NAPL – Separating Physics from Policy: A Tale of Two Countries

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"NAPL in the UK context, does it matter?"
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Overview

"*It was the best of times, it was the worst of times*"

- Why me?
- The Physics
- The Policy
- What I hope you walk away with
  - *Physics doesn't care about your policy*
  - *Give regulators what they need*

Why me?

- Virginia Tech
  BS in Soil and Environmental Science
- University of California
  MS in Soil and Environmental Science (Riverside)
  Research Associate in Soil Physics (Berkeley)
- 24 years experience:
  - 17 years of consulting experience in California
    Licensed civil engineer (PE)
    Soil & groundwater contamination and remediation
  - 7 years in London at Arup
    Groundwater resources, contaminated land, geothermal
- Arup global technical lead on NAPL, vapour intrusion, GW modelling, soil & GW remediation, HHRA, geothermal engineering

A Tale of Two ~~Cities~~ …*Countries*

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way – in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only"

Non Aqueous Phase Liquids

"*it was the season of Light, it was the season of Darkness*"

- LNAPLs float & DNAPLs sink
- But they both get stuck and become quasi-permanent sources of contamination

The Physics

“we had everything before us, we had nothing before us”

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The Physics – Permeability vs Conductivity

- Permeability: the *capability of a porous material* (rock or soil) *to permit* (or facilitate) *the movement* (flow) *of fluids* through its pore space.
  - Units of area, m^2, darcies

- Conductivity: the *ability of a* permeable *material to facilitate the movement of a specific fluid* through its pore space.
  - Unites of volume or length per time: l/s or m/s

Conductivity vs Permeability

$$K_{fluid} = \frac{k \rho_{fluid} g}{\mu_{fluid}}$$

- K_{fluid} = Fluid conductivity (NAPL / water / air)
- k = Intrinsic permeability of the media (soil / rock)
- ρ_{fluid} = Fluid density (don't forget about $PV = nRT$)
- g = Gravitational acceleration
- μ_{fluid} = Fluid viscosity

$$\rho_{fluid} \propto K_{fluid}$$

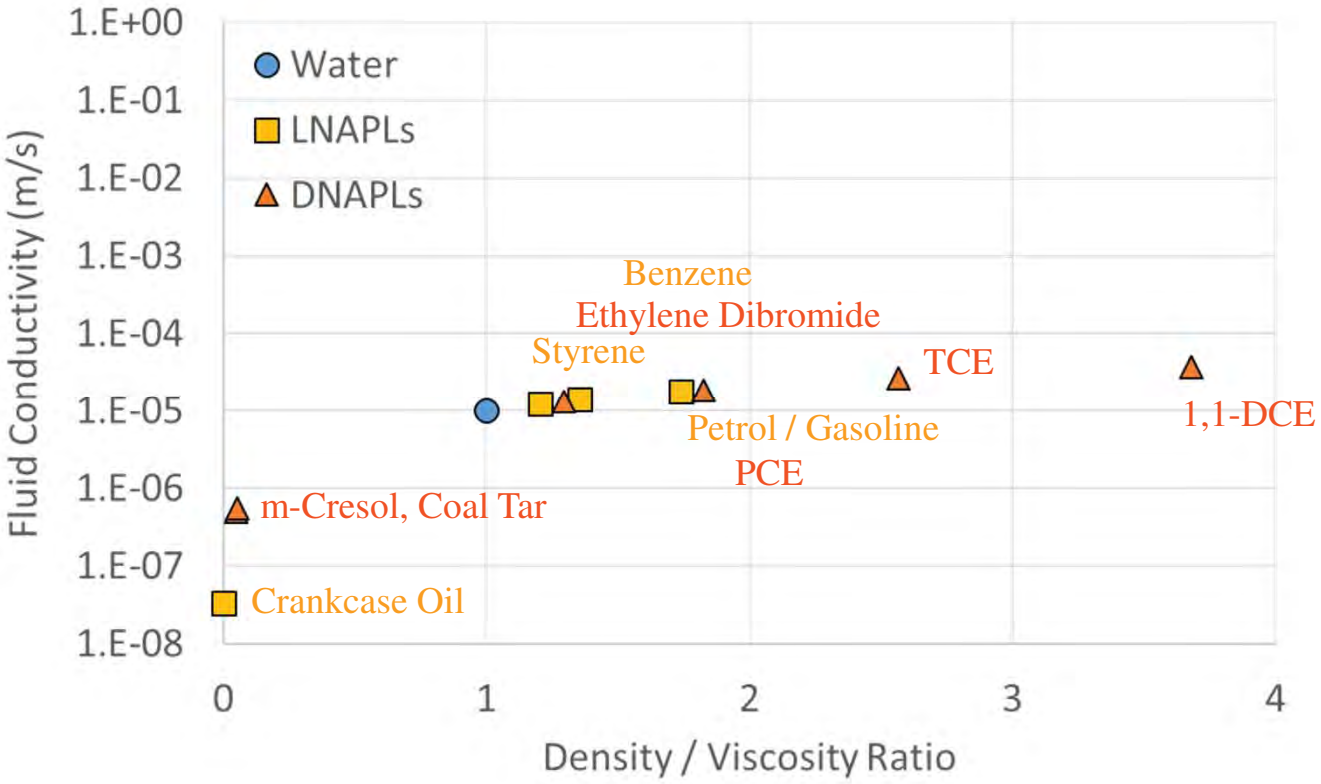
$$\mu_{fluid}{}^{1}/_{\propto} K_{fluid}$$

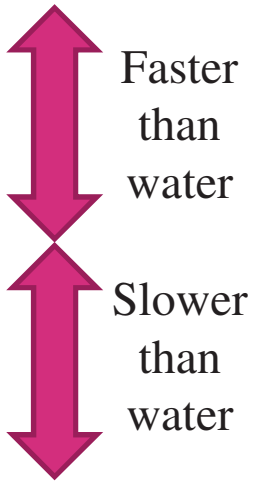
Conductivity vs Permeability

$$\rho_{fluid} \propto K_{fluid}$$

$$\mu_{fluid}{}^{1}/_{\propto} K_{fluid}$$

Density to viscosity ratio (D/V): useful to compare fluids with their conductivity and travel time

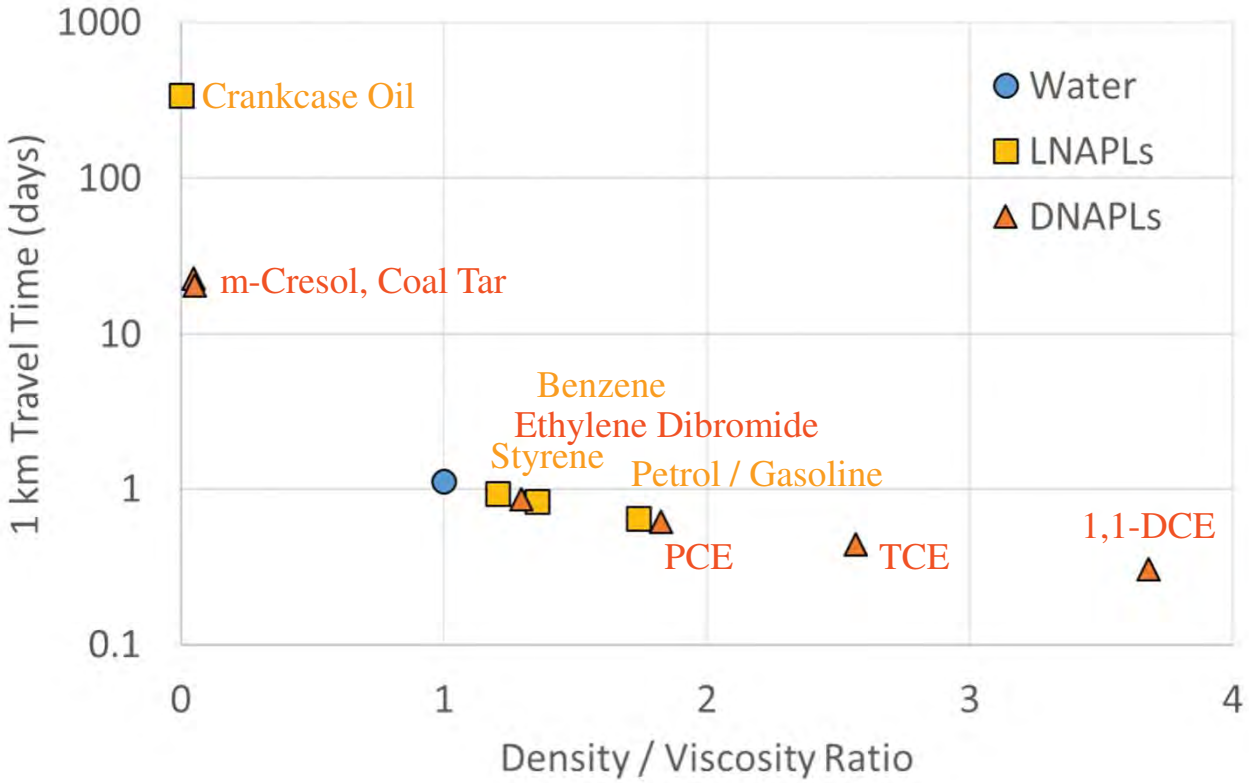


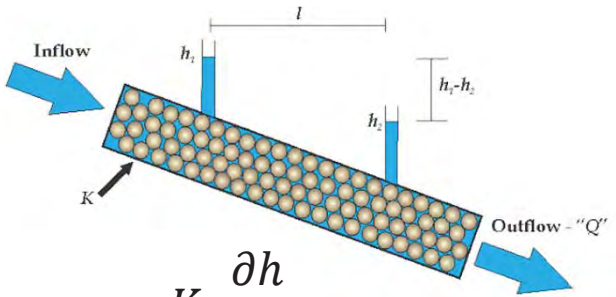


Based on fluid temperature of 20°C and k of $7x10^{-13}$ m^2

Impact on travel time

- Under the same gradient, high D/V ratio fluids move faster than water
- However NAPL gradients decrease rapidly away from source areas



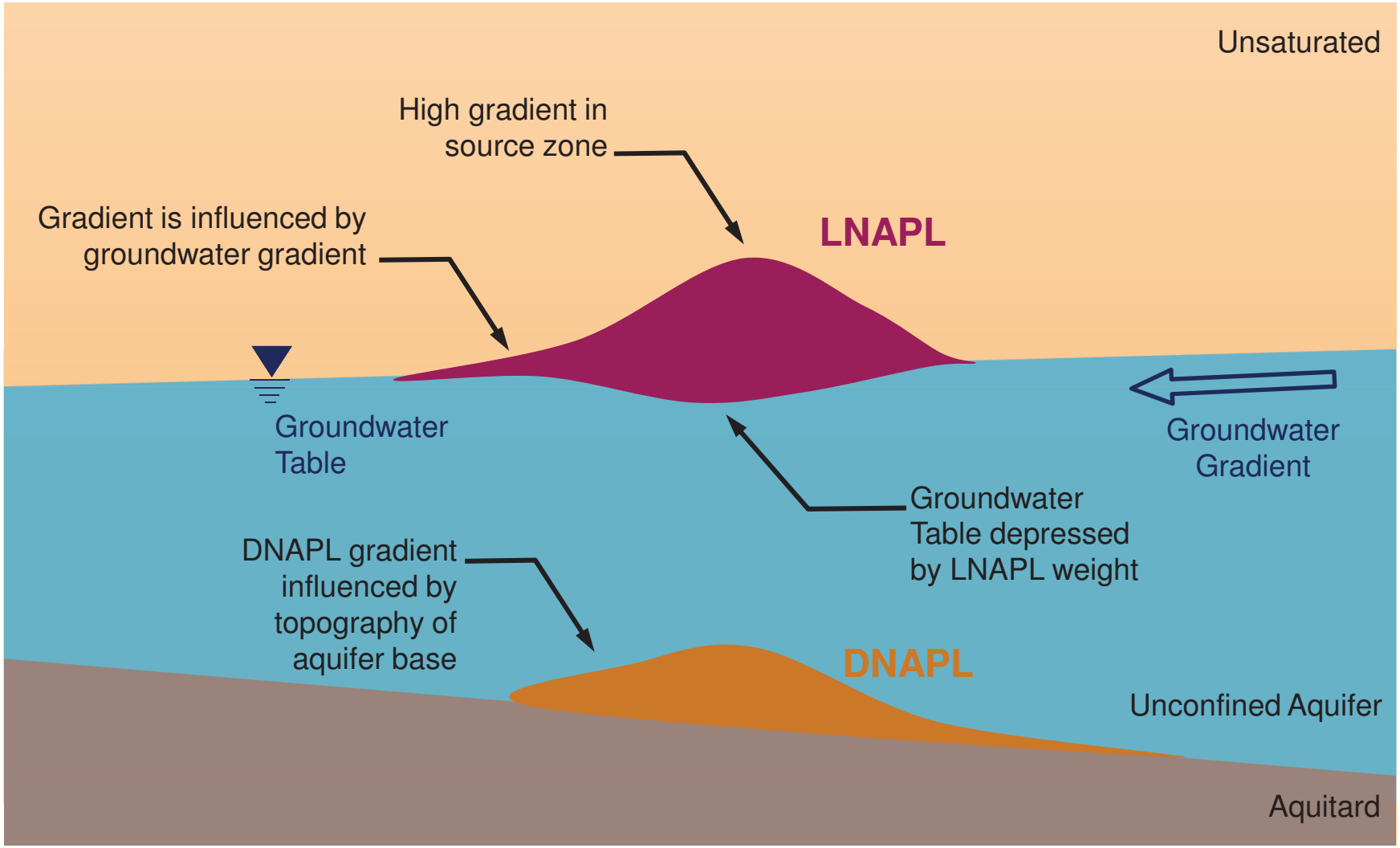


$$v = K_h \frac{\partial h}{\partial l}$$

Chart is based on:

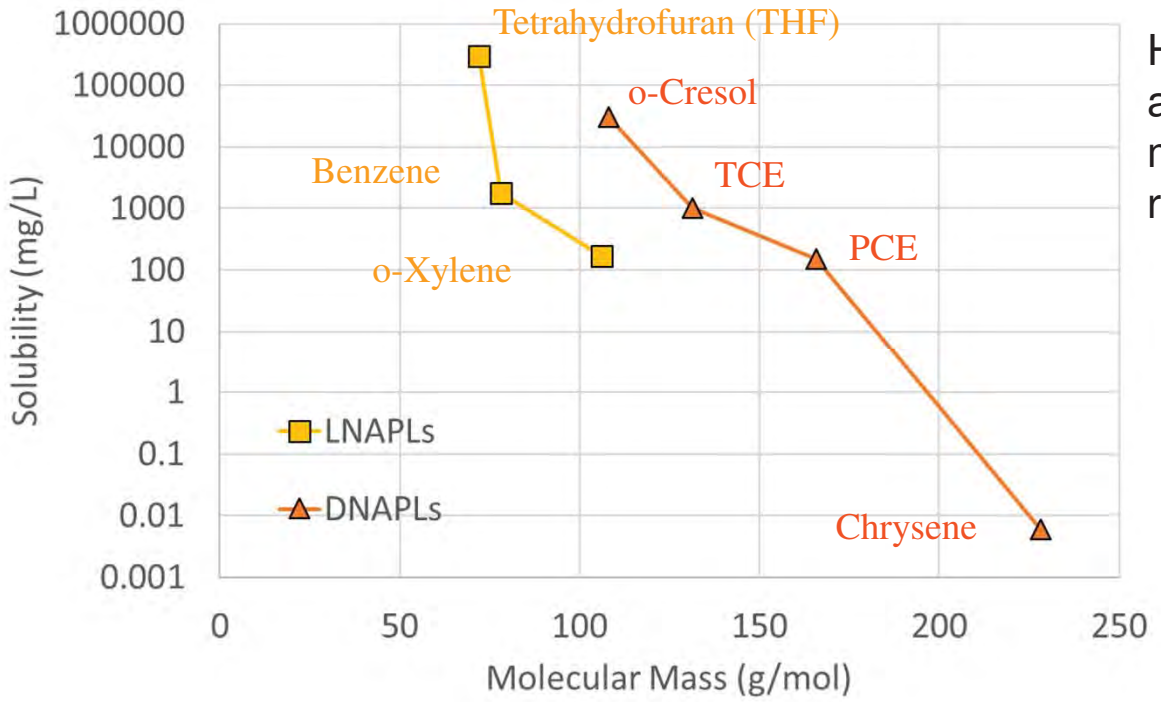
- *fluid temperature of 20°C*
- *fluid gradient of 0.0001*
- *Intrinsic permeability of $7x10^{-14}$ m^2 and K_h of water = 10^{-6} m/s*

NAPL Gradient



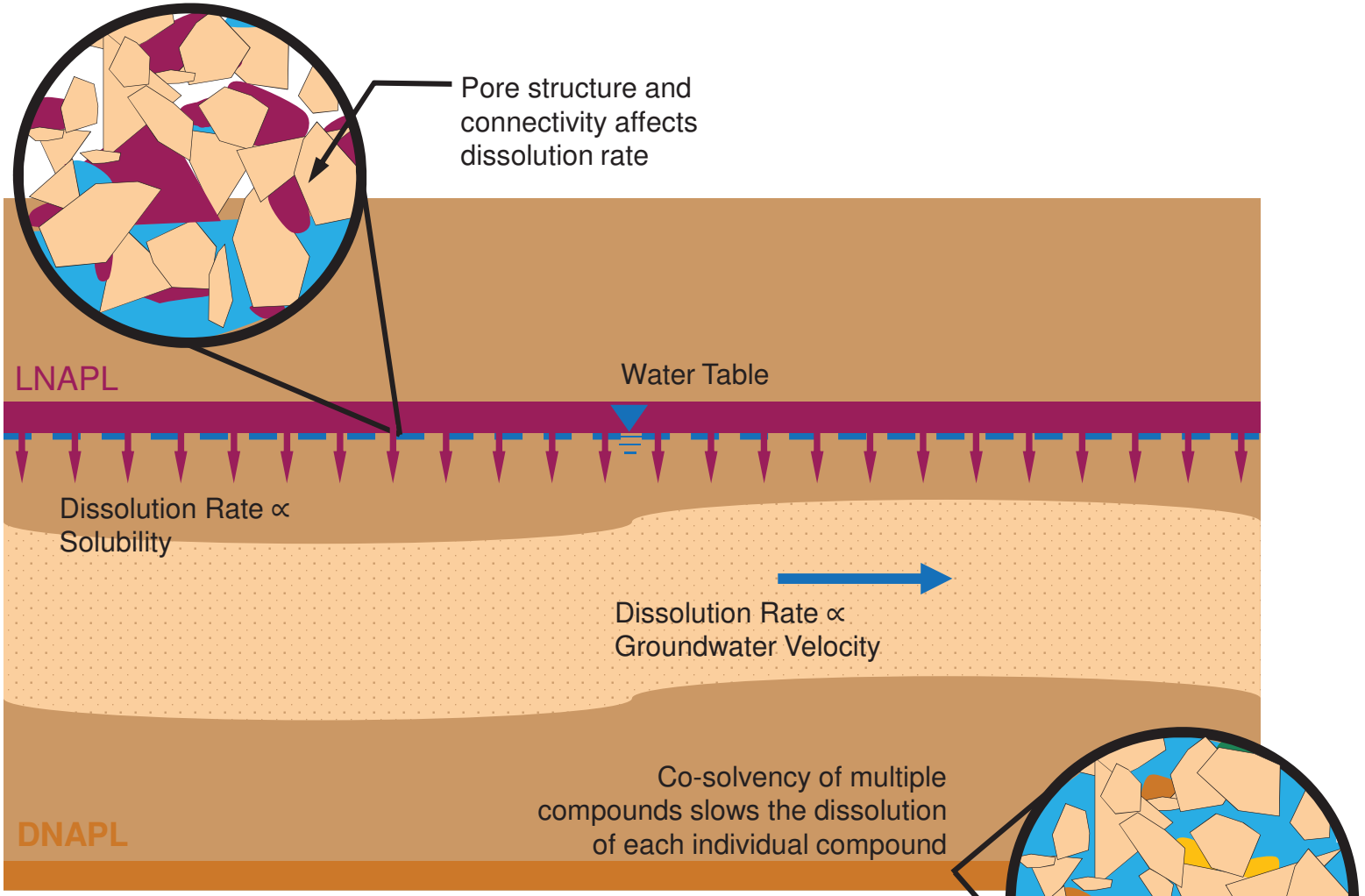
Solubility Rate

- Both LNAPLs and DNAPLs get stuck
- Eventually NAPLs become a residual & “permanent” source
- Dissolution rate is based on Mass Transfer across a Concentration Gradient



Higher solubility allows for higher mass transfer rates

Solubility Rate



General water quality affects solubility
(PH, TDS, etc.)

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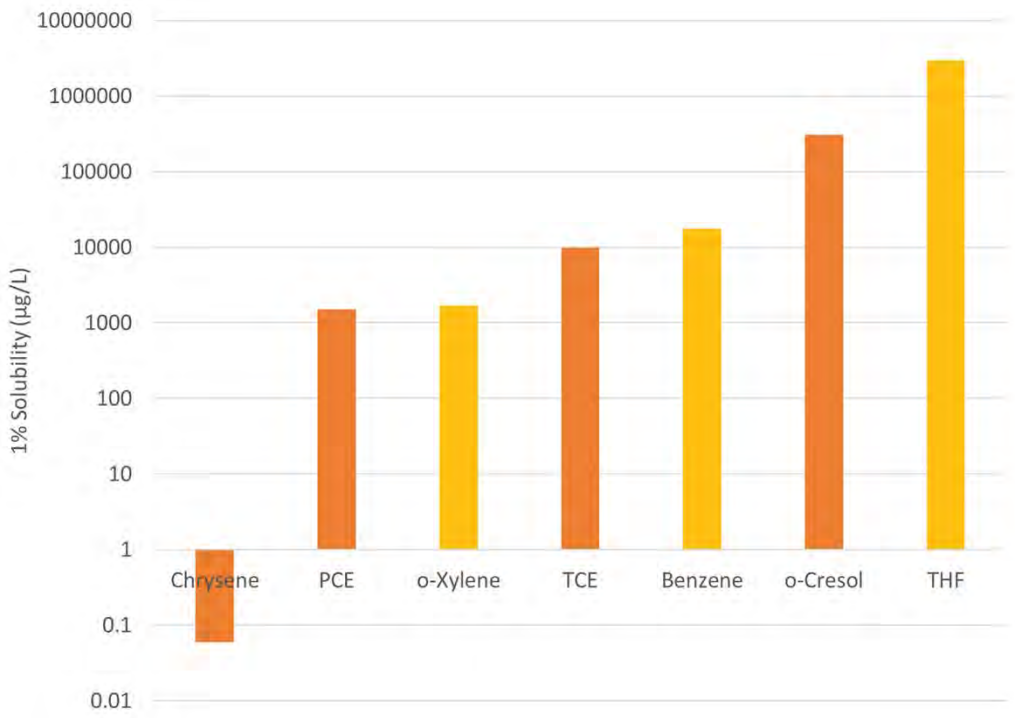
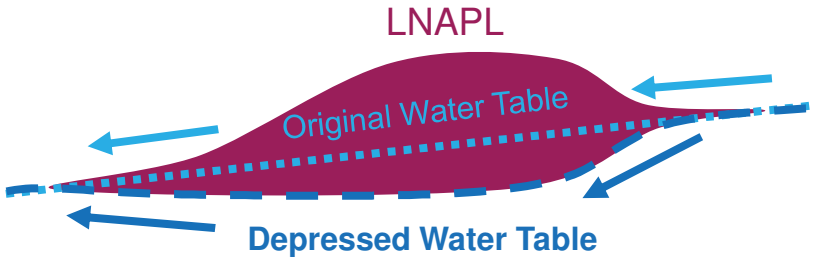
The 1% Rule

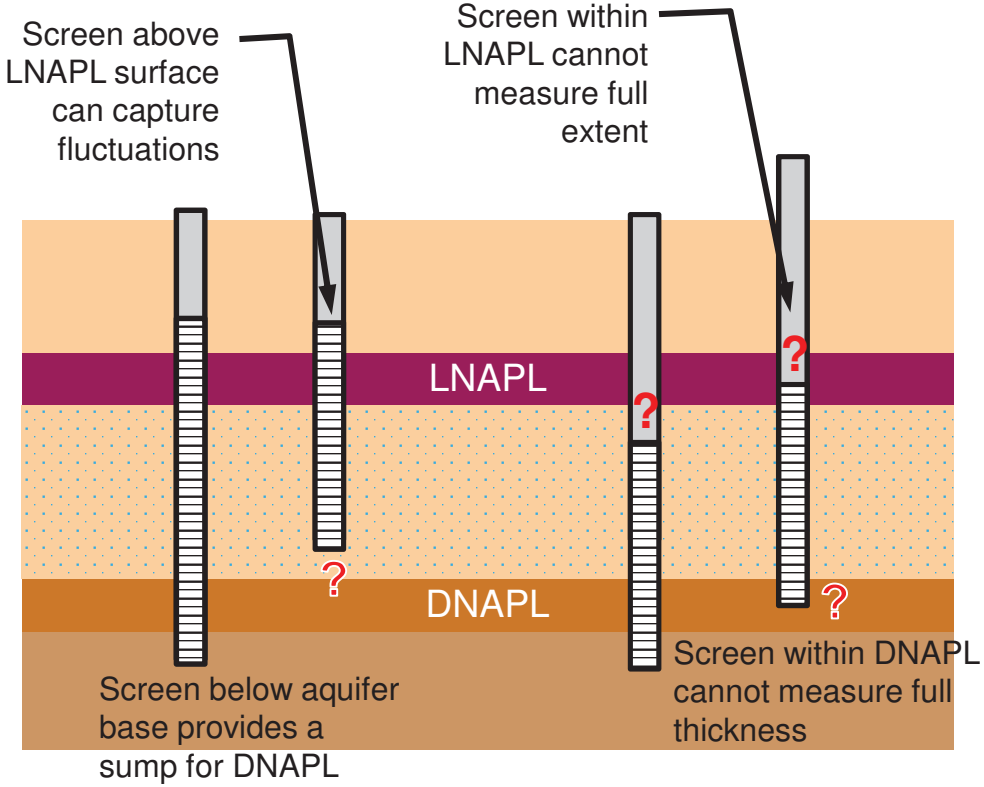
- NAPLs with concentrations above 1% suggests free product
- Doesn't 1% seems low?
  - Free phase compounds first dissolve into water
  - Then dissolved NAPLs are transported away
  - Measurable concentrations therefore unlikely to reach solubility limits



Investigation Design



- Hydraulic gradient can be miscalculated due to LNAPL depression of the water-table
- Well screen interval should identify full extent of NAPL contamination & fluctuation
- Care needed to not disturb NAPL in situ



The Policy

"*some of its noisiest authorities insisted on its being received*"

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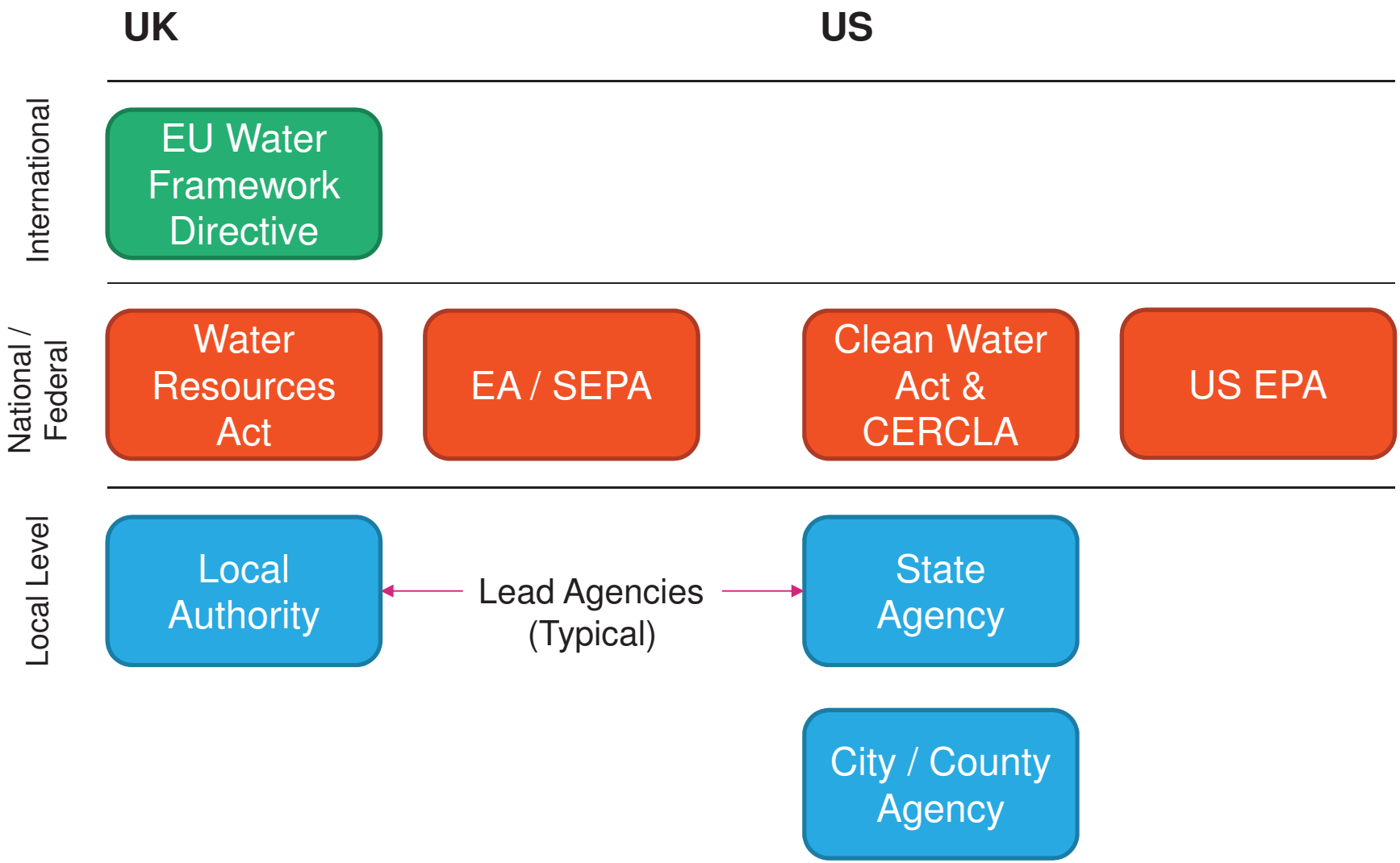
UK vs US Policy

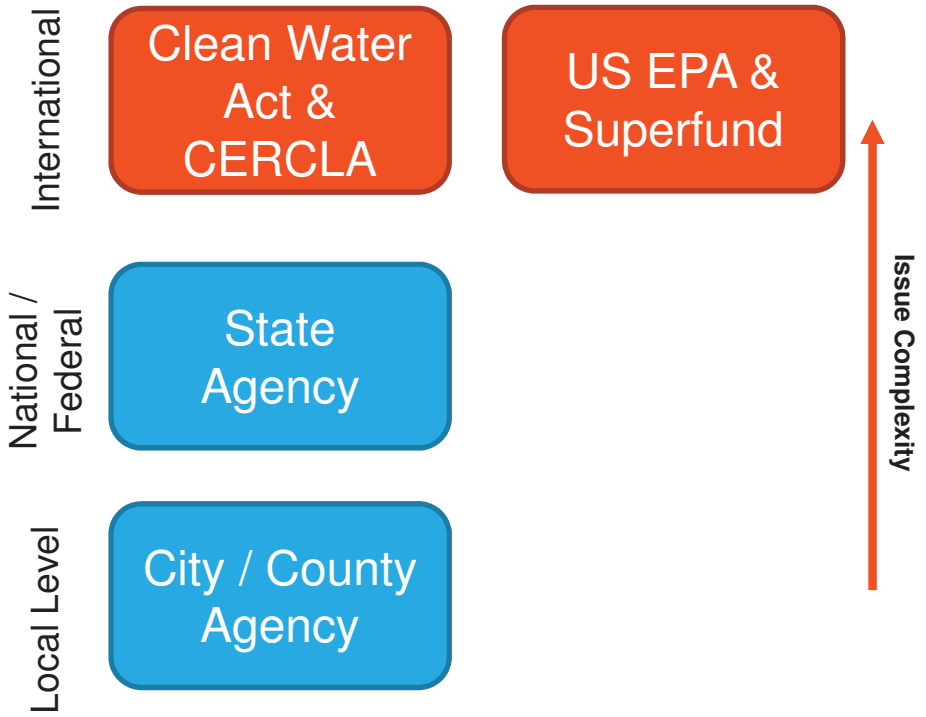


US Policy

- State agency typically leads but may change up or down depending on:
  - Site complexity
  - Agency resource availability
  - Superfund site eligibility
- But… all US states must be as stringent as US EPA regulations
  - States can be more stringent (California & New York)
  - For example: In California every drop of GW considered to be potable

US Policy

- Identify and mitigate initial source (source reduction)
- Risk based approach which
  - Generally accepts that NAPL will remain in subsurface as a permanent source
  - Allows for transport impact to receptor to be considered
- Acceptability based on monitoring compliance or statistical trends



What to walk away with

"*the superlative degree of comparison only*"

1. Physics doesn't care about your policy
   - It's not Darcy's Theory, it's Darcy's Law
2. All regulators basically need the same thing…
   - *Write in their language,* not yours
   - *Use science appropriately to generate risk based rationale*
   - *Needs to be understandable in 10 years* by someone unfamiliar with the project
   - *Complex things require a back and forth* to get the wording right