Mr Darcy was good enough for me - pragmatism and prediction in groundwater science

Alan Herbert

University of Birmingham

What are models for?

- Understanding the world
- Ensuring consistency
- Making decisions
- Justifying decisions
- Saving money

Why do we want to be simple

Mr Darcy

Mr Henry Darcy!

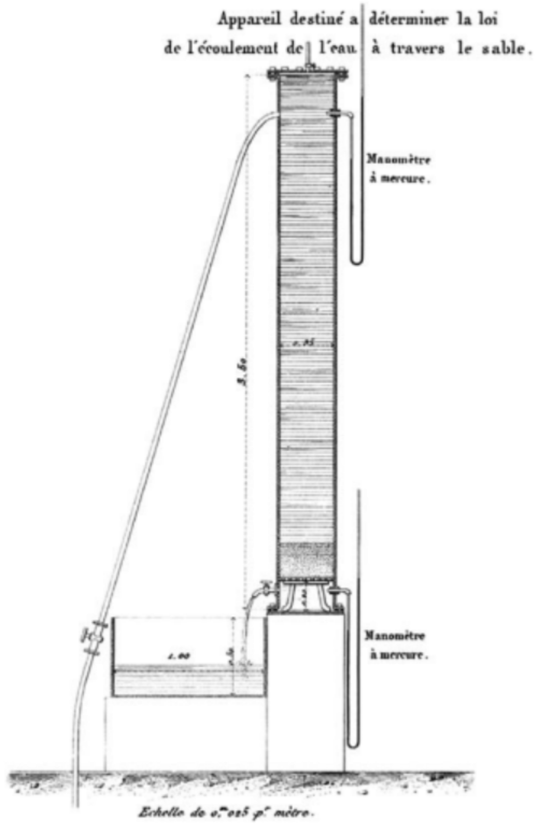
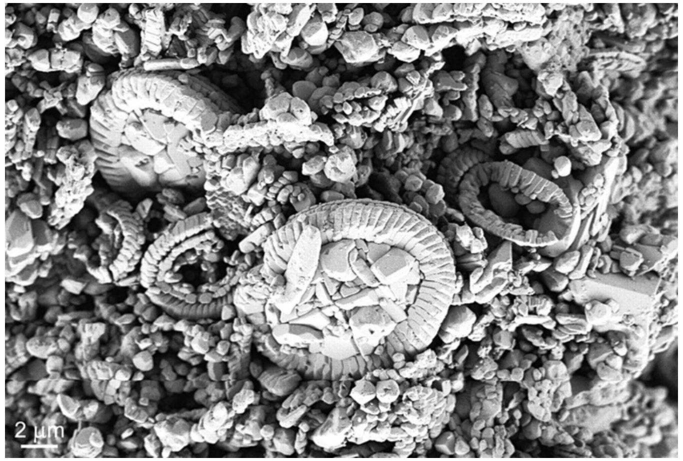


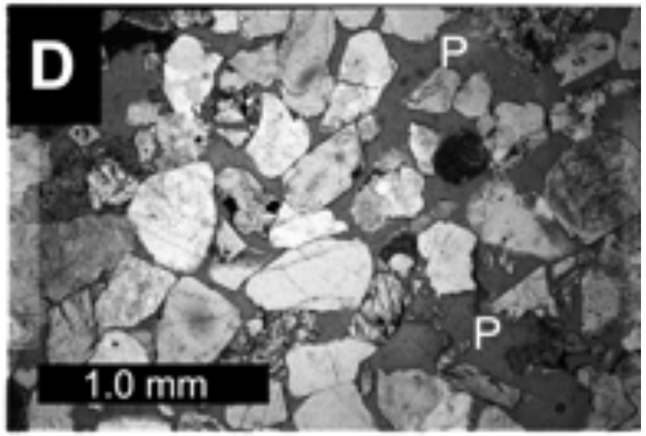
Fig. 5 Darcy's original sand column apparatus (Darcy 1856, Plate 24, Fig.3)

$$q = -K.\nabla h$$

Hydrogeology Journal (2008) 16: 1023–1038

Different types of sand





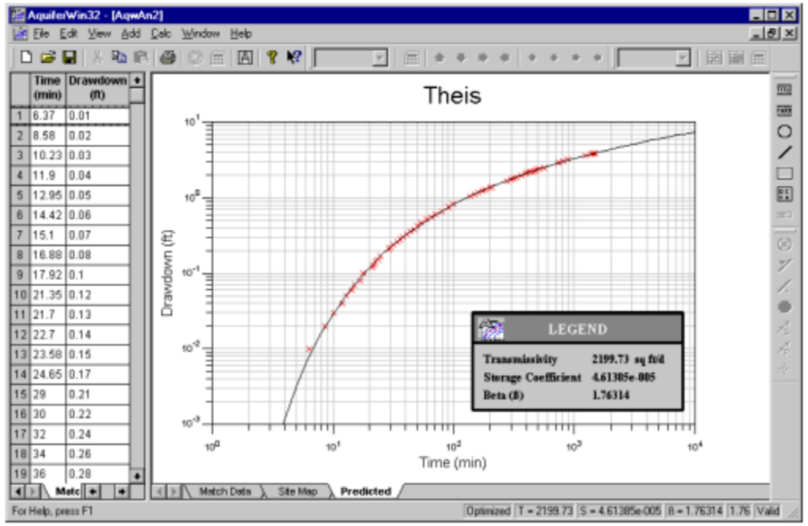
S. Strand, M. L. Hjuler, R. Torsvik, J. I. Pedersen, M. V. Madland, and T. Austad. Wettability of chalk: impact of silica, clay content and mechanical propertiesPetroleum Geoscience, , v. 13, p. 69-80

Quarterly Journal of Engineering Geology and Hydrogeology, 38, 143–154

FLUID FLOW AND SOLUTE MOVEMENT IN SANDSTONES: The Onshore UK Permo-Triassic Red Bed Sequence - Special Publication no 263

Measuring hydraulic conductivity

- Pump water from a borehole

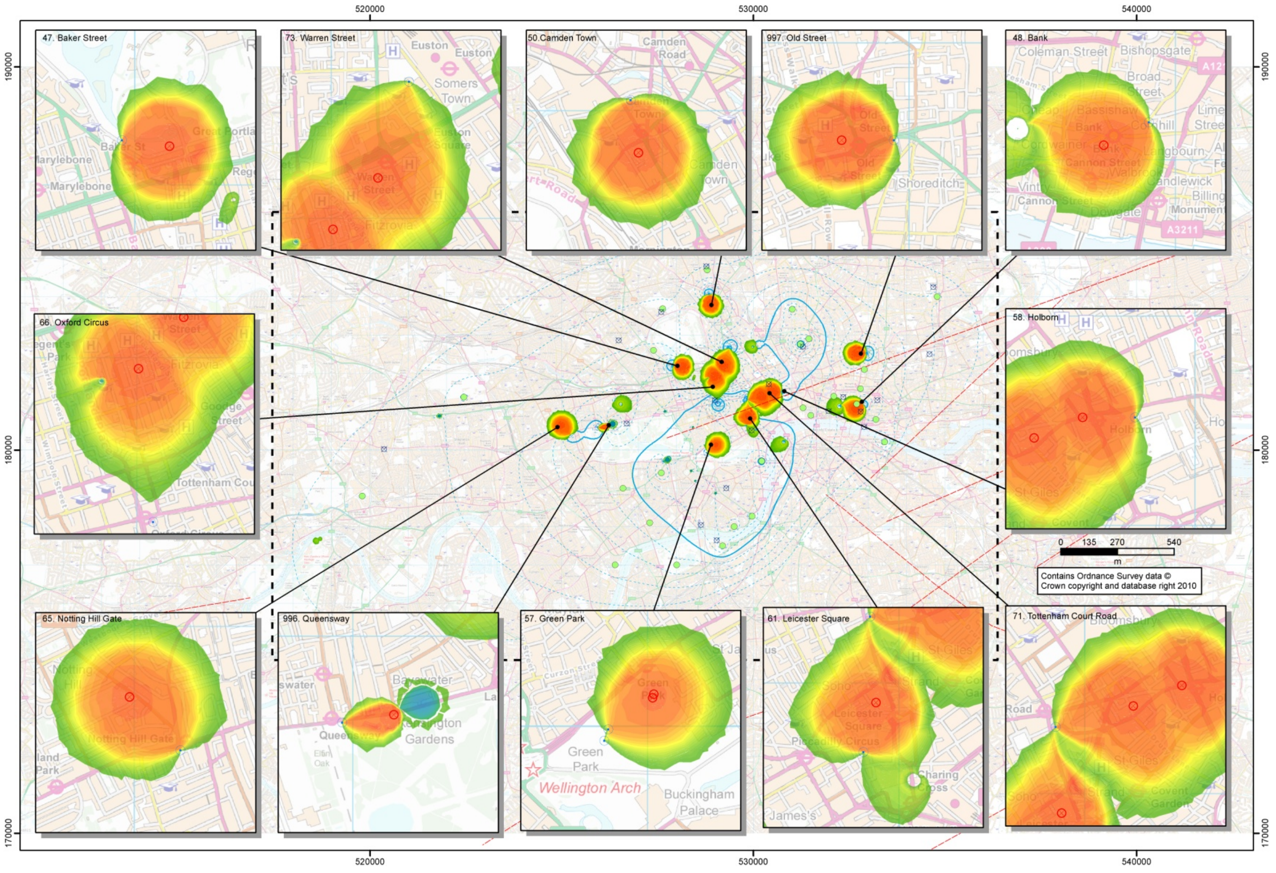


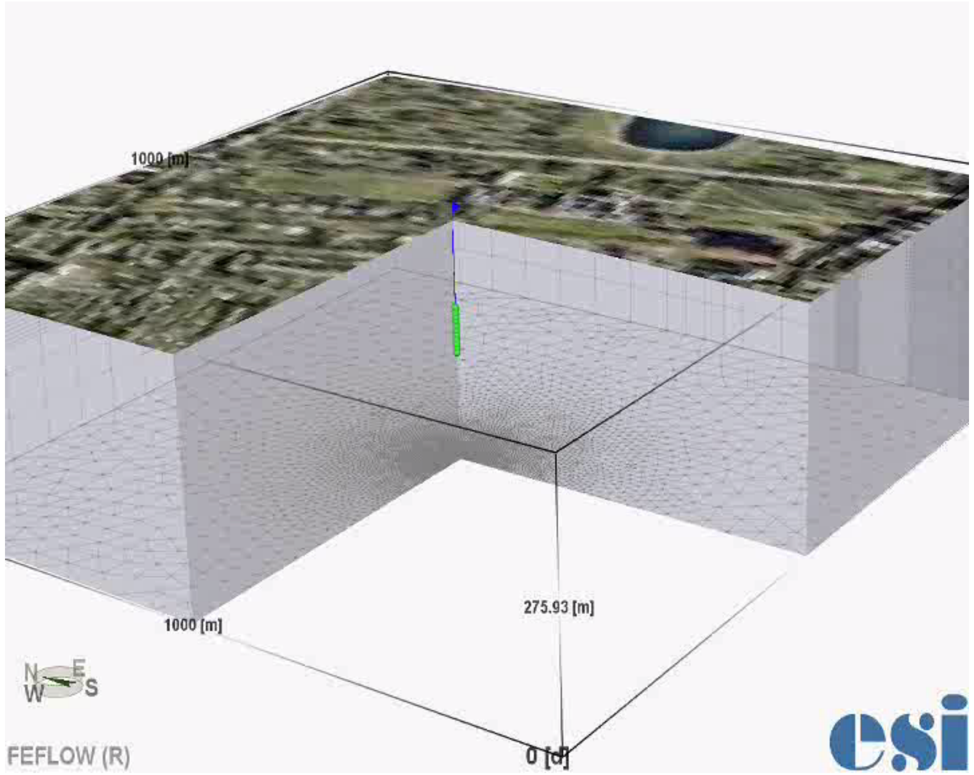
$$s = \frac{Q}{4\pi T} W(u)$$

$$u = \frac{r^2 S}{4Tt}$$

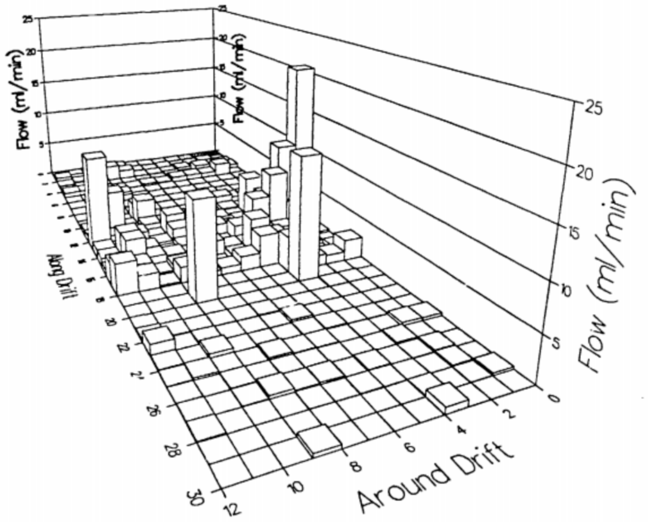
- …use the results to predict the consequence of pumping water from a borehole

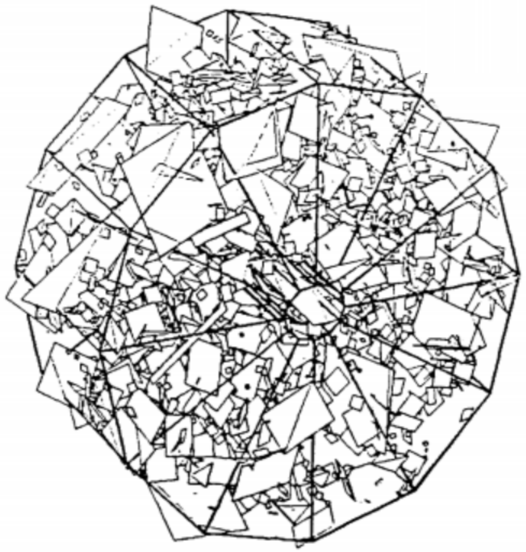
Calibrated regional models predict aquifer performance





At a big enough scale –
a Representative Elementary Volume



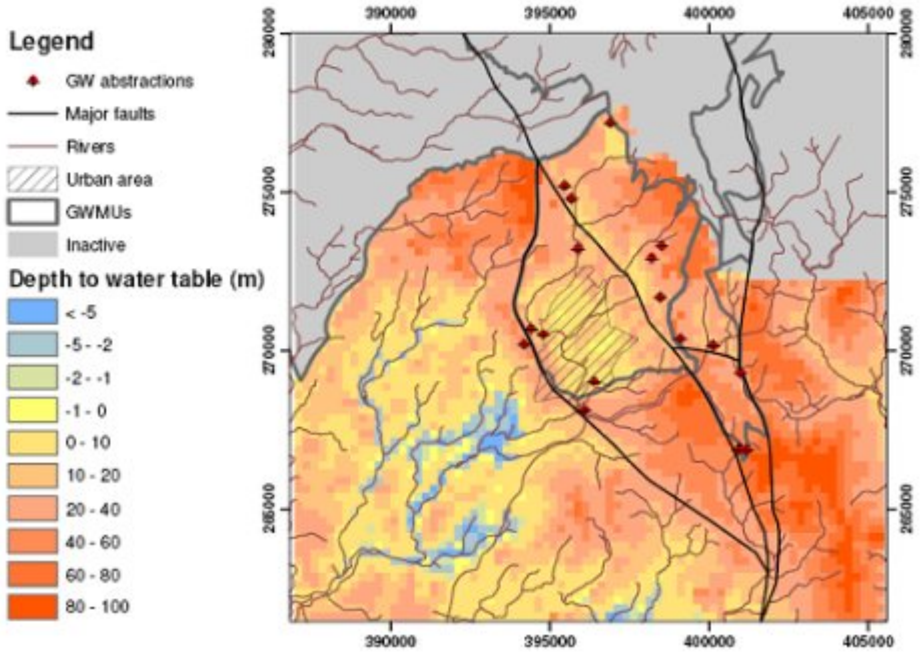


Purposes and scales of model

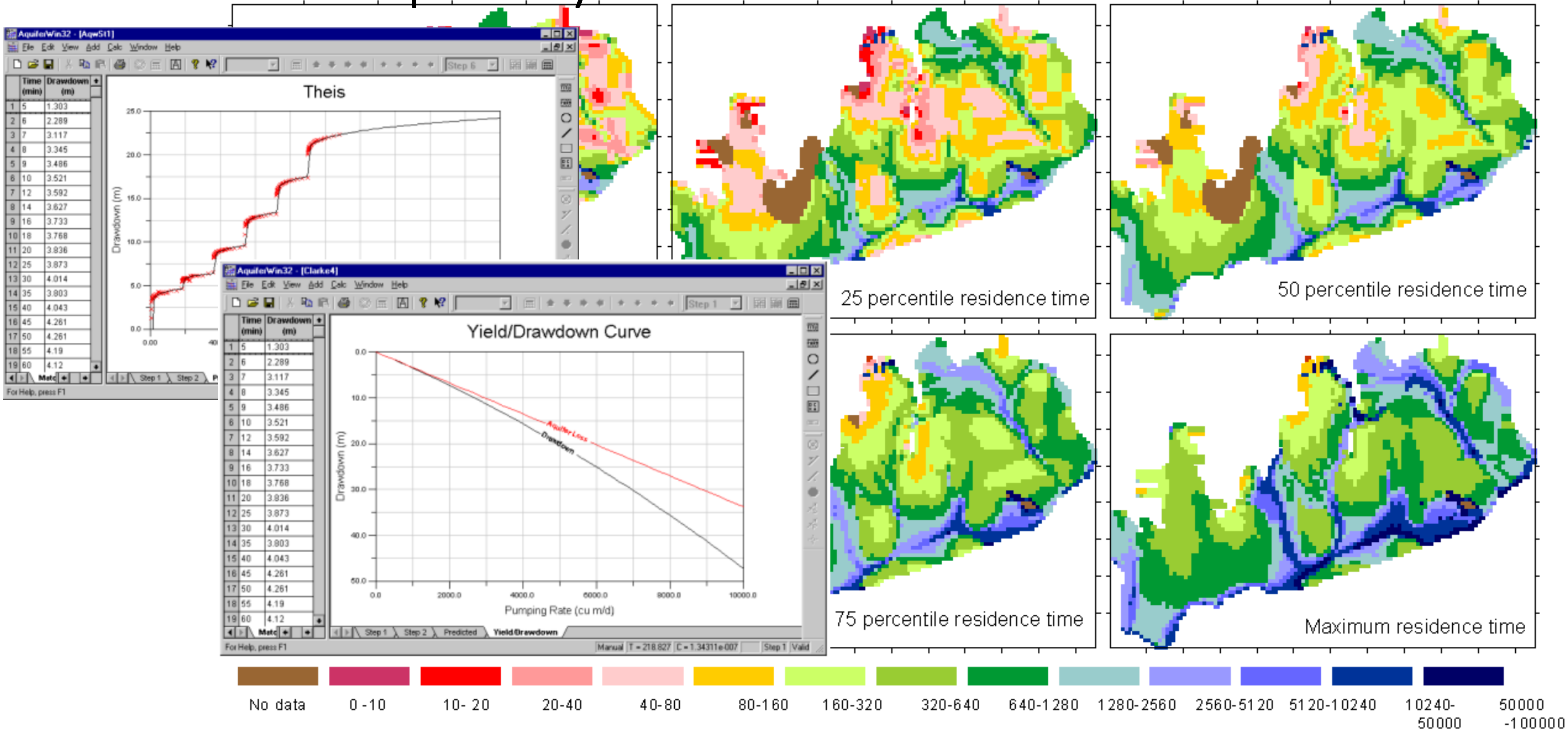
- Model at scales above REV
- Calibrate heterogeneous properties
- Match hydrographs over wet and drought years

Use to predict future groundwater conditions for:

- Groundwater resource management
- Source protection
- Risk assessment



Some complexity



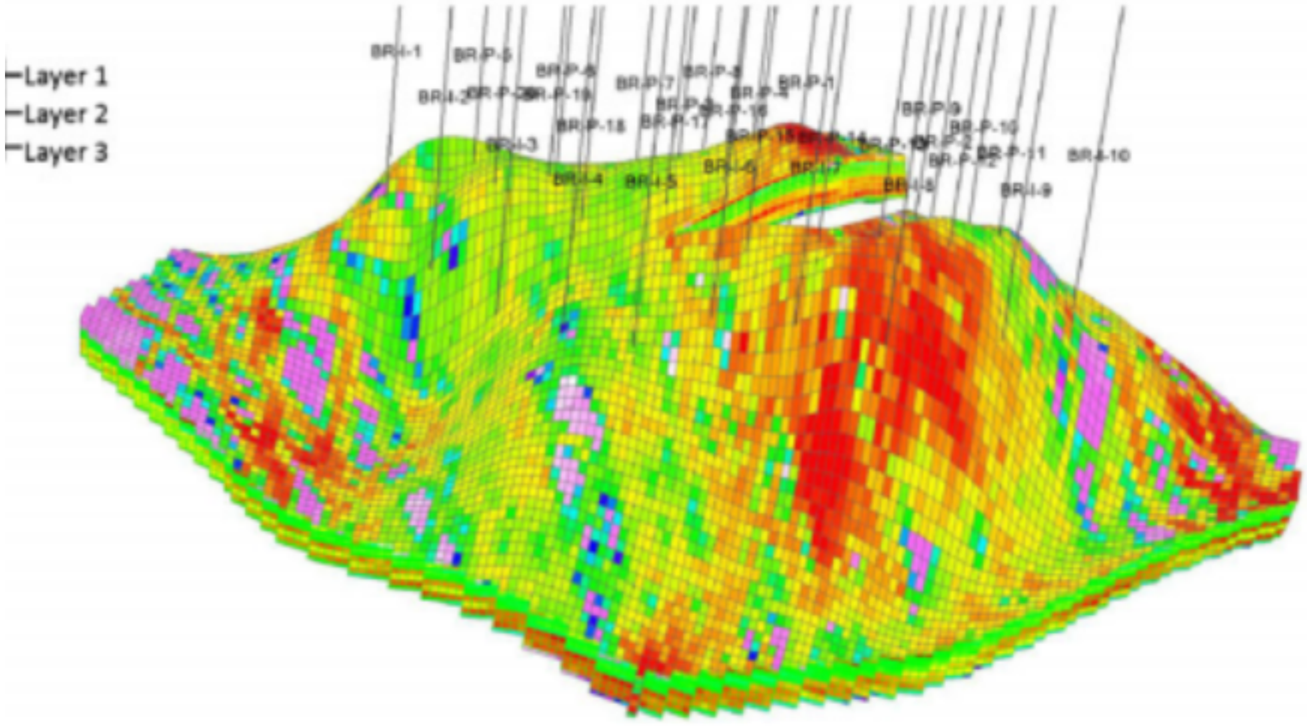
Uncertainty and Calibration

- Don’t actually use pump test results – use as a guide for calibration
- Each p test matches but interpretation affected by local properties
- Match head measurements to within uncertainty
- All parameters uncertain within plausible ranges
- Multiple solutions give acceptable matches – non-unique solution

- Non-uniqueness and uncertainty in outcome given uncertain input

…more detail

- Oil reservoir history matching



Recent progress on reservoir history matching: a review
Dean S. Oliver· Yan Chen, Comput Geosci (2011) 15:185–221

We can rewrite the equation as

$$\frac{dP}{dx} = \left(\frac{\mu}{KA}\right) q \left(1 + \frac{\beta\rho qK}{A\mu}\right)$$

then

$$q = \left(\frac{KA}{\mu}\right)\left(\frac{dP}{dx}\right) / \left(1 + \frac{\beta\rho qK}{A\mu}\right) = \left(\frac{KA}{\mu}\right)\left(\frac{dP}{dx}\right) F_{ND}$$

with the non - Darcy flow factor given by :

$$F_{ND} = \frac{1}{\left(1 + \frac{\beta\rho qK}{A\mu}\right)}$$

The flow velocity is a function of F_{ND} and F_{ND} is a function of the flow velocity, so we have two coupled equations to solve for phase p. Thus we have a quadratic equation for F_{ND} whose solution is:

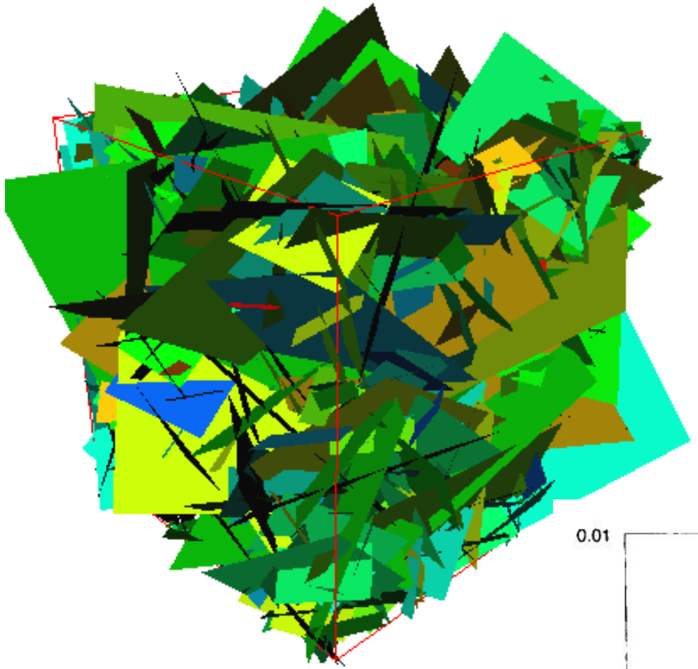
$$F_{ND} = \frac{-1 + \sqrt{(1+4B)}}{2B}$$

where

$$B = \left(\frac{C_2 \beta TK}{A}\right)(\Delta\phi_p)\left(\frac{\rho_p K_{rp}^{\ 2}}{\mu_p^{\ 2}}\right)$$

C_2 is a unit conversion constant. You can output the values of F_{ND} and $B/\Delta\Phi$ using the mnemonics FFORG and BFORG in the **Error! Reference source not found.**RPTSOL or **Error! Reference source not found.**RPTSCHED keywords.

…even more detail



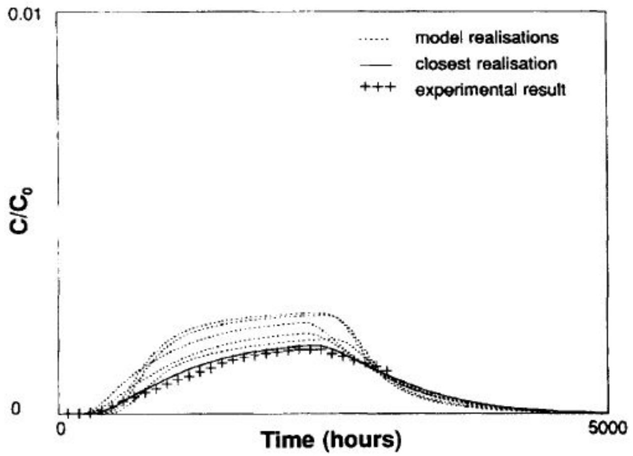
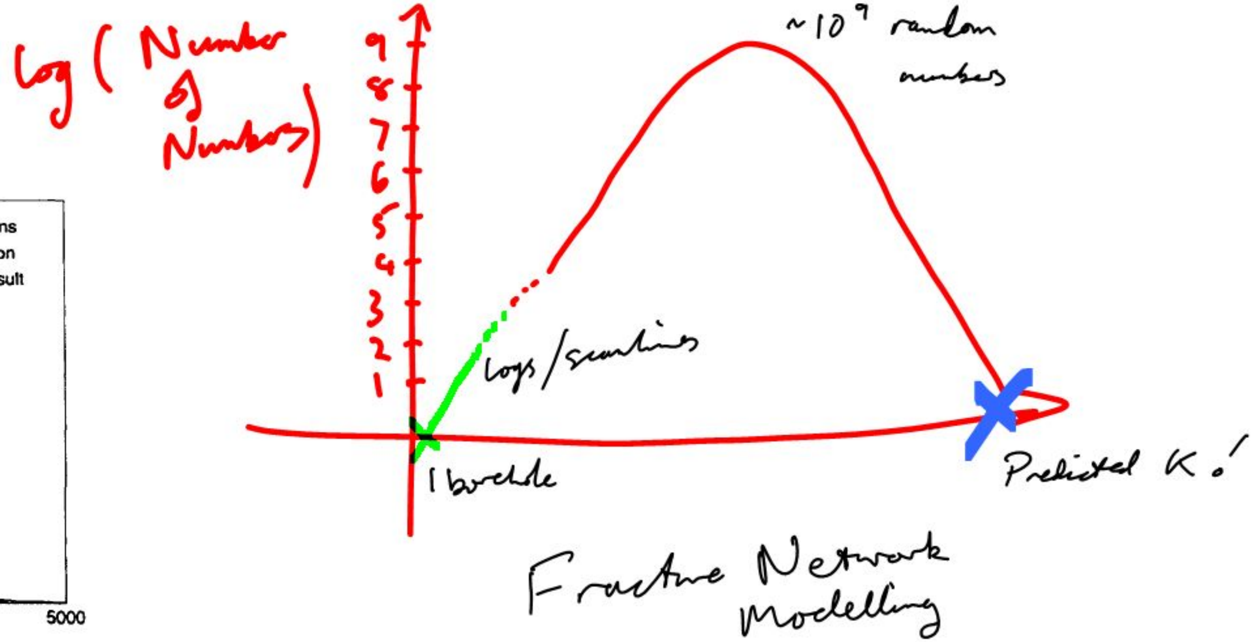
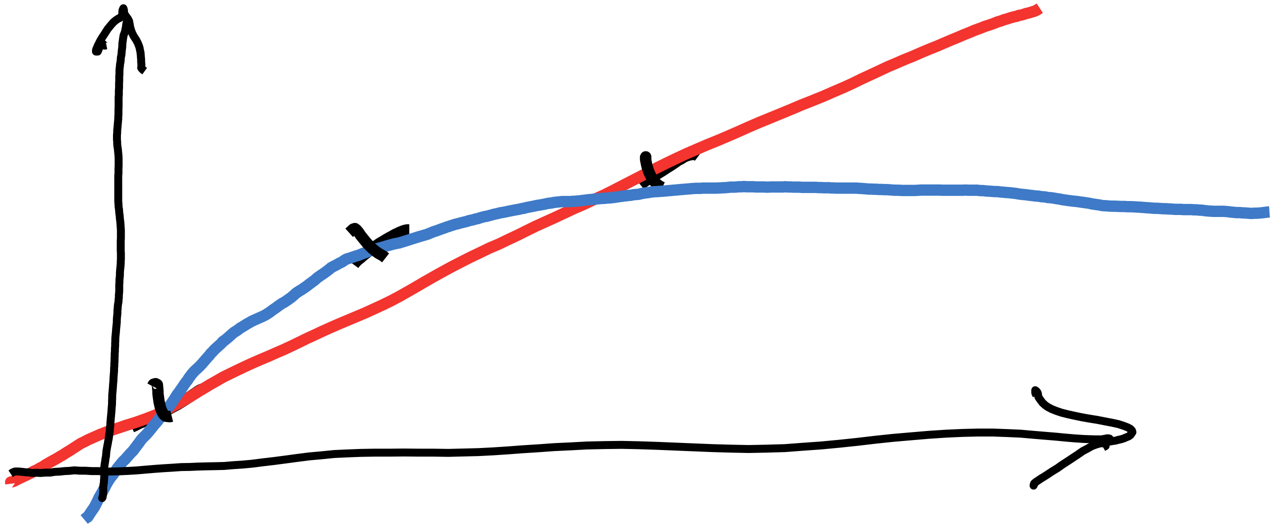


FIG. 11. Predicted and measured tracer breakthrough for injection in borehole C2 and recovery in the validation drift. Transport predictions produced by the NAPSAC code.



Nuclear waste disposal modelling requirements

- Need simple models of bulk behaviour to predict future performance

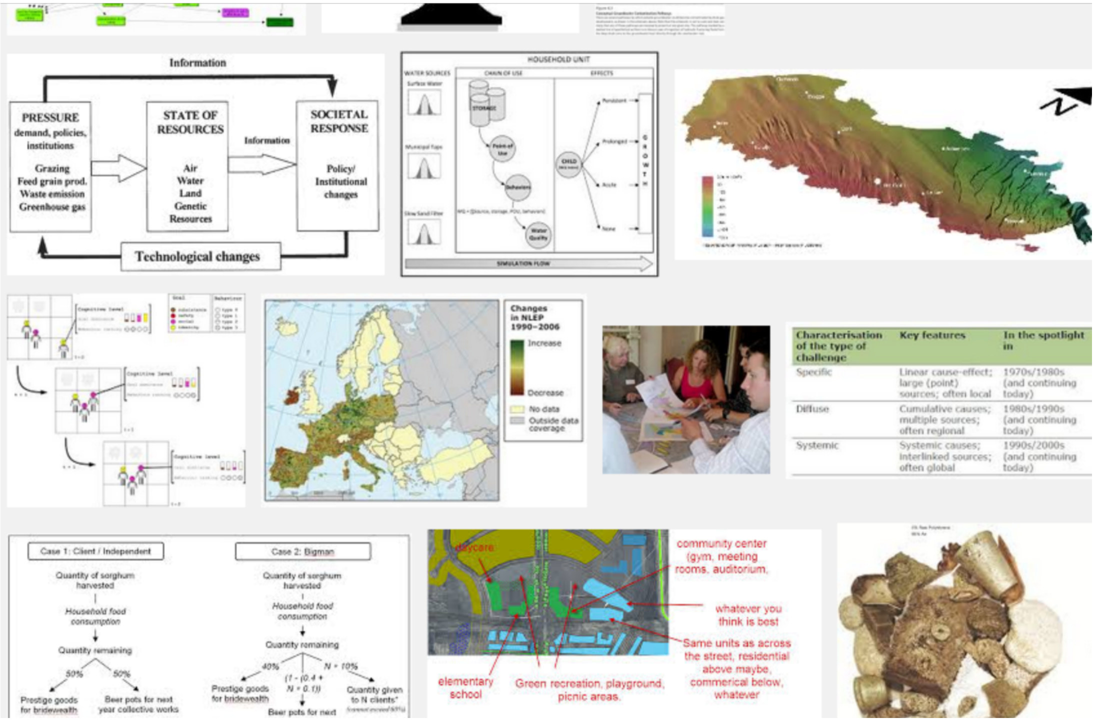


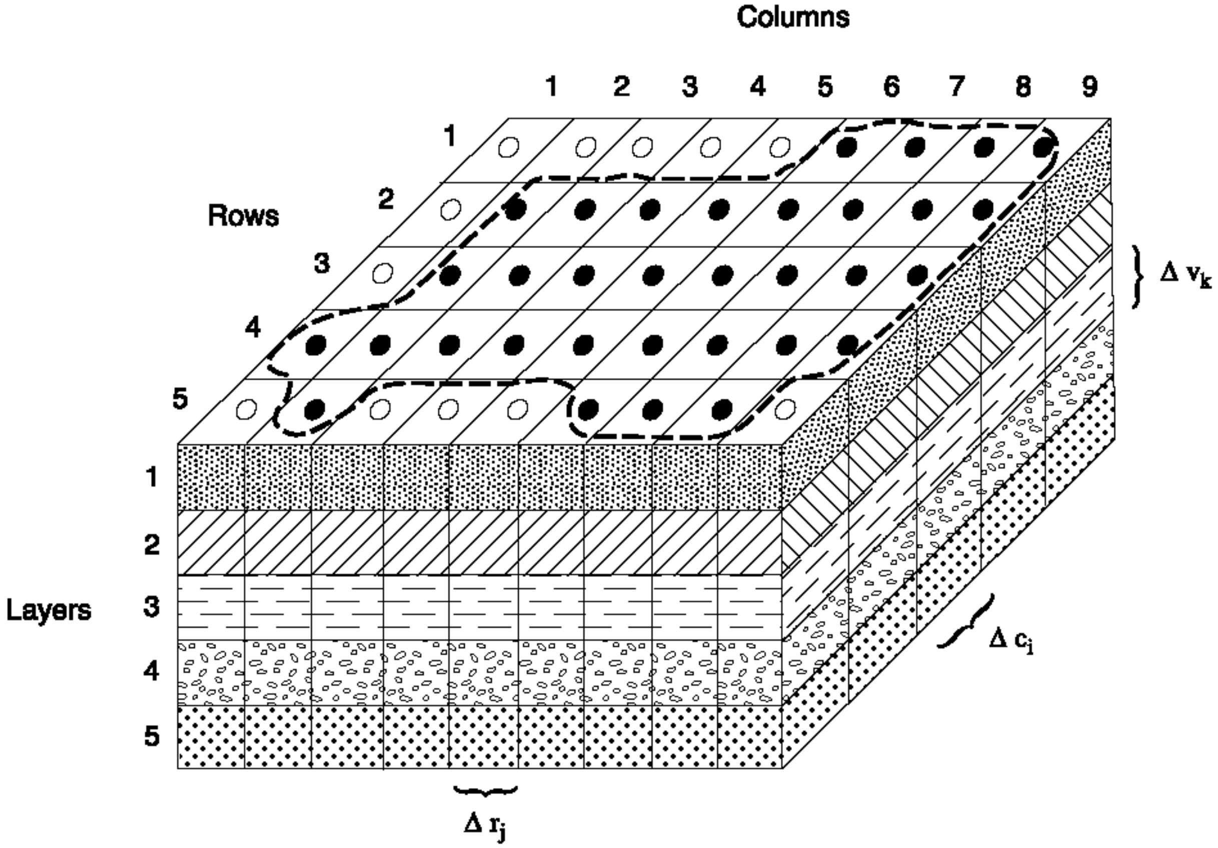
- Need detailed models of observations to show understanding that the simple models are accurate!
- Need to quantify uncertainty

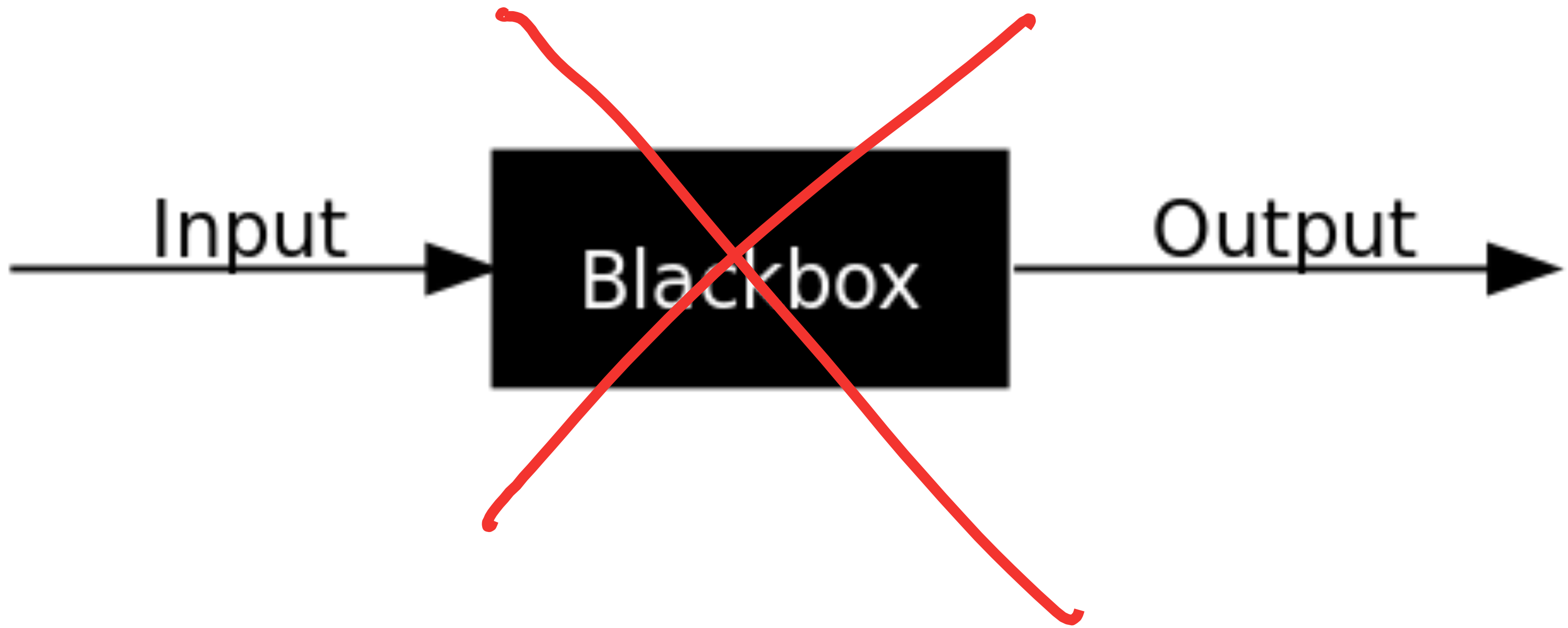
Sources of prediction error

- Uncertain parameter values
- Uncertain groundwater processes
- Conceptual uncertainty

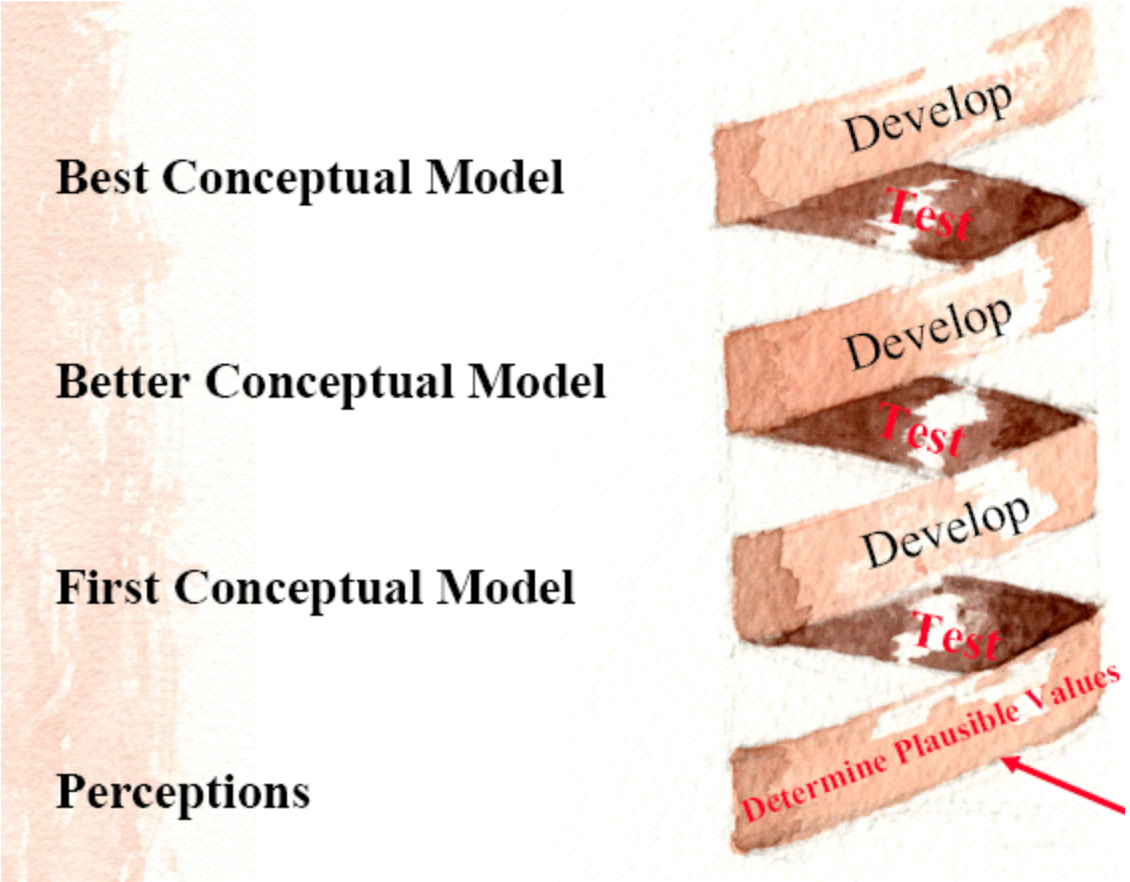
Conceptual model and Numerical model

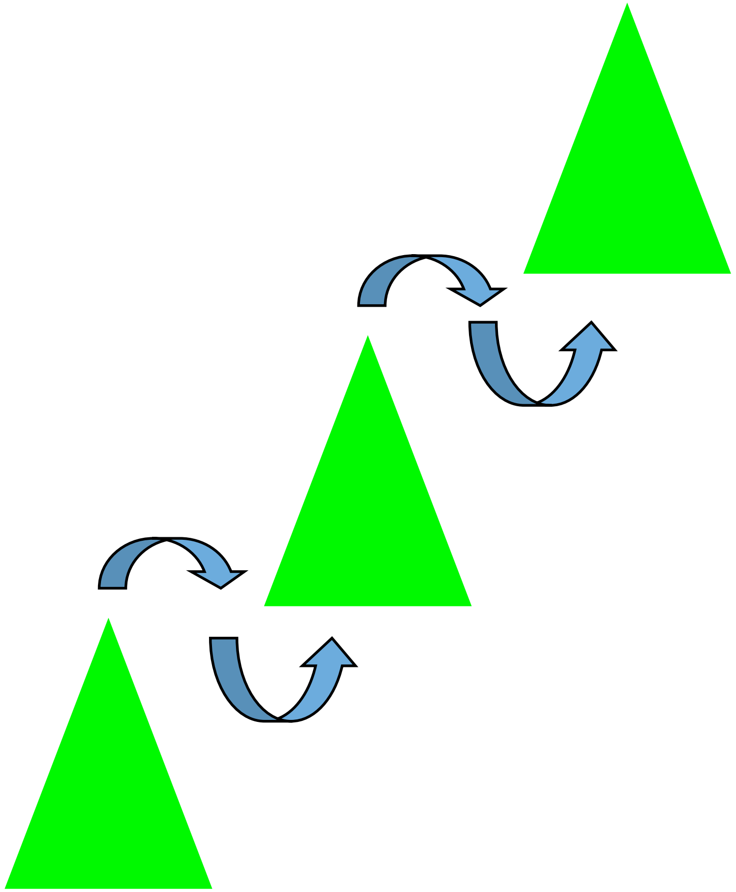





Input
Blackbox
Output

Iterate and Validate





Models are tools

- The model will not be a complete description of the real complex system
- It will make the best prediction we can of the future performance of the system and associated uncertainty
- It will be reproducible
- It will not give the answer!
- It will support decision makers

Hydrogeology is not a real science!

- Mostly I'm not trying to understand everything – I'm trying to help make a decision

PER ARDUA AD ALTA

PER ARDUA AD ALTA