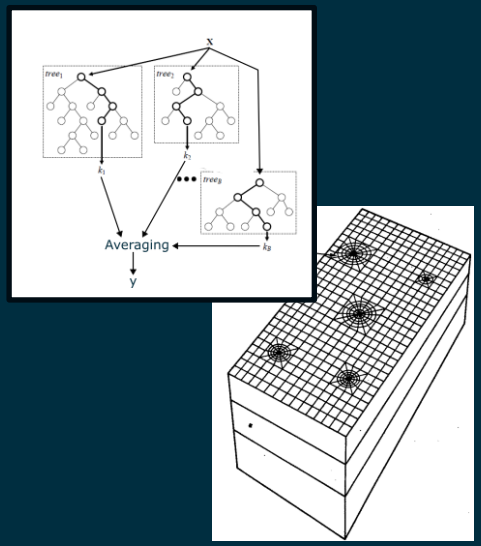


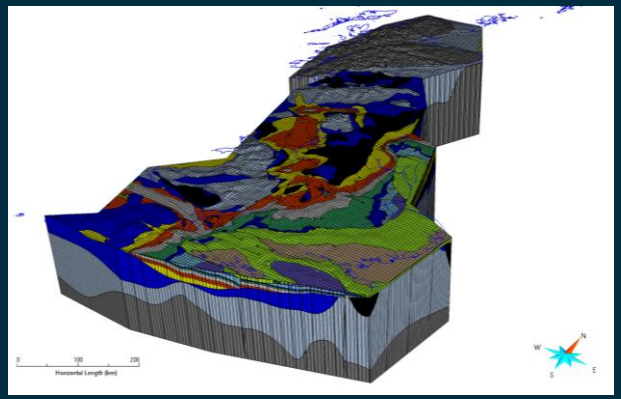
Collins et al, *in prep*

The future…

Borehole to Global

Time series modelling and forecasting
Machine learning





Regional Models

Water resource planning within the BGWM Framework?

Global Earth System Model

Impact of groundwater processes on the global earth system



Future pressures on integrated systems

Future climate change

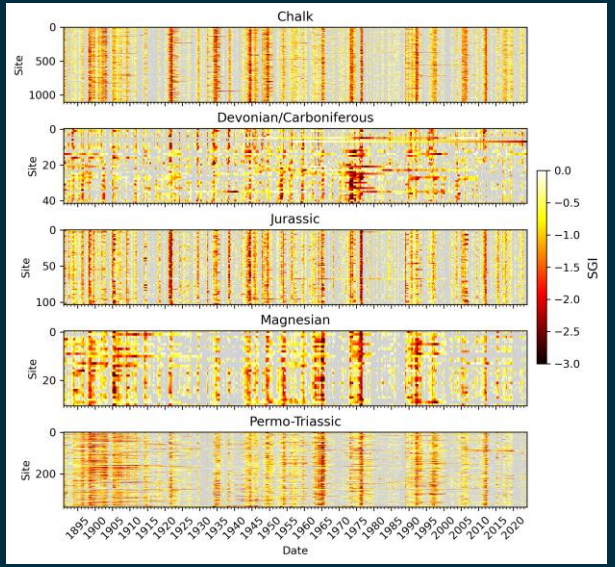
- CANARI large ensemble of global climate projections
- TerraFIRMA global overshoot scenarios

Human pressures

- Abstraction – future demand in Scotland?
- Systems approach

Multiphase??

Communication and delivery of model results



British Geological Survey

THANK YOU

Any questions?