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Secondary Source Zones: Towards an understanding of contaminant rebound

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Contaminant Source Zone Characterisation and Remediation, The Hydrogeology Group of the The Geological Society, University of Sheffield, 22nd April 2009

Introduction

What is a Secondary Source Zone?

A low permeability deposit into which dissolved- or NAPL-phase mass has migrated, either over a diffusion gradient or via NAPL transport through preferential flow paths.

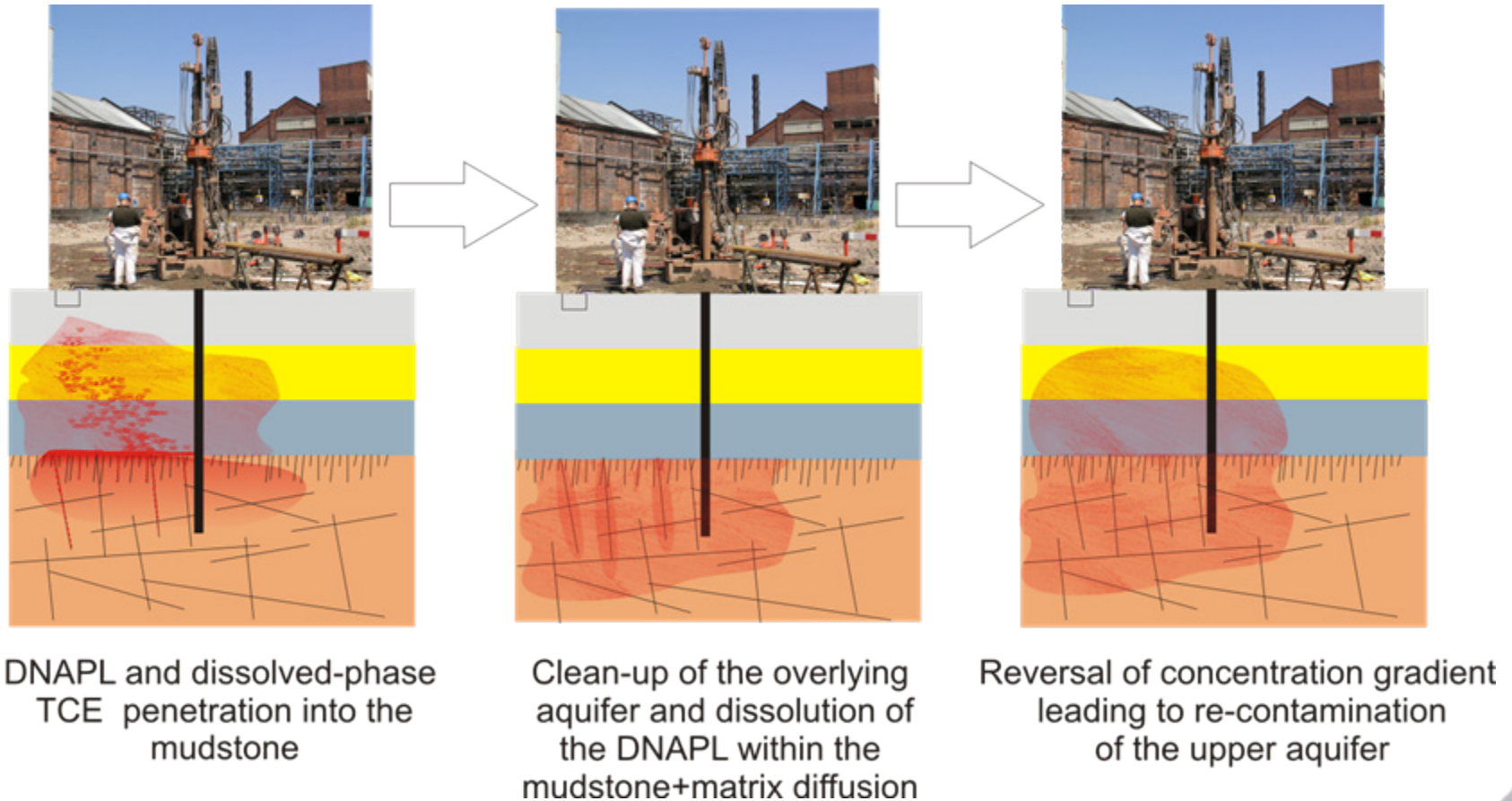
Of interest because?

Following remediation of the adjacent aquifer, diffusion gradients are reversed prompting mass transport from the low K deposit back into that adjacent aquifer.

Causing?

Prolonged contaminant tailing in the adjacent aquifer and hence increased remediation periods and costs

Secondary Source Issue



Aim and objectives

- To determine the ability of the Mercia mudstone to act as a secondary source zone
 - Collect TCE depth profiles in the Mercia mudstone underlying the Sabre research site
 - Quantify the physical properties of the Mercia mudstone
 - Deduce possible inward TCE migration processes
 - Investigate the mudstone characteristics which influence mass removal flux

Study site/geology



Study site:

Sabre site

TCE release period:

1963-1990

Mass of release:

~1000 kg



MDGR

ALL

RTG

MDST

General geology

Made ground

Alluvium

RTG

Weathered MDST

Unweathered MDST

Depth (m bgl)

0-1 m

1-3 m

3-6 m

6-7 m

7->30 m

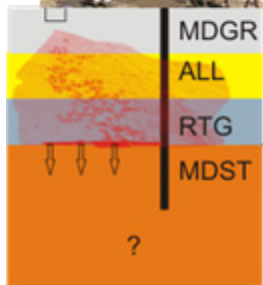
Weathered Mercia mudstone properties

- The upper ~1 m of Mercia mudstone varies from being partially to fully weathered. Hence near the RTG-MDST interface, mudstone may exhibit:
 - Matrix only – with little or no trace of original structure, exhibiting lower permeability than underlying layers (*Weathering classification IV*)
 - Matrix with some lithorelicts of 3-50 mm dia. (*Weathering classification III*)
- The extent of weathering at the mudstone surface is likely to influence transport of TCE (dissolved-phase or NAPL) into the formation

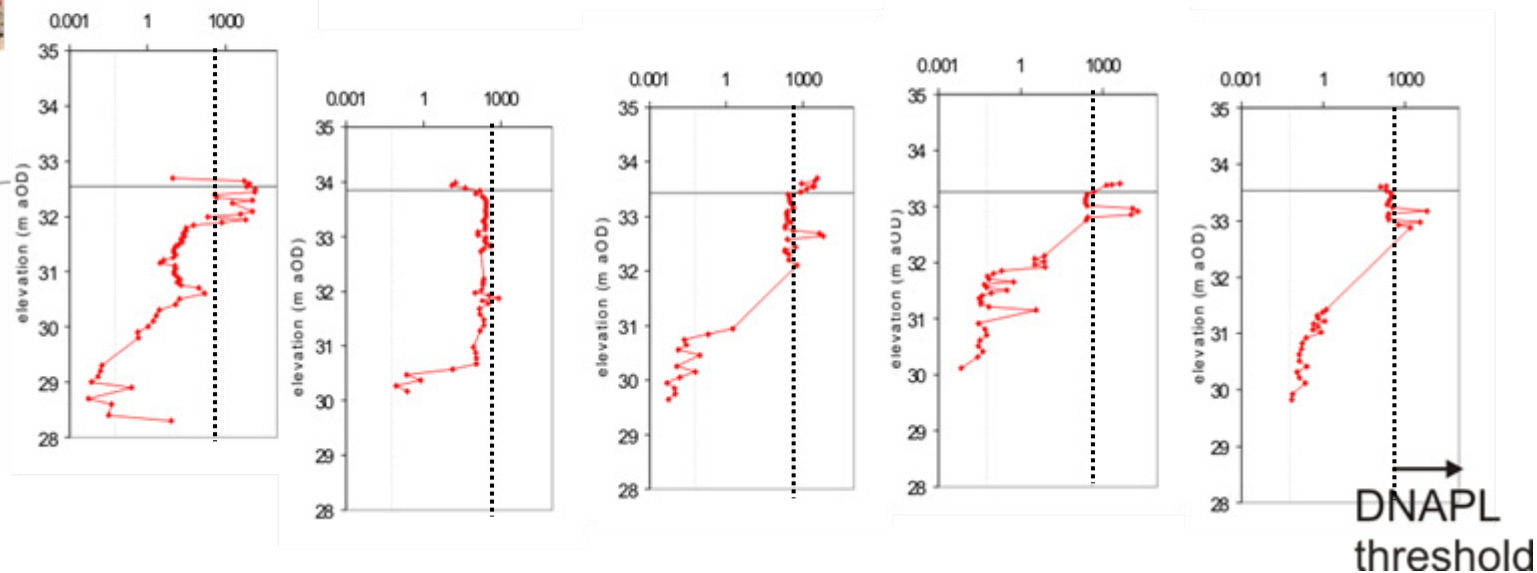
Unweathered Mercia mudstone properties

- Below ~2 m (from the RTG-MDST interface) the Mercia mudstone is classified as being partially weathered to unweathered. Hence mudstone may exhibit:
 - Interbedded sequences of mudstone/siltstone (*Weathering classification III/II*)
 - Angular blocks of unweathered mudstone (*Weathering classification II*)
 - Fissured mudstone (*Weathering classification I*)
- Mineralogy: Dolomite, gypsum and quartz
- Contains microfracturing: likely originating from 40% volume expansion associated with re-hydration of anhydrite to gypsum
- Fraction of organic carbon: Generally low <0.1

TCE profiles into mudstone



TCE concentration (mg/kg)



Mass of TCE (kg/m ³)	1.38	0.30	0.58	1.57	0.53
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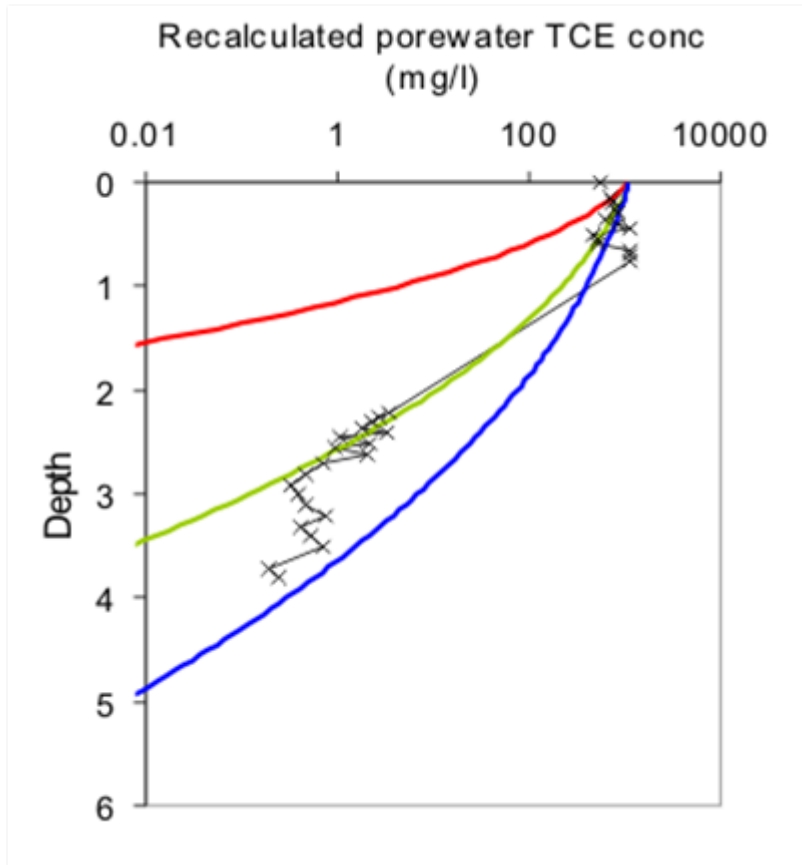
- TCE DNAPL present
- Different types of profile...



Inward migration processes I

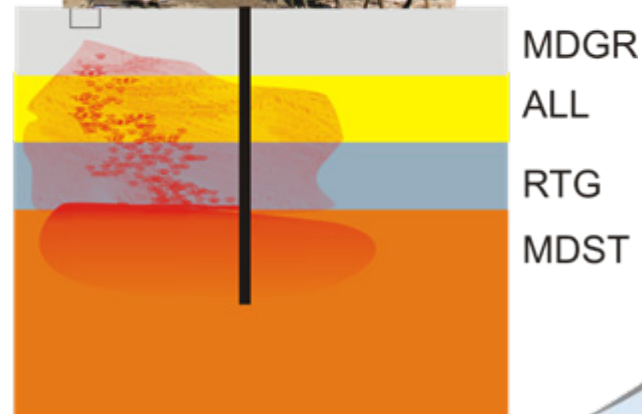
Model: Fractran (aqueous phase, 2-D transport model)

Sparse dataset, but perhaps diffusion?

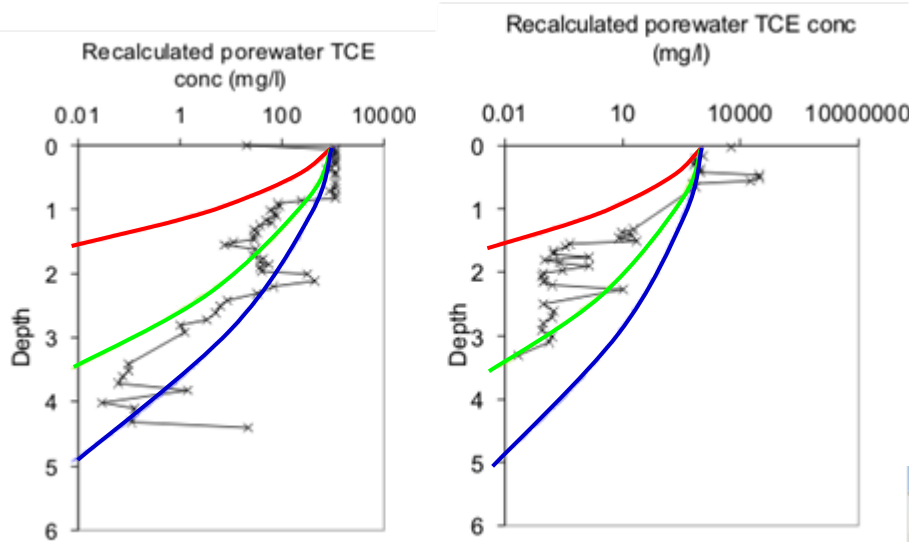


Effective diffusion coefficient

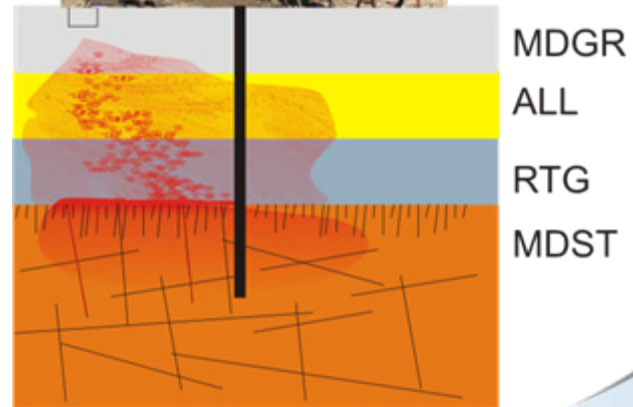
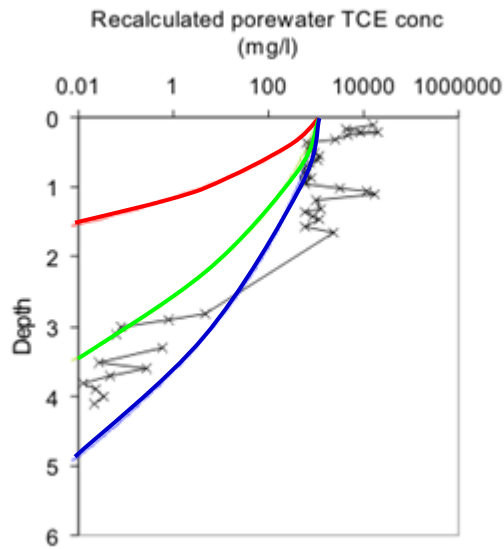
- 1e-10 m²/s
- 5e-10 m²/s
- 1e-9 m²/s



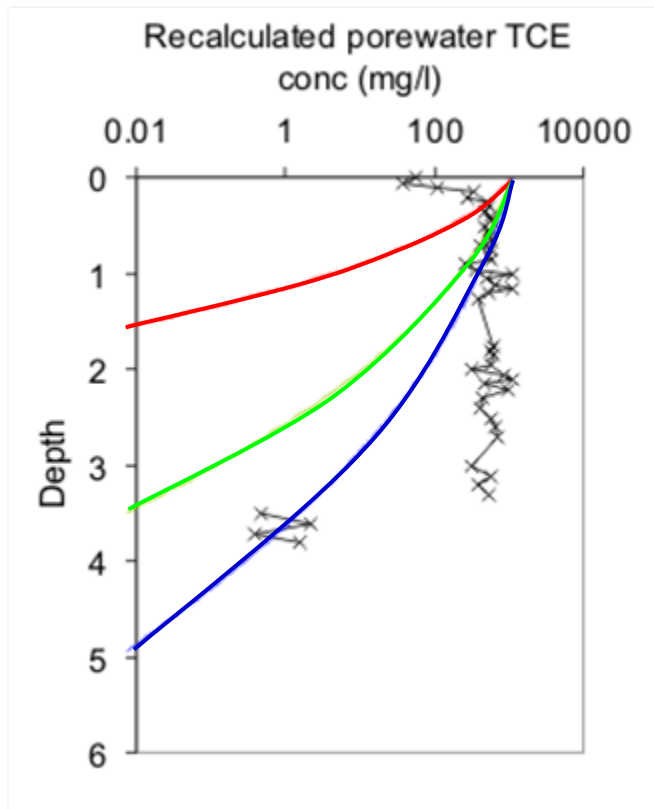
Inward migration processes II



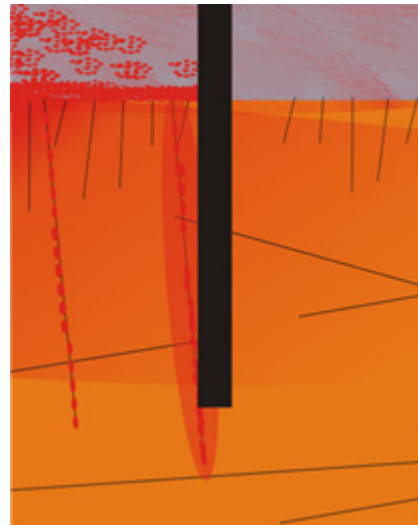
Diffusion profile intersected by DNAPL-containing fractures?



Inward migration processes III

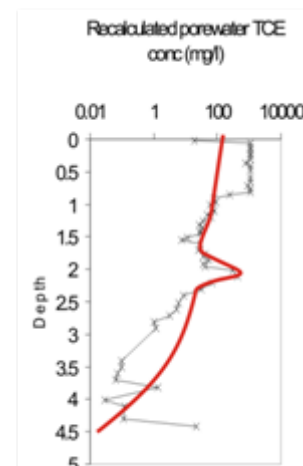
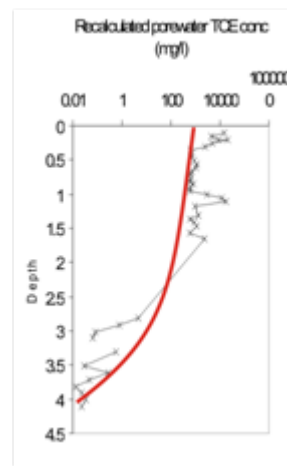
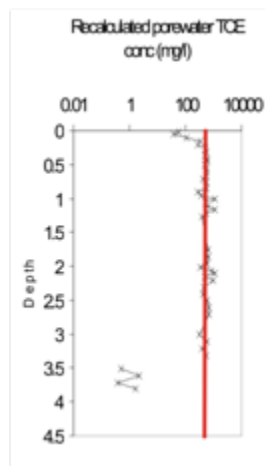


Not diffusion... Profile adjacent to a DNAPL containing fracture?



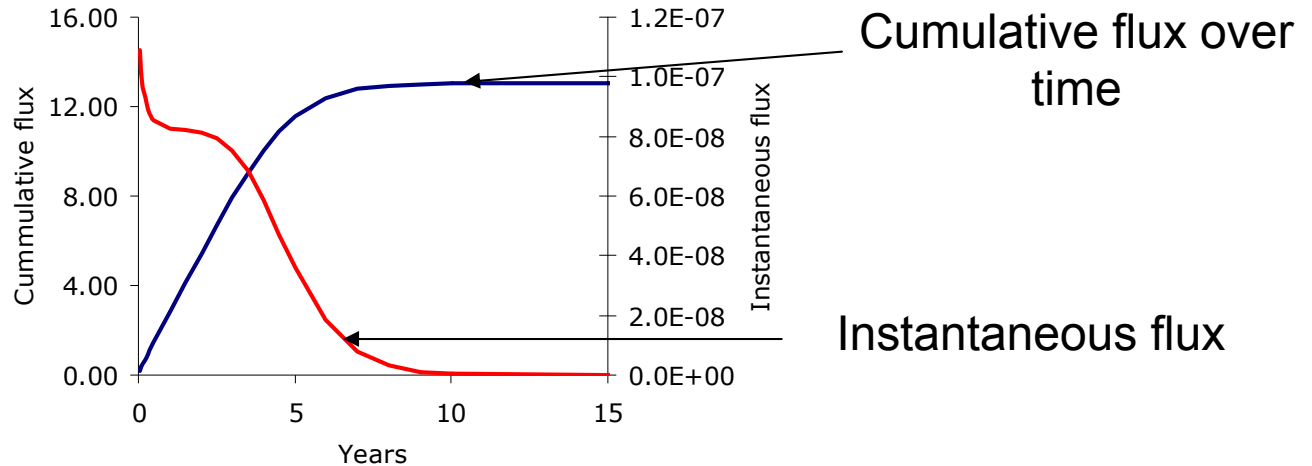
Mass Removal Simulations

- Model: Fractran (Uni. Of Waterloo)
- Parameters: Site specific where possible
- Assumes upward hydraulic gradient of 0.02
- Assumes all DNAPL above and within the mudstone has dissolved
- Three initial concentration distribution scenarios
 - Constant concentration profile
 - Diffusion profile
 - Diffusion profile with high concentration peaks
- Three fractured mudstone scenarios

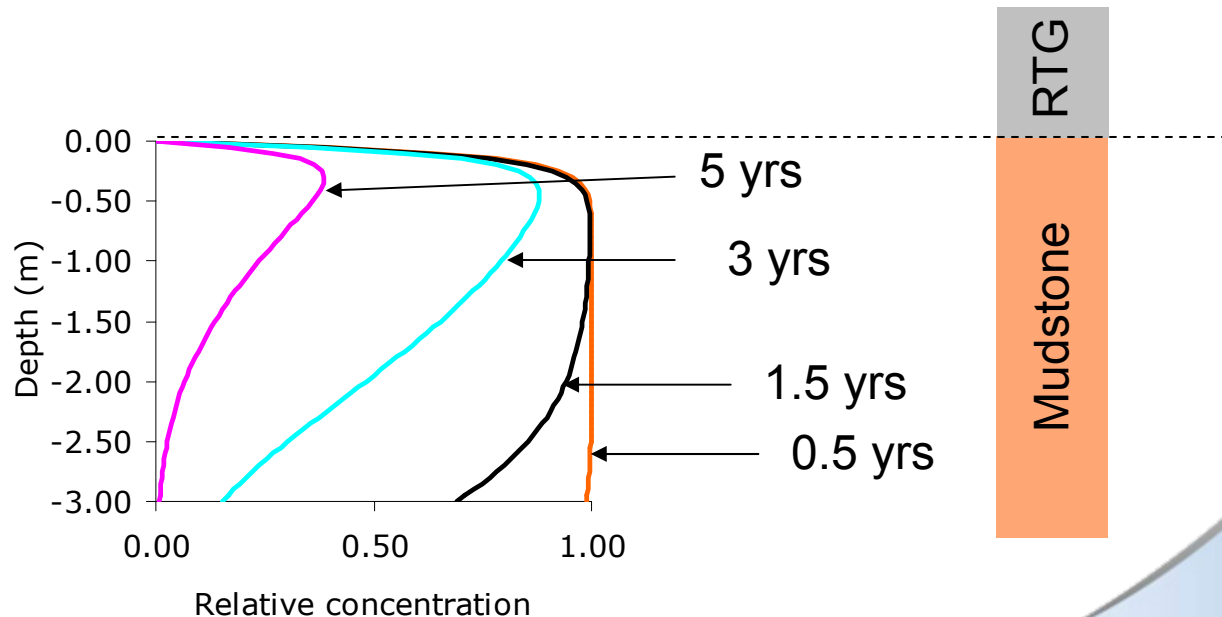


Outward mass transport diagrams

Fluxes

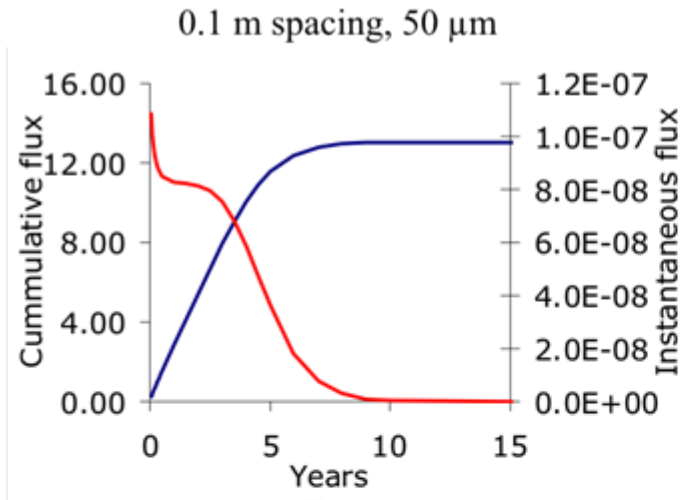
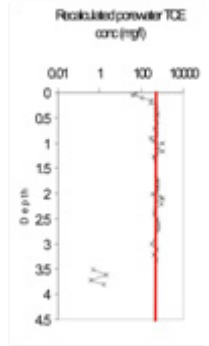


Concentration profile over time

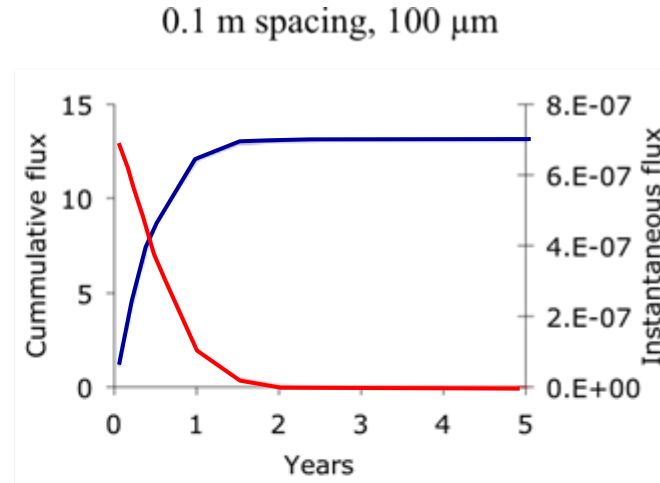


Mass removal fluxes I

Initial concentration profile: constant concentration over 4 m

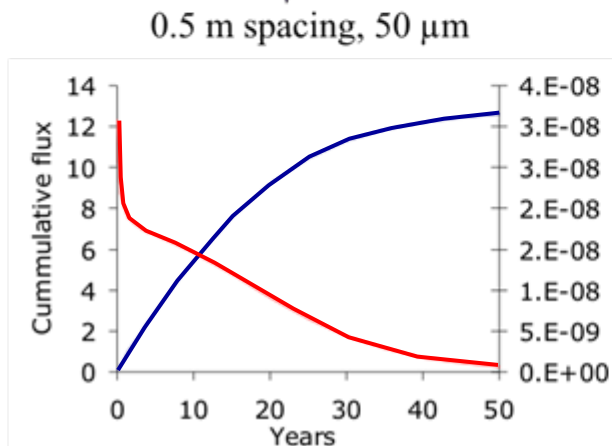


Increase aperture \rightarrow



- Higher ins. flux at early time
- Flux lowers to ~ 0 after ~ 2 yrs

Increase spacing \downarrow

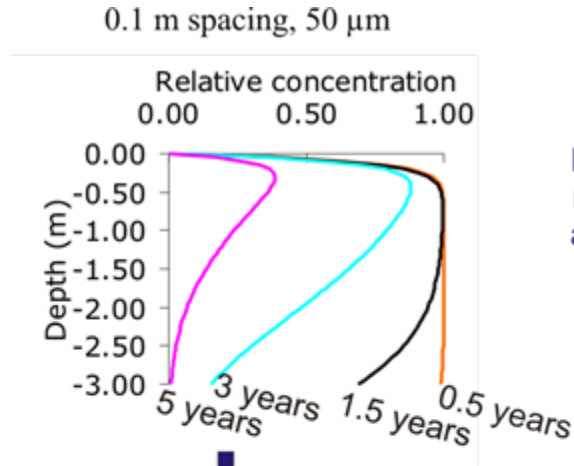
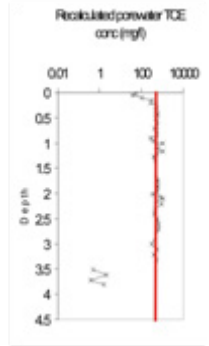


- Lower ins. flux at early time
- Flux lowers to ~ 0 after ~ 50 yrs

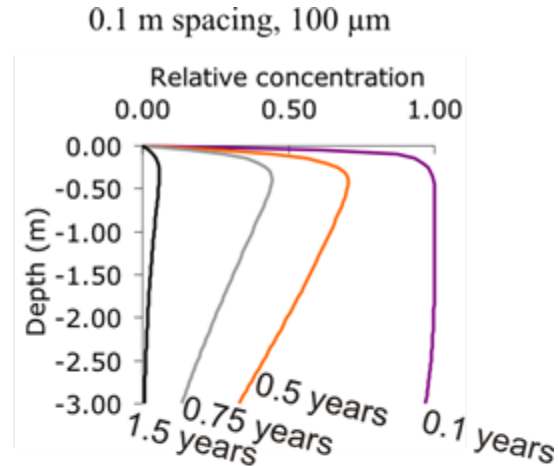
— Instantaneous flux
— Cumulative flux

Mass removal profiles I

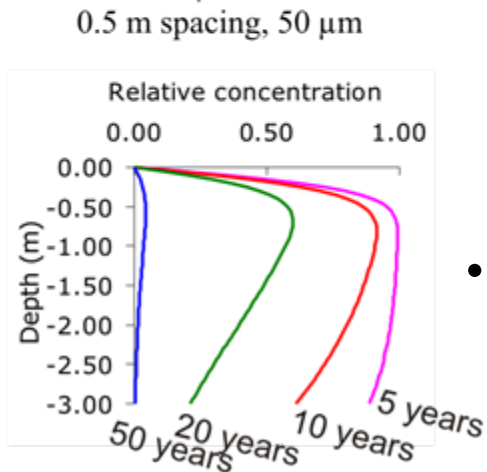
Initial concentration profile: constant concentration over 4 m



Increase
→ aperture



Increase
↓ spacing

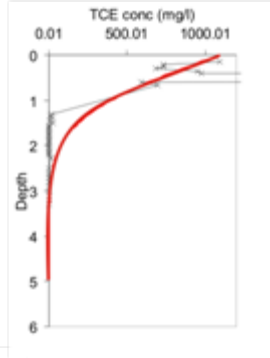


- Low concentrations at 1.5 yrs

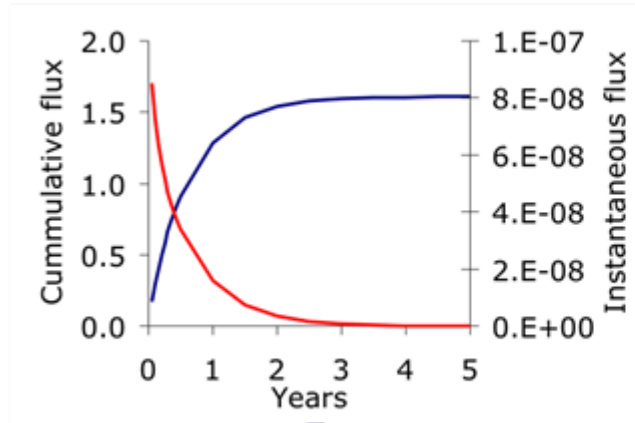
- Low concentrations at 50 yrs

Mass removal fluxes II

Initial concentration profile: diffusion profile

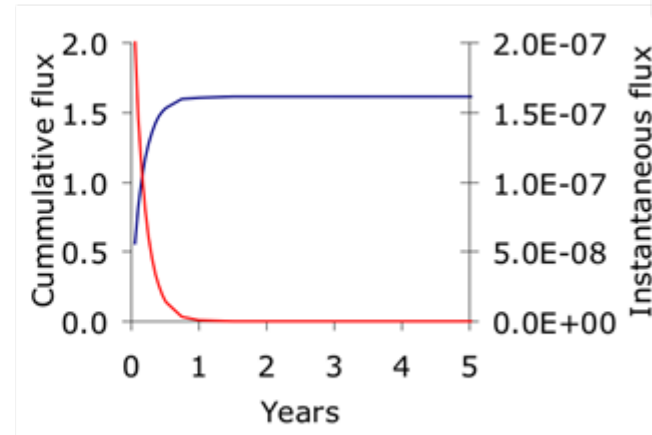


0.1 m spacing, 50 μm



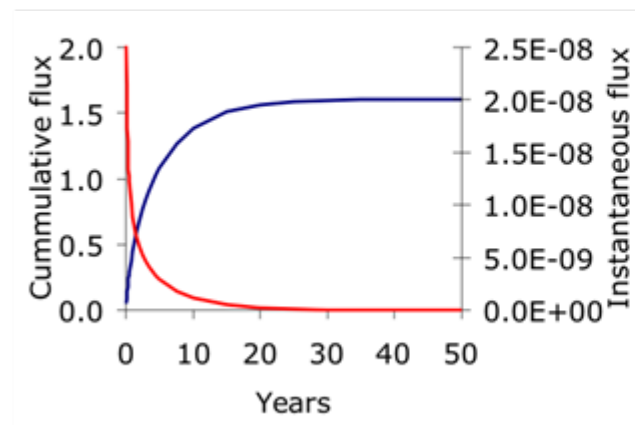
Increase aperture \rightarrow

0.1 m spacing, 100 μm



Increase spacing \downarrow

0.5 m spacing, 50 μm

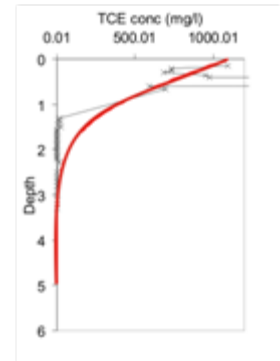


- Higher ins. flux at early time
- Flux lowers to ~ 0 after ~ 1 yrs

- Lower ins. flux at early time
- Flux lowers to ~ 0 after ~ 15 yrs

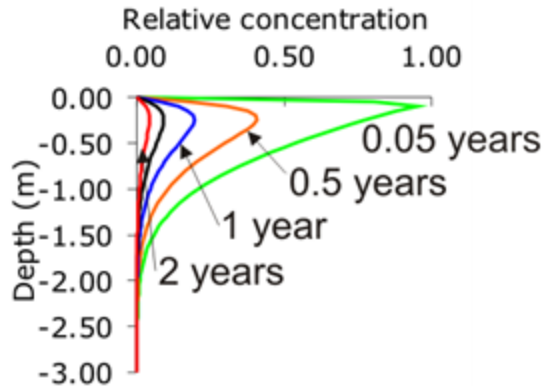
— Instantaneous flux
— Cumulative flux

Mass removal profiles II



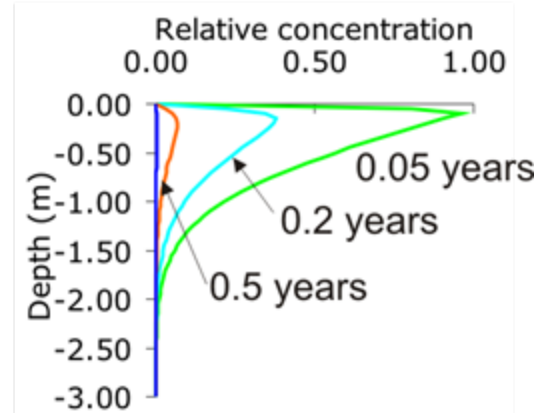
Initial concentration profile: diffusion profile

0.1 m spacing, 50 μm



Increase
aperture

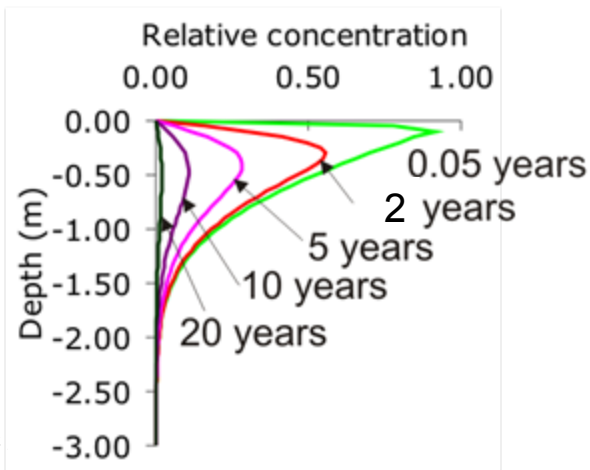
0.1 m spacing, 100 μm



- Low concentrations at ~1 yr

Increase
spacing

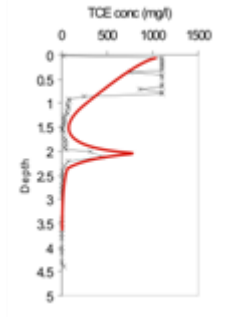
0.5 m spacing, 50 μm



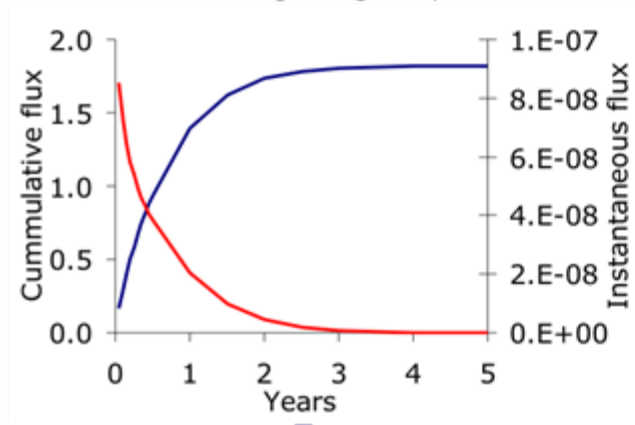
- Low concentrations at ~20 yrs

Mass removal fluxes III

Initial concentration profile: diffusion profile with peak

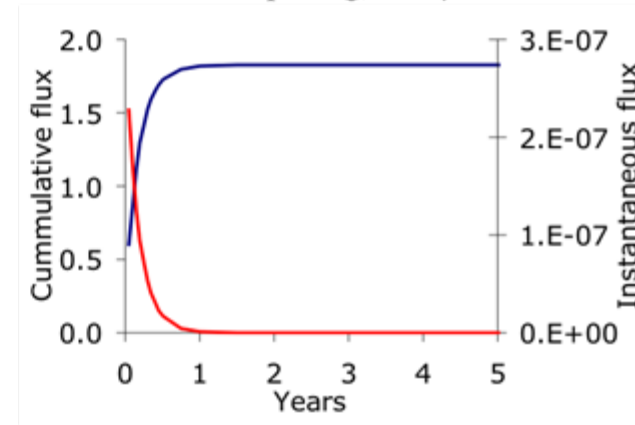


0.1 m spacing, 50 μm



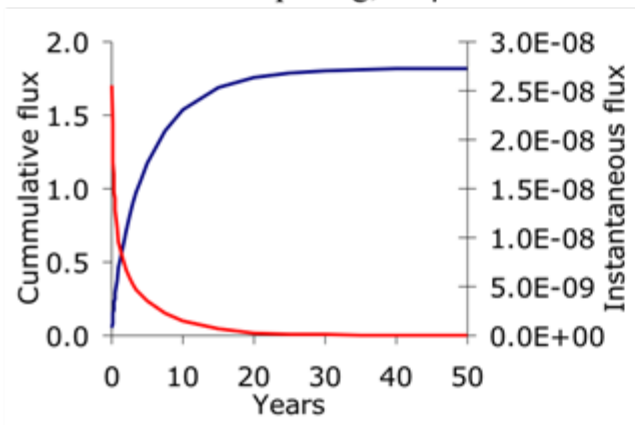
Increase aperture \rightarrow

0.1 m spacing, 100 μm



Increase spacing \downarrow

0.5 m spacing, 50 μm



- Higher ins. flux at early time
- Flux lowers to ~ 0 at < 1 yr

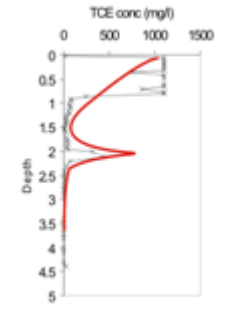
- Lower ins. flux at early time
- Flux lowers to ~ 0 after ~ 20 years

— Instantaneous flux

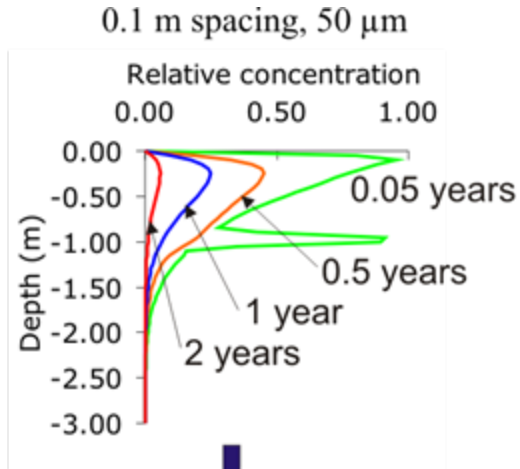
— Cumulative flux



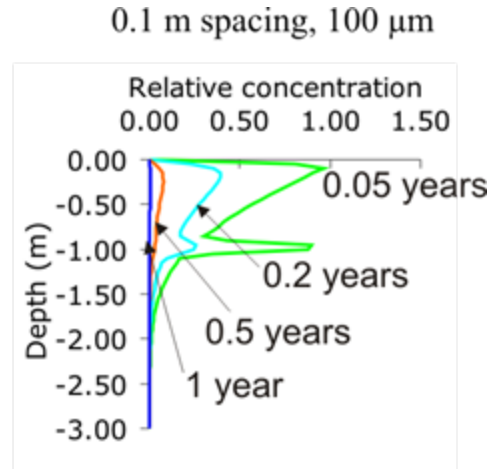
Mass removal profiles III



Initial concentration profile: diffusion profile with peak

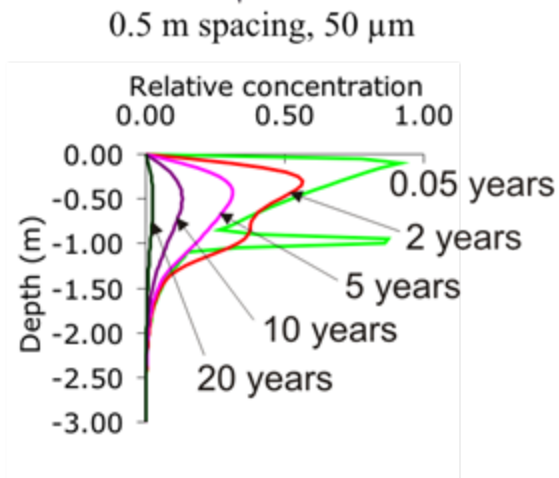


Increase aperture



- Low concentrations at ~1 yr

Increase spacing



- Low concentrations at ~20 yrs

Expected concentrations in the RTG

- Following reversal of concentration gradients, what TCE concentration will be in the RTG?

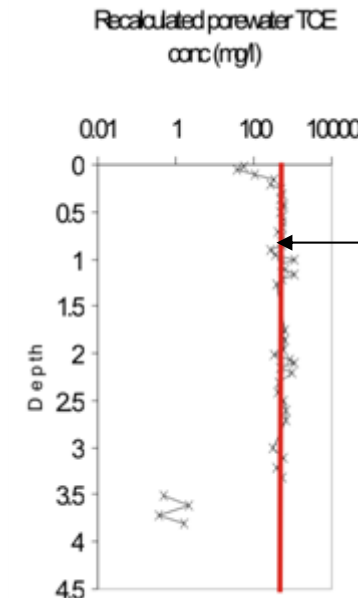
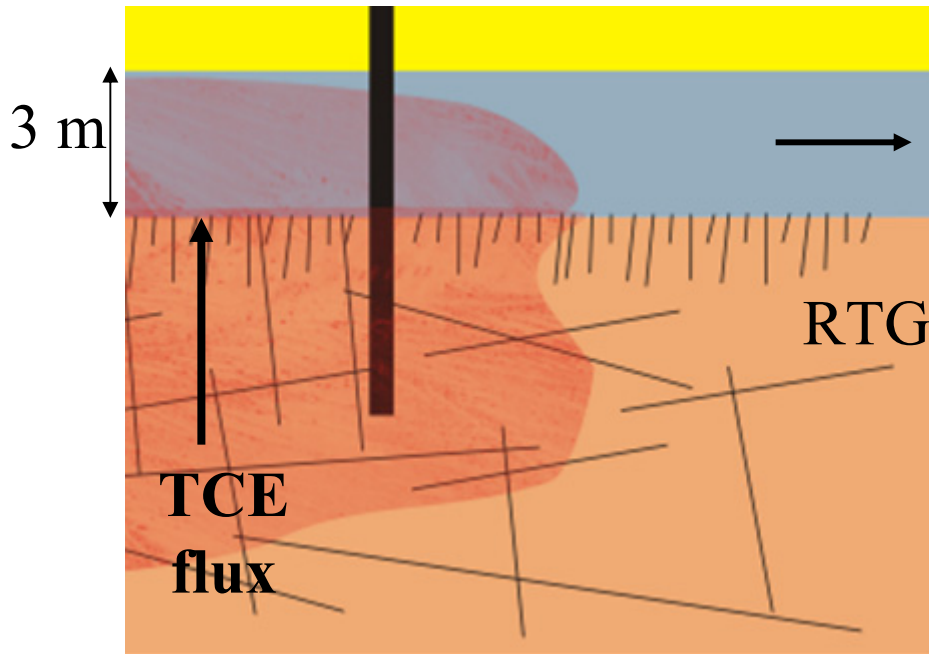
- e.g.. using a constant concentration profile, at 553 mg/l

$$Conc_{RTG} = \frac{Flux_{MDST-RTG}}{Q_{RTG}}$$

RTG, $i = 0.0017$

RTG, $K = 3 \text{ m/d}$

RTG thickness = 3 m



553 mg/l

Expected concentrations in the RTG

Concentration in porewater in profile: 553 mg/l

Concentration profile type: Constant with depth

Fracture spacing (m)			
Diffusion only	0.5	0.1	0.1
Fracture aperture (μm)			
Diffusion only	50	50	100
Concentration in upper aquifer vs. time			
Concs at 1 mg/l after 50 years, but likely to continue long term	Slowly declining concs, still at 1 mg/l after 50 years	Concs <DWS after 15 years	High concs near solubility declining to <DWS in 3.5 years



DWS: 10 ug/l

Conclusions

- The total mass in mudstone underlying a contaminated site is dependent on the contaminant migration process causing inward transport
- The magnitude and time period of mass removal flux from the Mercia mudstone is highly sensitive to both fracture aperture and spacing – hence influenced by the degree of weathering at the mudstone surface
- The occurrence of fractures within the mudstone will cause increased concentrations in the receiving aquifer at early times, however will decrease the overall mass removal time period