The Three Heads of the Well
(Aestifer, Aquifer and Foundation)

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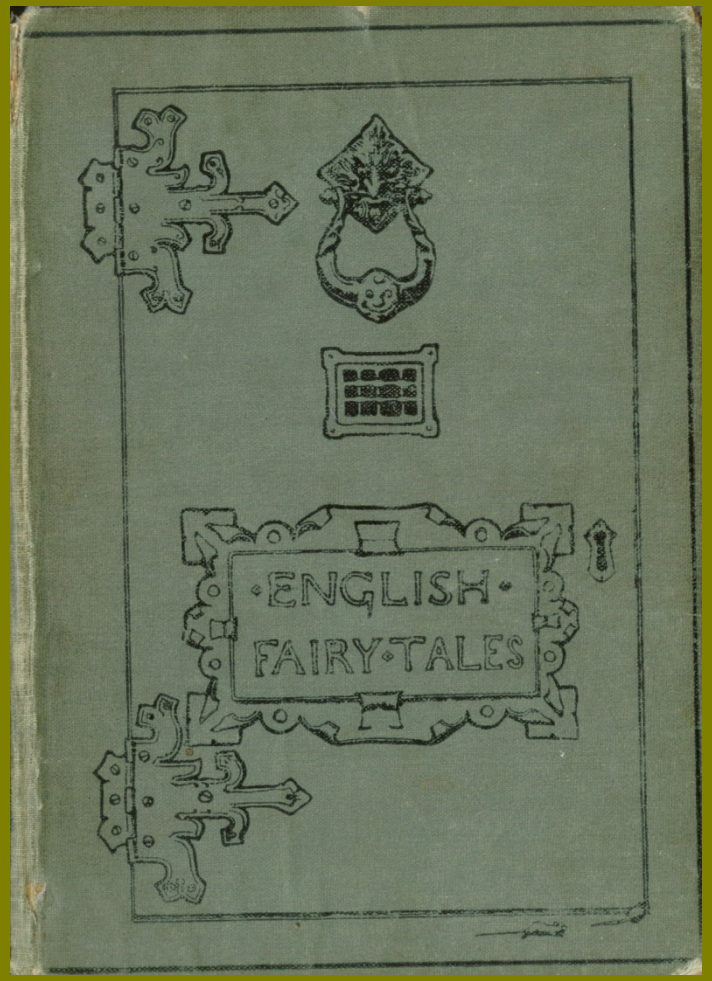


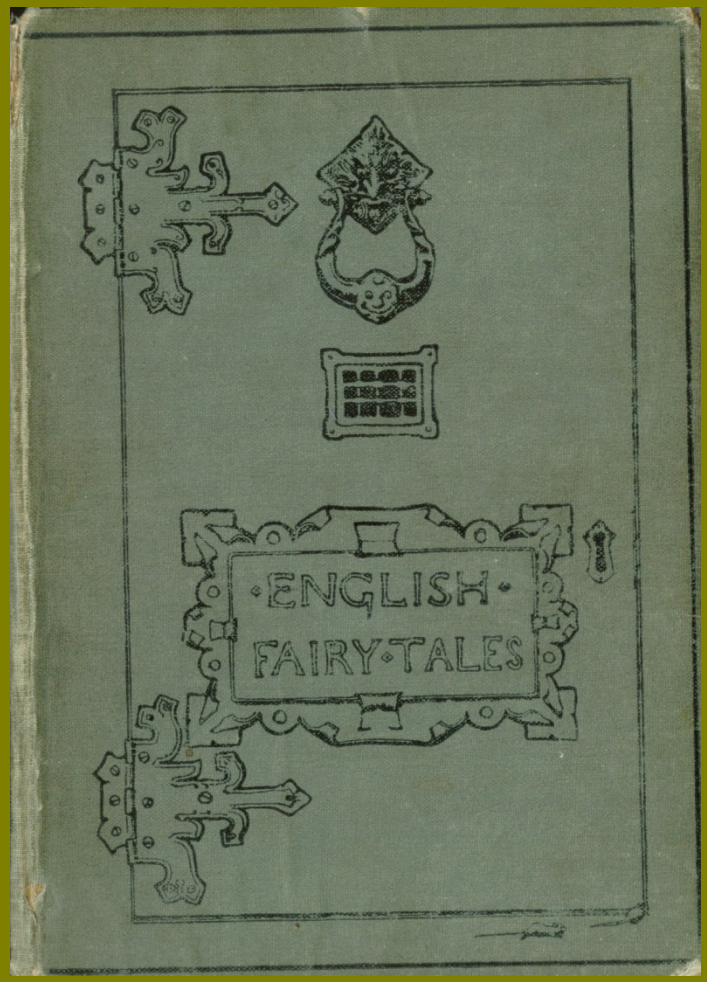
The Three Heads of the Well

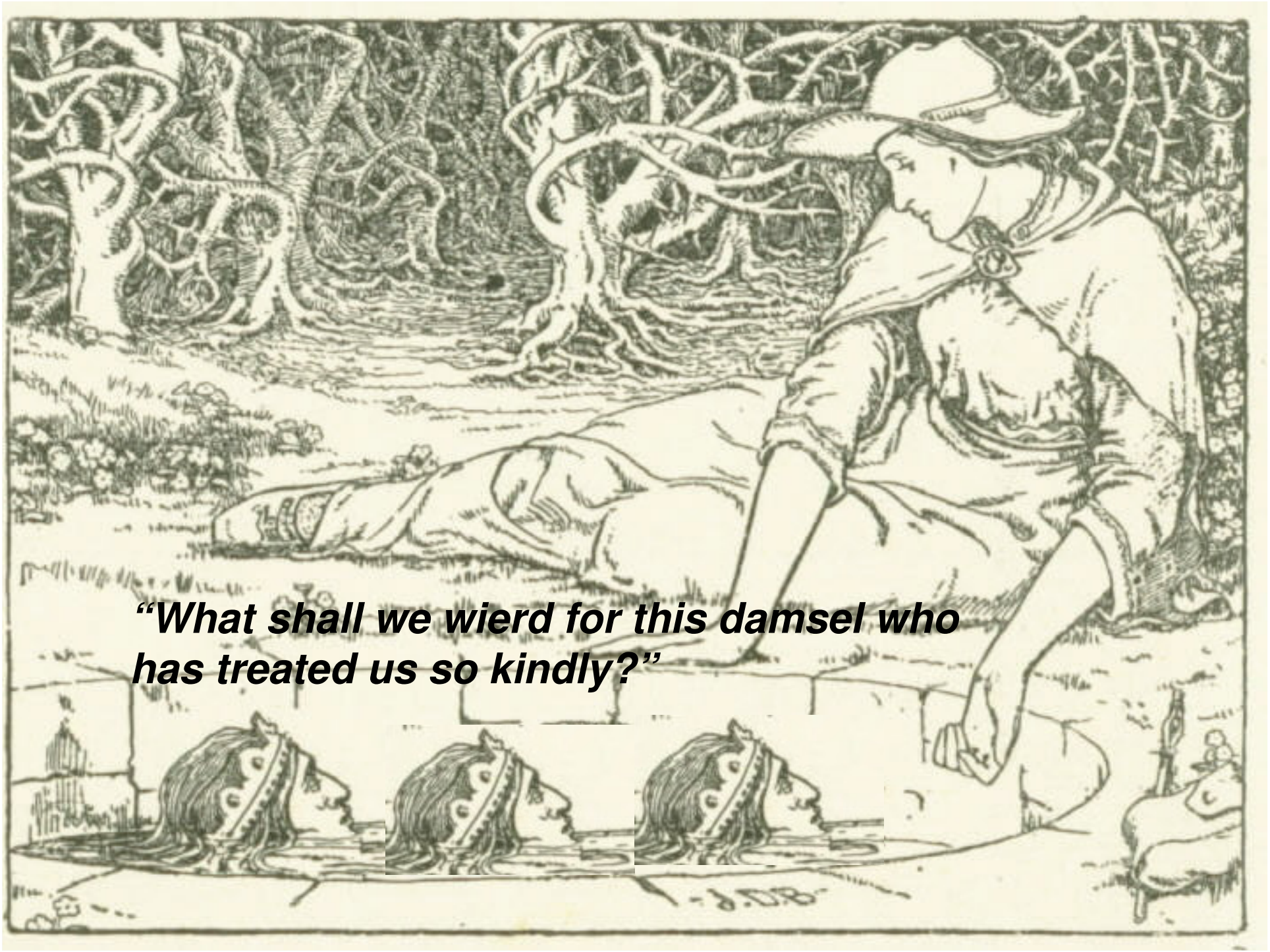
Once upon a time....

....long ago....

....in a distant country....

...somewhere near Colchester....




“What shall we wierd for this damsel who has treated us so kindly?”

The Moral of the Tale

1. If you're born rich and good-looking, success is assured. If not...you're doomed....

2. We must treat the three aspects of groundwater with respect

The Three Heads in the Well

Hydrogeologists are used to dealing with the first aspect of groundwater:

1. as a high-quality water resource (an aquifer)

...and geotechnicians are familiar with the second

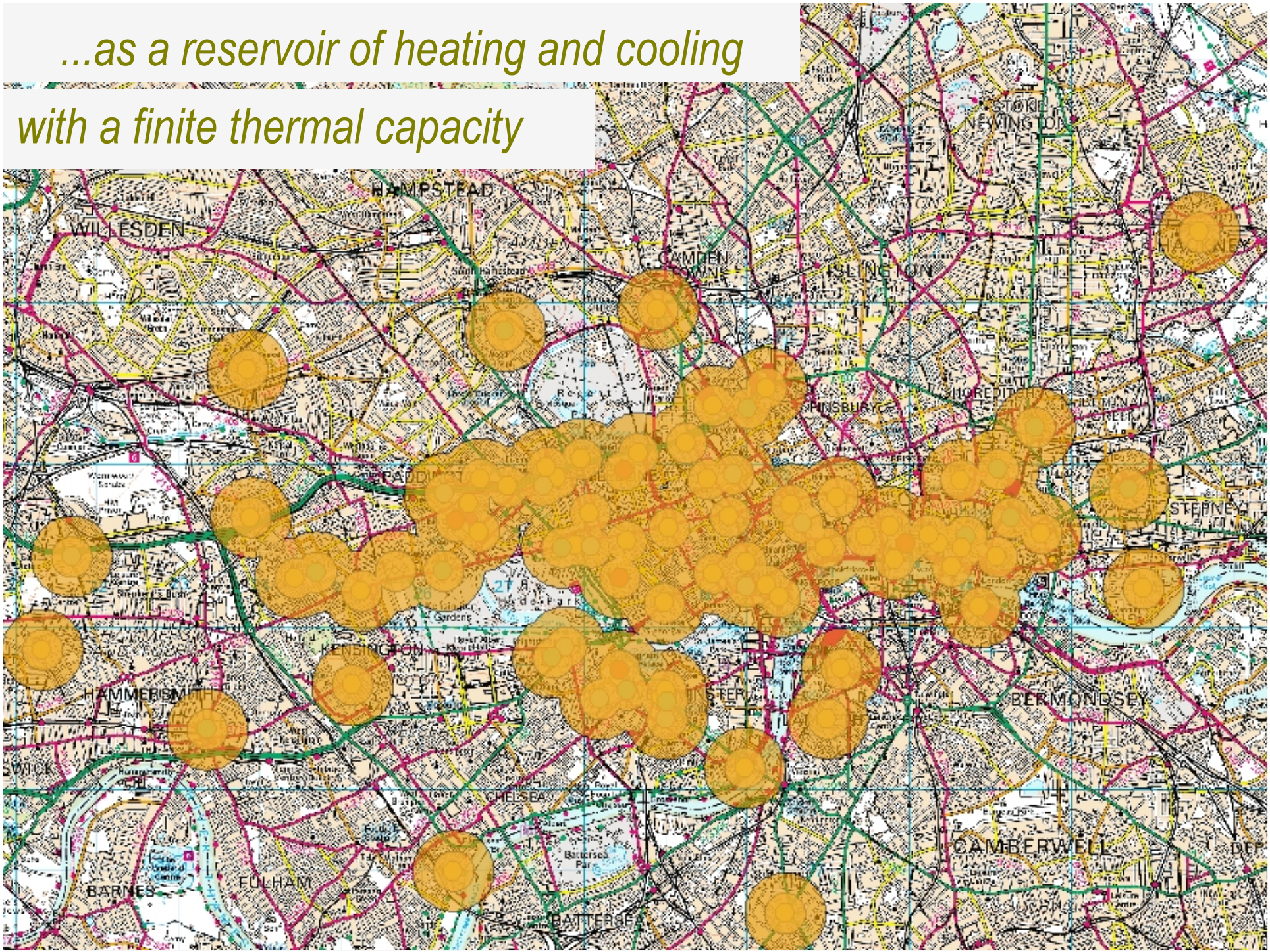
2. as an infrastructural substrate (a foundation)

...but we're beginning to realise that there is a third aspect to groundwater

3. as a thermal resource (an aestifer)

...as a reservoir of heating and cooling

with a finite thermal capacity



We have been here before...

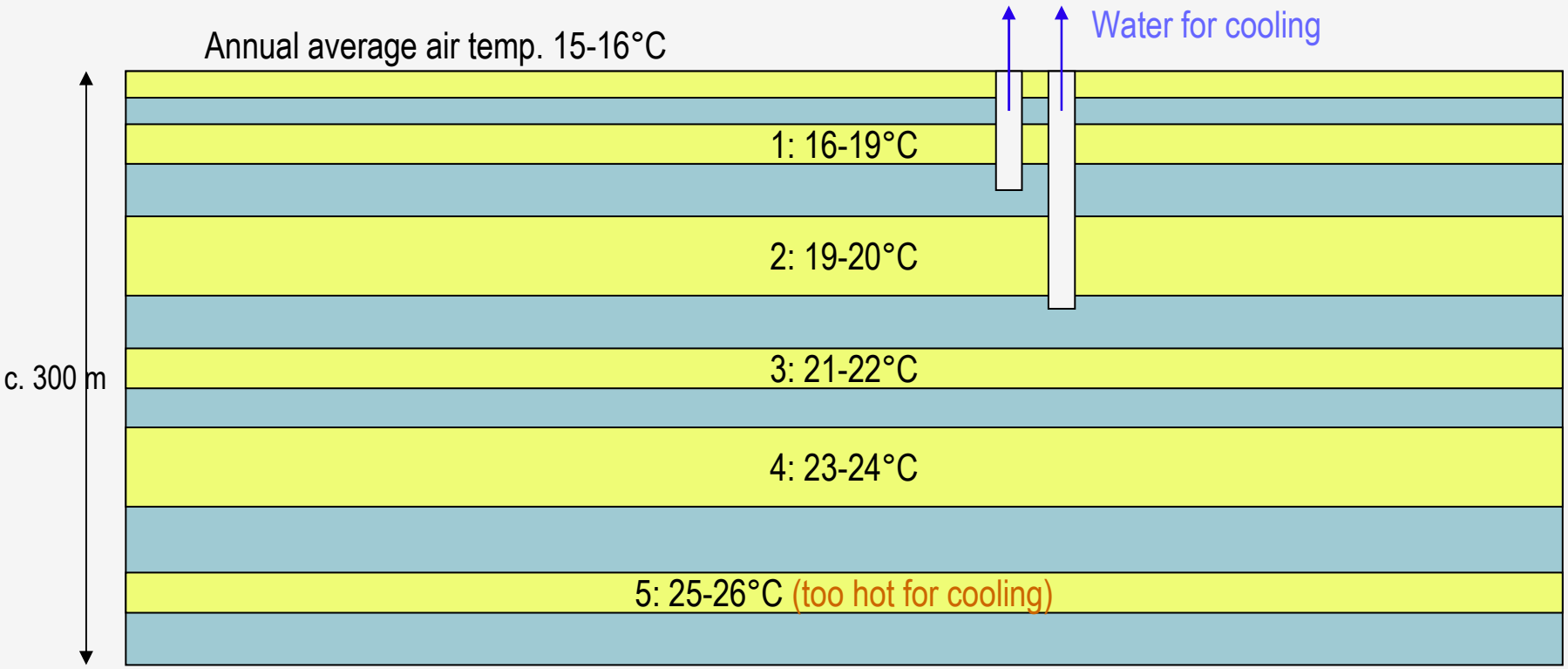
In the 1920s and 1930s

- groundwater was used for cooling and air conditioning in Brooklyn and Long Island...
- ...to the extent that its usage caused concern over water resources sustainability.
- Necessity for recharge of thermally spent water?
- Renewed concern over thermal sustainability and regional warming of the aquifers.

Kazmann, R.G. and Whitehead, W.R., 1980, The spacing of heat pump supply and discharge wells. *Ground Water Heat Pump Journal* **1(2)**: 28-31.

In Shanghai

Long history of (consumptive) shallow groundwater usage for air-conditioning and cooling (since 1860)



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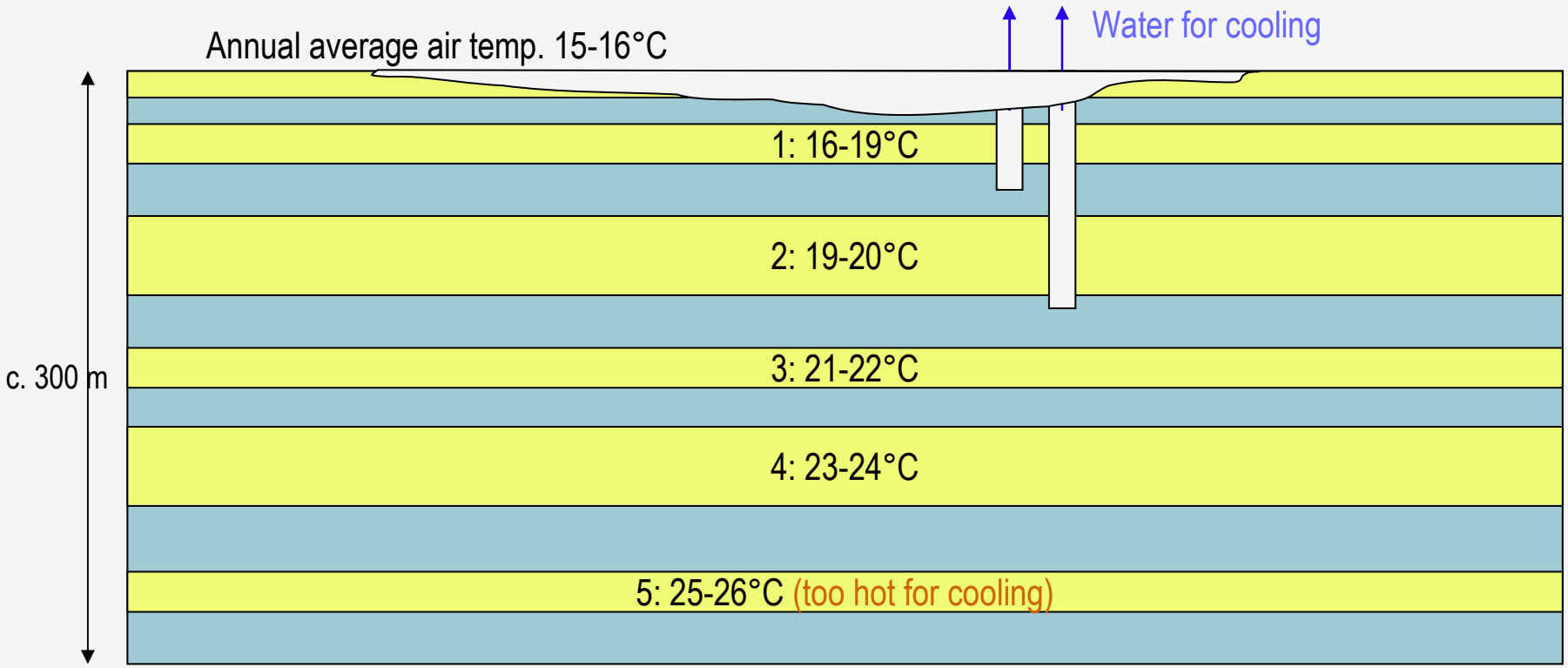
In Shanghai

This led to massive ground subsidence of up to 100 mm/a, and totals of 2-3 m in places by the 1960s



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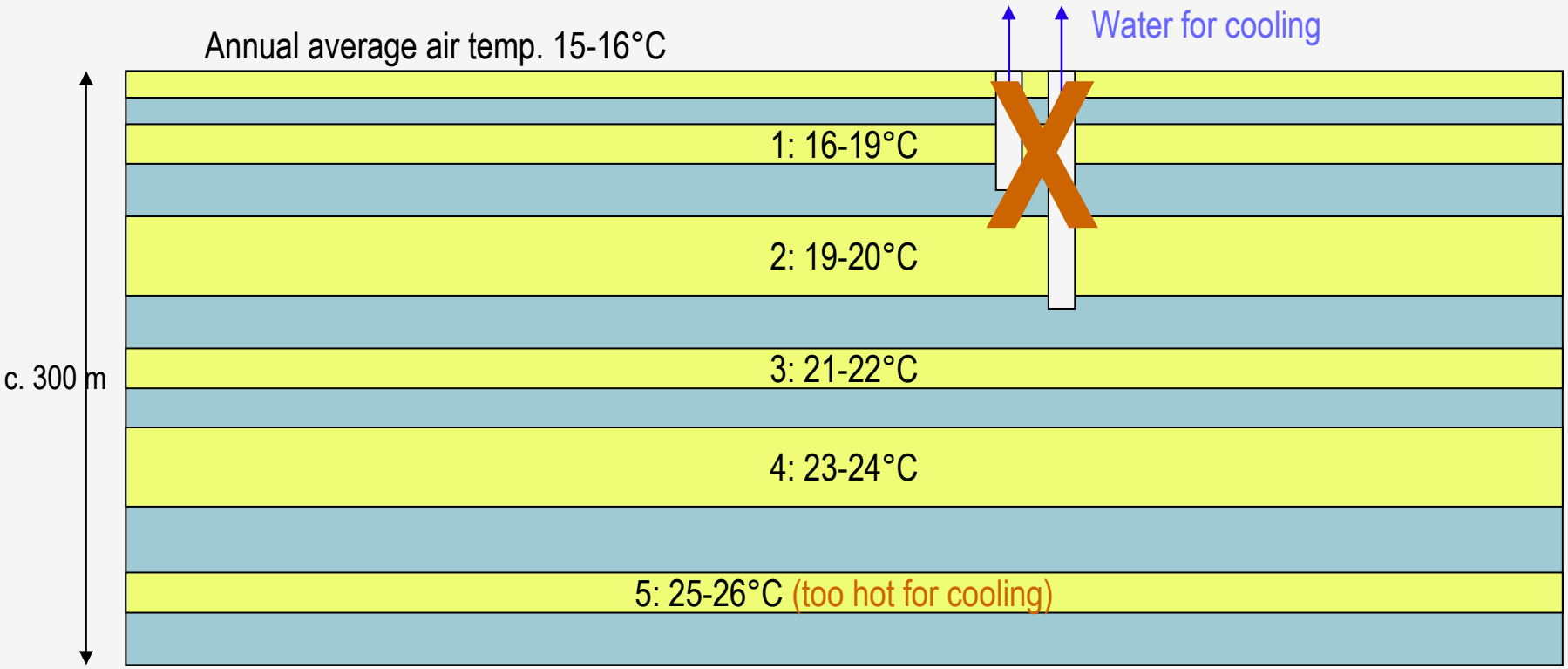
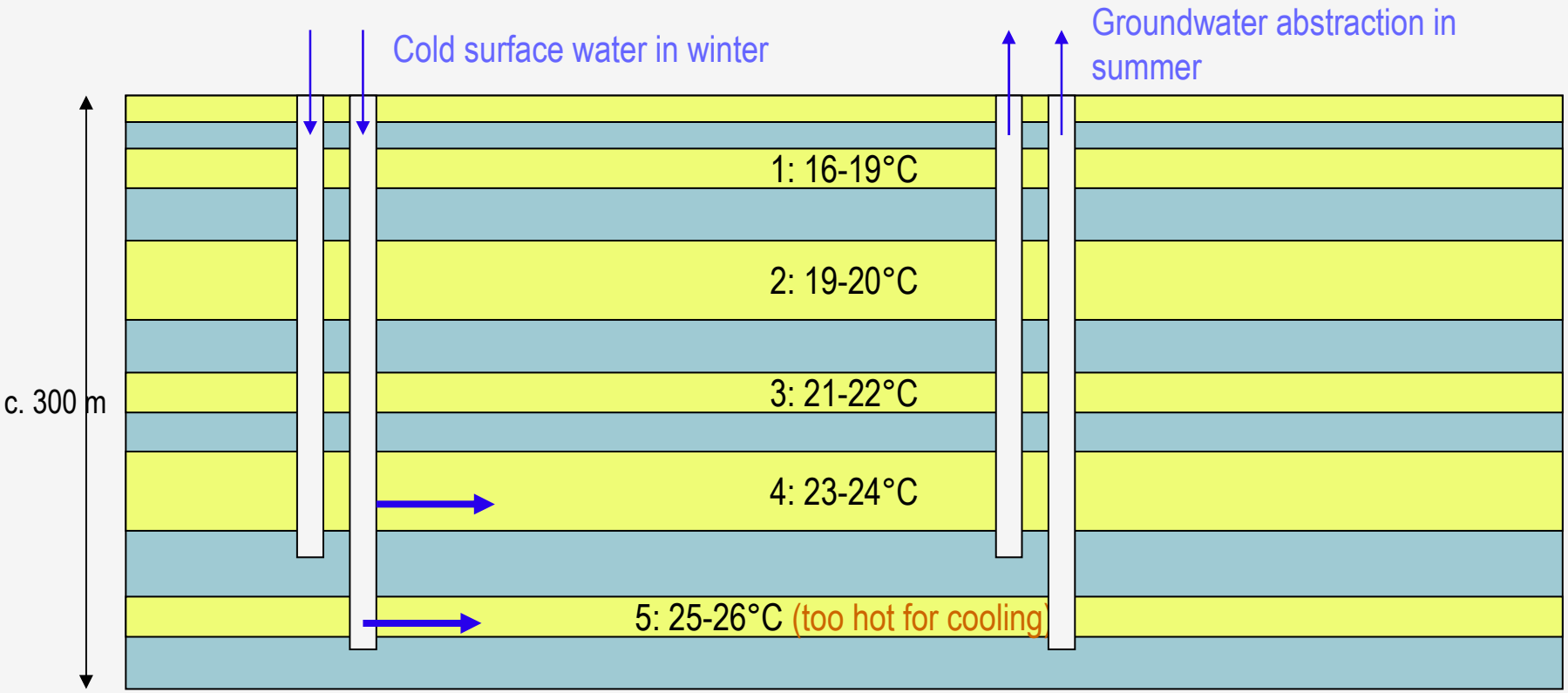
Consequence: authorities severely restricted use of water from shallower aquifers and shifted abstraction to Aquifers 4 and 5



In Shanghai

They also commenced injecting cold surplus winter surface water to the deep aquifer horizons:

- limited subsidence
- lowered temperature



Thus, in communist China in the 1960s/1970s

We can see the first example of the integrated management of:

- water resources
- land stability / subisdence
- heat resources

Luxiang S & Manfang B (1984). Case History No. 9.2; Shanghai, China, *In* Poland JF (ed) "Guidebook to studies of land subsidence due to ground-water withdrawal". *UNESCO Studies and Reports in Hydrology* **40**, 155-160

Volker A & Henry JC (1988). Side effects of water resources management : overviews and case studies. A contribution to IHP Project 11.1.a, prepared by a working group for IHP-III. *IAHS Publication* **172**.

In London

Water resources are effectively managed and more-or-less stabilised

Subsidence is arguably less of an issue

- but a 4 L/s open loop cooling well, pumping 1 mg/L suspended solids removes 126 kg sediment per year!

But elsewhere, geothermal drilling has caused serious stability issues

e.g. Staufen in Germany (transition of anhydrite to gypsum)

In London

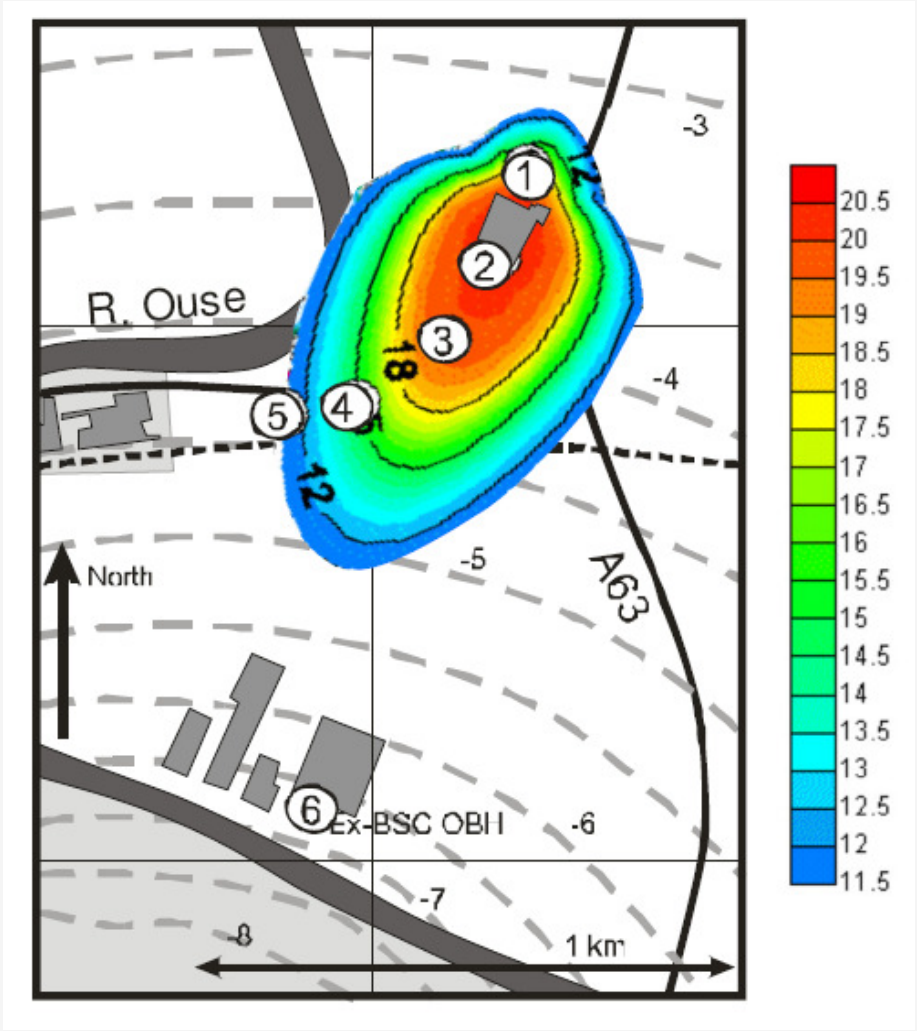
Water resources are effectively managed and more-or-less stabilised

Subsidence is arguably less of an issue

- but a 4 L/s open loop cooling well, pumping 1 mg/L suspended solids removes 126 kg sediment per year!

...and we have all the tools to be able to manage the thermal resource

As regards thermal management..We have modelling tools

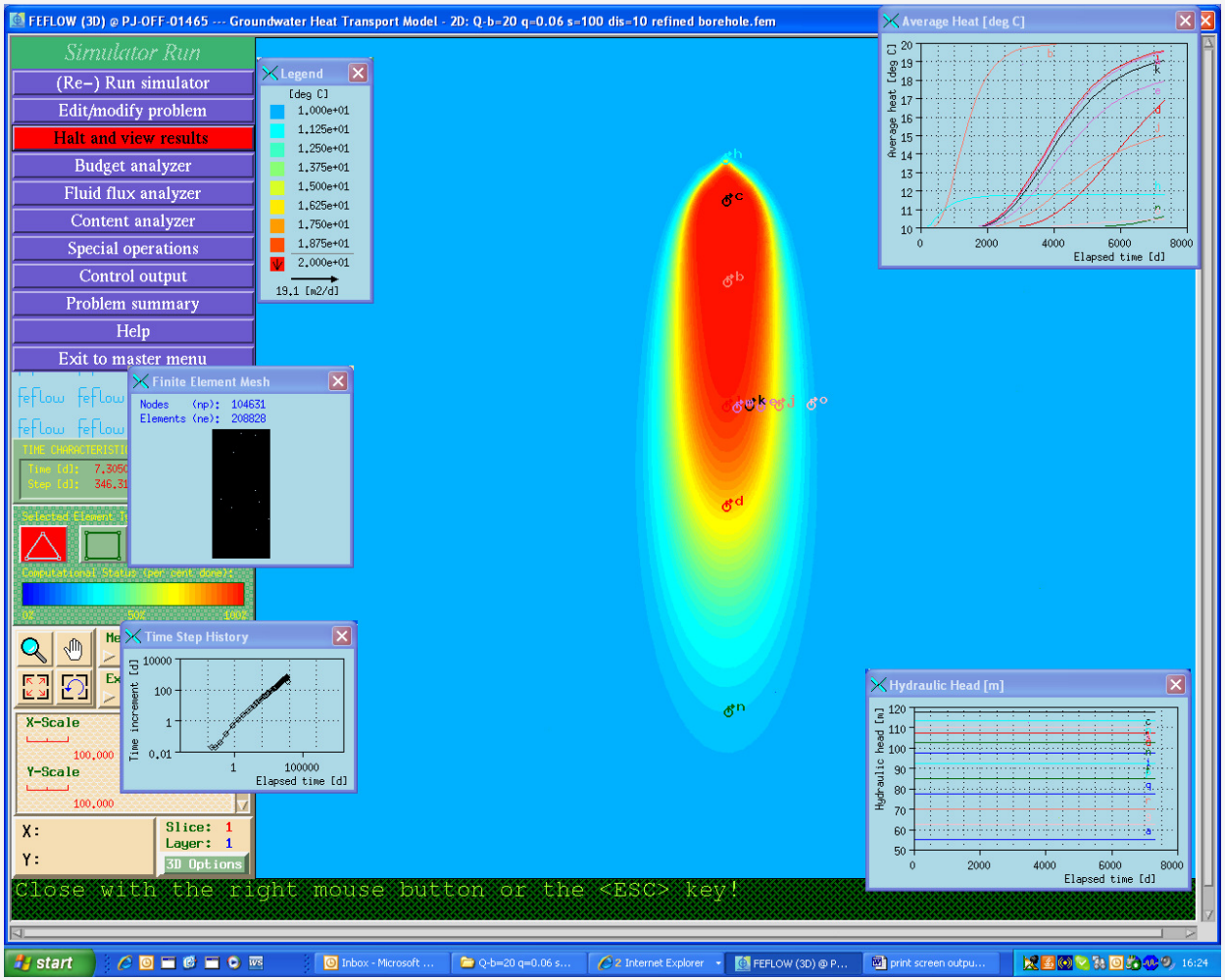


SHEMAT, HST3D, FEFLOW

Sensitive to numerical dispersion issues

•Diagram from the SHEMAT modelling work of Fiona Todd (2008) in the Sherwood Sandstone of Selby

We have modelling tools...both 2D



- Example of FEFLOW modelling work performed by Carbon Zero Consulting and Holymoor Consultancy for the Environment Agency on generic well-doublet systems

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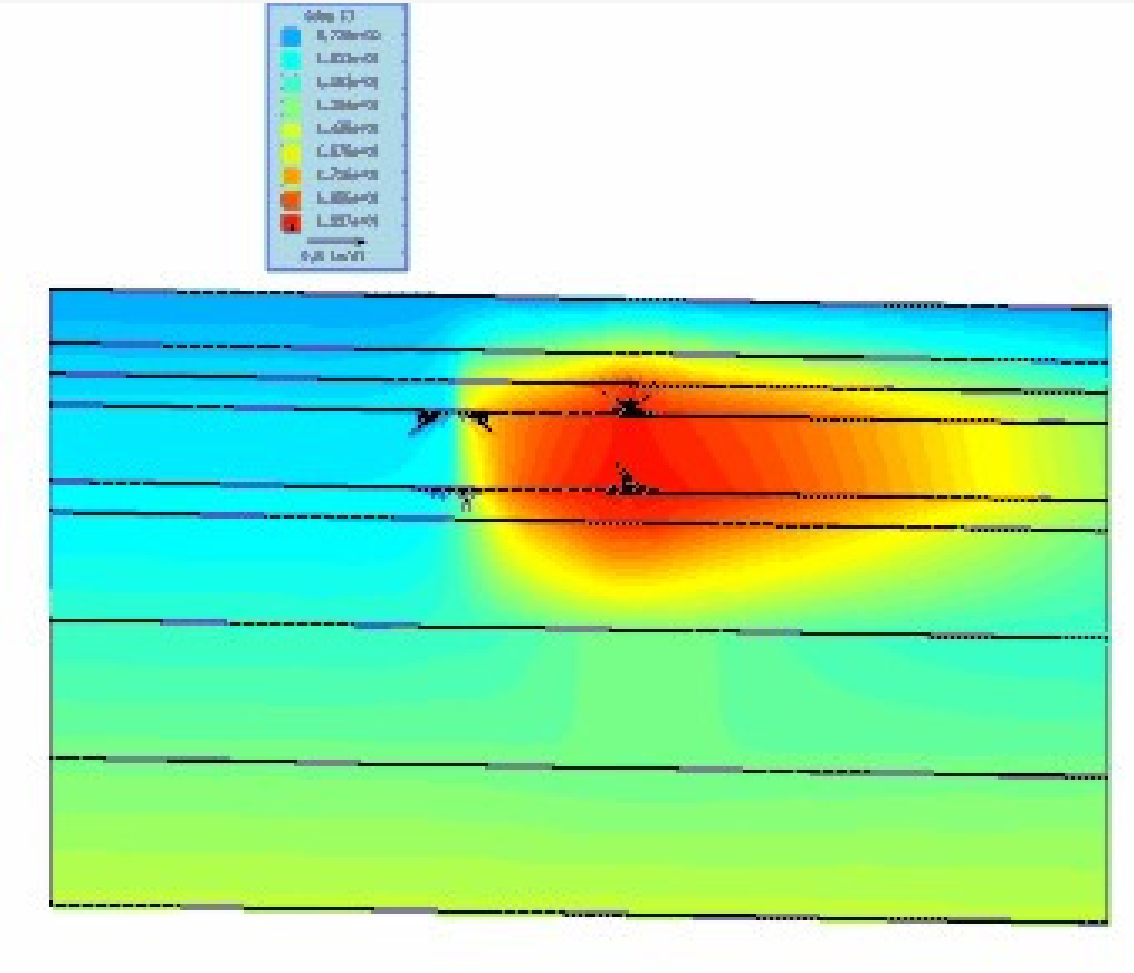
....and 3D modelling tools



- Example of FEFLOW modelling work performed by Carbon Zero Consulting and Holymoor Consultancy for the Environment Agency on generic well-doublet systems

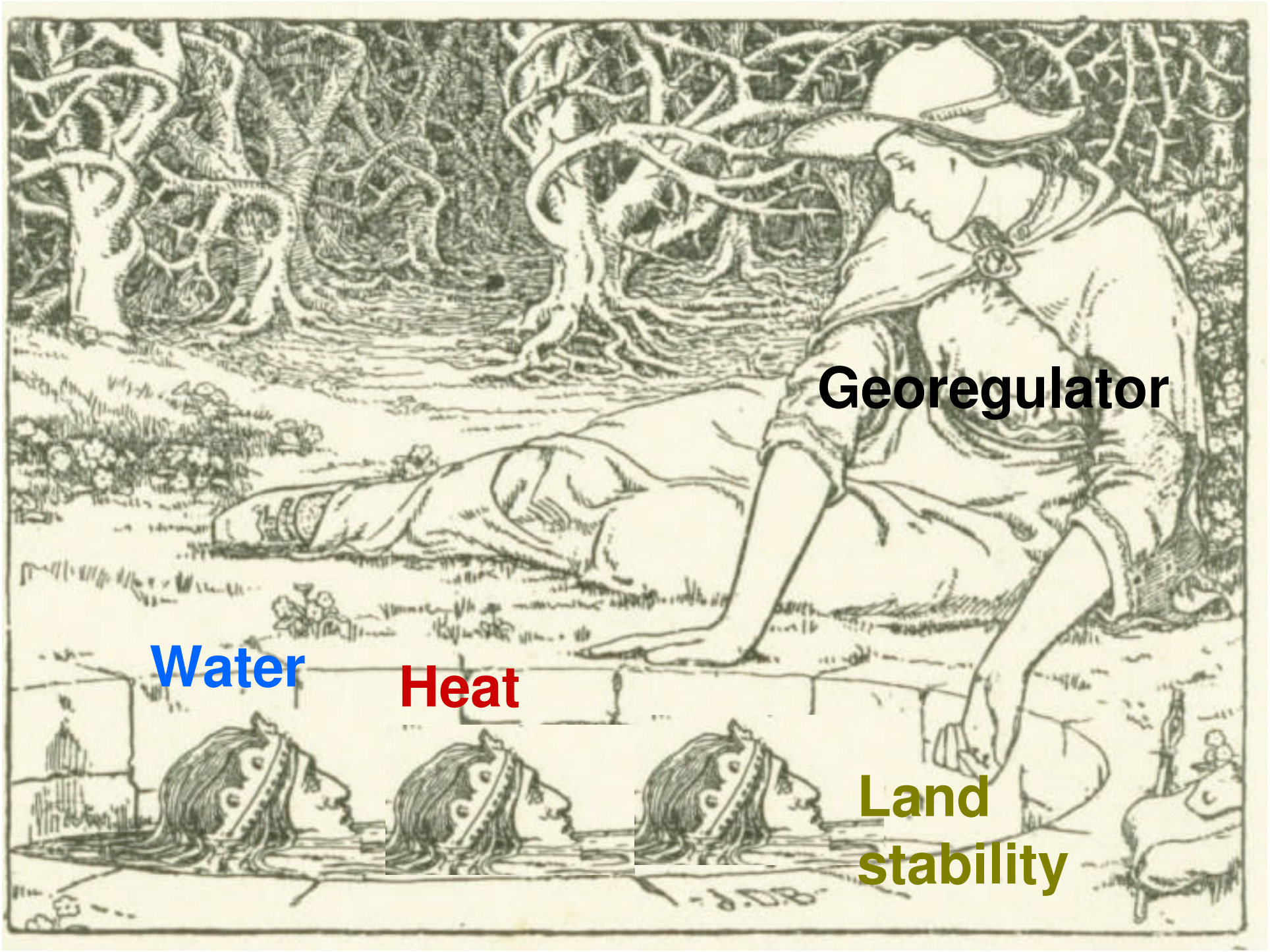
...and we have legislative tools

We can impose temperature constraints ΔT and flow constraints on discharge consents

Total heat discharge = flow x ΔT x 4190 J/L/°C

So, we could impose a net heat discharge limit on each open loop scheme of, say, several hundred MWh/annum in aquifers with a high net density of heat discharge

This would effectively encourage thermally balanced schemes


Georegulator
Water
Heat
Land
stability

...and they all lived happily ever after !

THE END