Practical applications of NAPL scoping calculations

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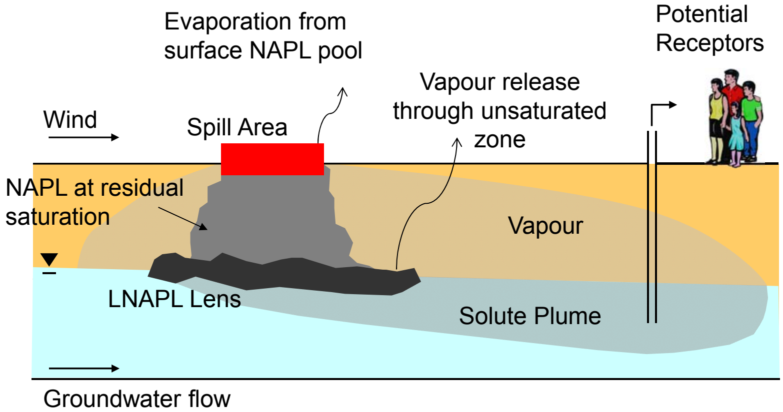
Unique problems

- How can we quantify
  - –distance of vertical migration in the unsaturated zone
  - –water table depression
  - –horizontal migration upon the water table (rather than the dissolved phase)
  - –loss due to evaporation

Key LNAPL flow and transport processes



NAPL modelling approach

- There are models/calculations which tackle components of the whole conceptual model
  - Different assumptions and approximations
  - Assemble together appropriate models for each case study
  - e.g. LNAPL lens characterisation, vapour release
- Techniques to cope with limited site data
  - e.g. Capillary pressure – saturation curves from particle size distribution curves

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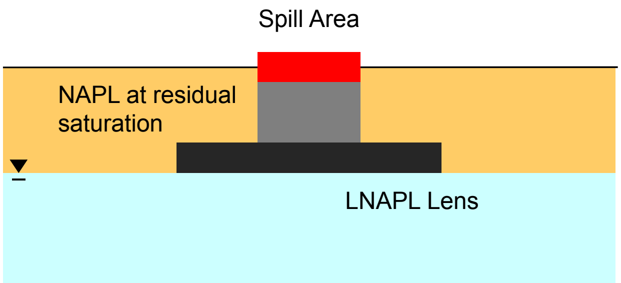
LNAPL lens characterisation

- Moving on from a 'pancake' conceptual model ...



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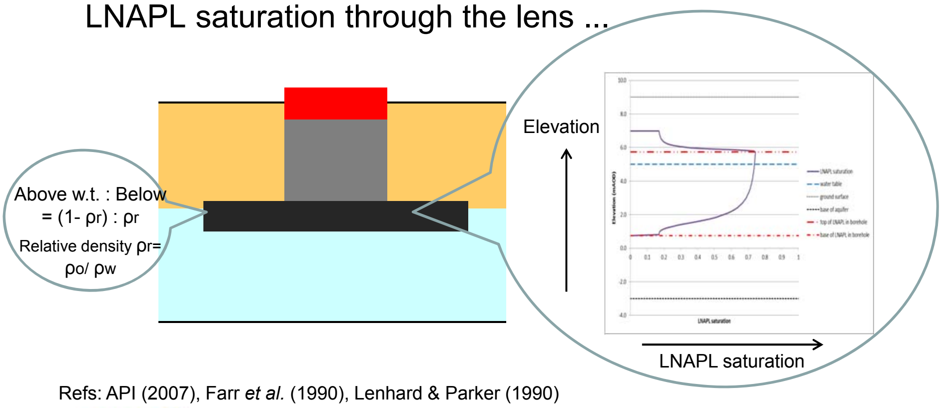
LNAPL lens characterisation

- ...to a model of water table depression and varying LNAPL saturation through the lens ...



Refs: API (2007), Farr *et al.* (1990), Lenhard & Parker (1990)

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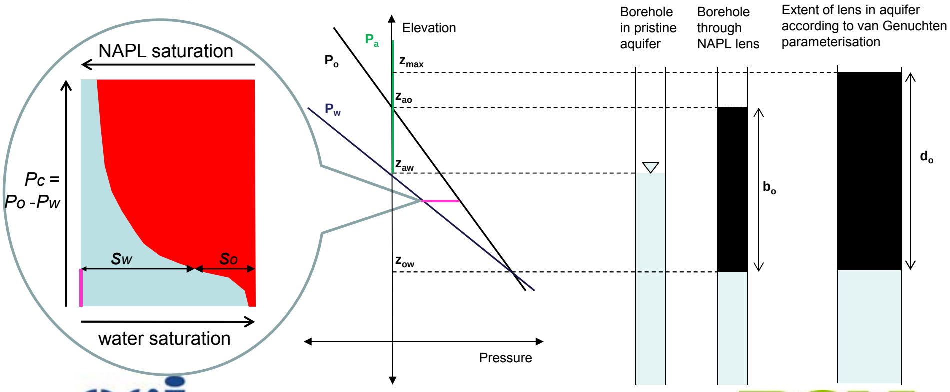
LNAPL lens characterisation

- ...via equilibrium consideration of pressures and a capillary pressure – saturation relationship



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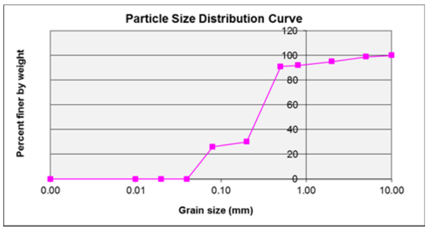
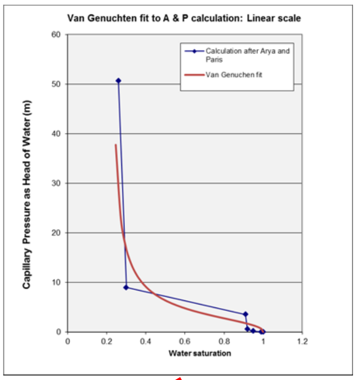
From PSD to Pc-S



Capillary pressure as a function of water saturation



Ref: Arya and Paris (1981)

Grain radius R

Pore radius r

Capillary pressure expressed as head h_c

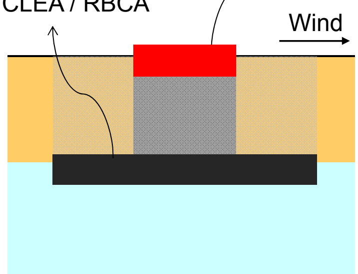
$$h_c = \frac{2\,\sigma_{aw}\cos\theta}{\rho_w\, g\, r}$$

Scale for NAPL-water systems using surface tension and density

Vapour release

Evaporation from surface NAPL pool

Vapour release through unsaturated zone treated as per CLEA / RBCA



Evaporation rate E (kg/m³)

$= A\, C_a\, k_m$

A is the area of the surface NAPL pool (m²)
C_a is the vapour concentration (kg/m³)
k_m is the mass transfer coefficient (m/s)

$k_m = 0.0048\, u^{7/9}\, S_c^{-2/3}\, D^{-1/9}$

u is the 10m wind speed (m/s)
S_c is the dimensionless Schmidt number
S_c=viscosity/diffusivity
D is the diameter of the NAPL pool (m/s)

Ref: Kawamura & Mackay (1987)

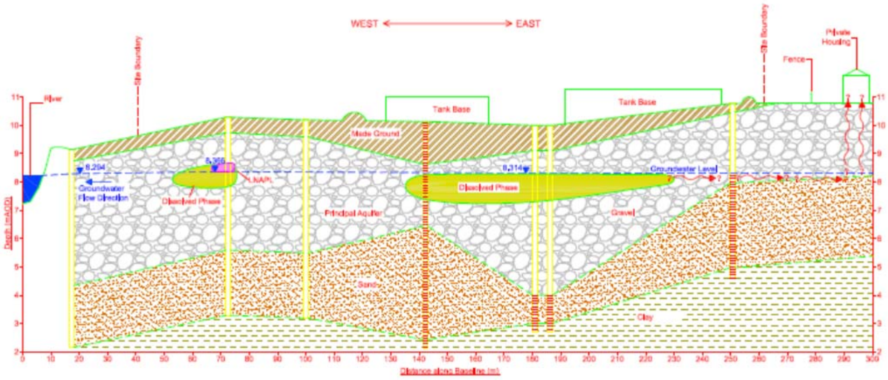
Case study 1: problem

- fuel distribution centre, UK
- NAPL observed on the water table
- river located <100m down hydraulic gradient
- will the NAPL ever reach the river?

Case study 1: process

- composition of the plume was analysed
- aquifer and NAPL properties were entered
- tool used to calculate
  - volatilisation and dissolution rates
  - NAPL velocity
  - Time for the NAPL pool to be depleted
- time to reach the river was calculated

Case study 1 CSM



Case study 1: selected input parameters

Parameter	Value
Hydraulic conductivity of aquifer	6.8m/d (field data)
Distance to river	<100m
Hydraulic gradient	0.003 (field data)
NAPL volume	138600l (estimated from site observations)

Case study 1: results of scoping calculations

Item	Result
Rate of movement of LNAPL given the hydraulic gradient of the water table	0.217m/d (267 days to reach river)
Reduction of LNAPL mass due to leaving residual NAPL in pore space, dissolution into groundwater and volatilisation	Initial volume NAPL = 16.44m^3 **After ~1year:** Volume left in NAPL lens = 0m^3 Dissolution to groundwater = 0.525mg Mass loss due to volatilisation = 160249.6mg **After 267 days:** Volume left in NAPL lens = 4.23m^3 Dissolution to groundwater = 0.39mg Mass loss due to volatilisation = 119616mg

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Case study 1: discussion

- scoping calculations are a useful first step
- NAPL had not reached boreholes adjacent to the river within the time frame predicted
- Importance of
  - good quality site specific data
  - robust conceptual site model

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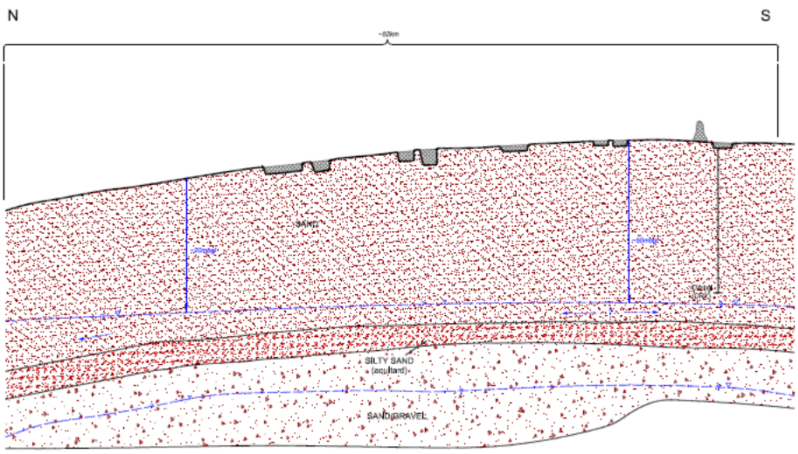
Case study 2

- Large spills of unknown dimensions
- High surface temperature (Middle East)
- Variable water table locally governed by evaporation (~2.5m/yr)
- 2 aquifers over a large area (sandy and silty)
- Paucity of site specific physical and chemical data

Case study 2



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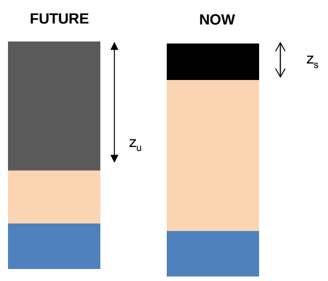
Case study 2: problem

- Conservative soil RTV calculated on the basis of
  - the critical concentration of TPH in soil before it could theoretically move
  - given soil types: sand (lower) or silt (higher)
- But in some sandy areas the water table was 20-50mbgl
  - how deep would the NAPL extend?
  - Could the silty RTV also be used in sandy areas without NAPL reaching the water table for ease of remedial management?

Case study 2: theory

- An extension of the spreadsheet tool
- the volume on NAPL originally contained in the source zone equals the volume of NAPL once it has spread to its maximum extent vertically



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Case study 2: theory

$$Z_u = Z_s \frac{S_o}{S_{ro}}$$

$$S_o = \frac{C_T \rho_b}{10^6 n \rho_o}$$

Parameter	
Residual NAPL saturation within the unsaturated zone (-)	S_{ro}
Thickness of current source zone (m)	Z_s
Porosity of soil sample (-)	n
Soil bulk density (g/cm^3)	ρ_b
NAPL density (g/cm^3)	ρ_o
Soil concentration in source area (mg/kg)	C_T
Total thickness of unsaturated zone material that NAPL will spread through before it reaches equilibrium (mbgl)	Z_u

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Case study 2: input

Parameter	Value	Justification
Geology	Fine to medium gravelly sands	Based on RSK logs and cross sections for the area
Residual NAPL saturation within the unsaturated zone (-)	0.1	Based on the API, 2000 value for a fuel oil in sand which is the best approximation for the characterised site specific oil and local geology
Thickness of current source zone (m)	5	Assumed maximum thickness of residually impacted sands that may remain post-remediation

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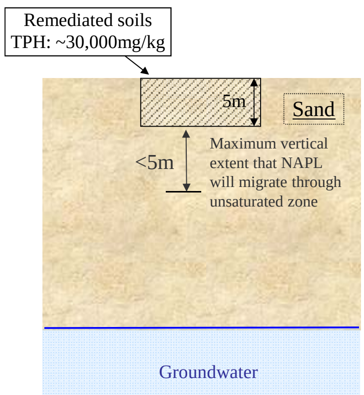
Case study 2: input & results

Parameter	Value	Justification
Porosity of soil sample (-)	0.37	Calculated utilising site specific moisture content, particle and soil density values obtained for sand materials
Soil bulk density (g/cm^3)	1.67	Site specific data for sands
NAPL density (g/cm^3)	0.9165	Laboratory data
Soil concentration in source area (mg/kg)	~30,000	Based on assumption that soils will be remediated to this remediation standard
Total thickness of unsaturated zone material that NAPL will spread through before it reaches equilibrium (mbgl)	**<10m**	Calculated. Note: Considering that the source thickness is assumed to extend to 5mbgl, this total thickness equates to <5m below the base of the original source zone that was 5m thick

Case study 2: result

- the remediated soil thickness could be present at depth or at the surface provided that at least 5m 'clean' unsaturated sand is present below the base of the remediated soil

- risk to groundwater from dissolved phase then modelled conventionally



Conclusions

- A spreadsheet tool has been developed to help carry out scoping calculations for fate and transport of NAPL
- Successfully used on 2 projects and counting…

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