Improved Approaches for Performance Assessment Monitoring of Contaminant Source Zones

Ryan Wilson and Zuansi Cai
University of Sheffield

Geological Society, Hydrogeology Group
Contaminant Source Zone Characterisation and Remediation
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Remediation monitoring

- Historically, asking “simple” questions:
  - is treatment working?
  - is risk reduced?
  - when can it be shut off?

- Clients simply ask:
  - are we there yet?

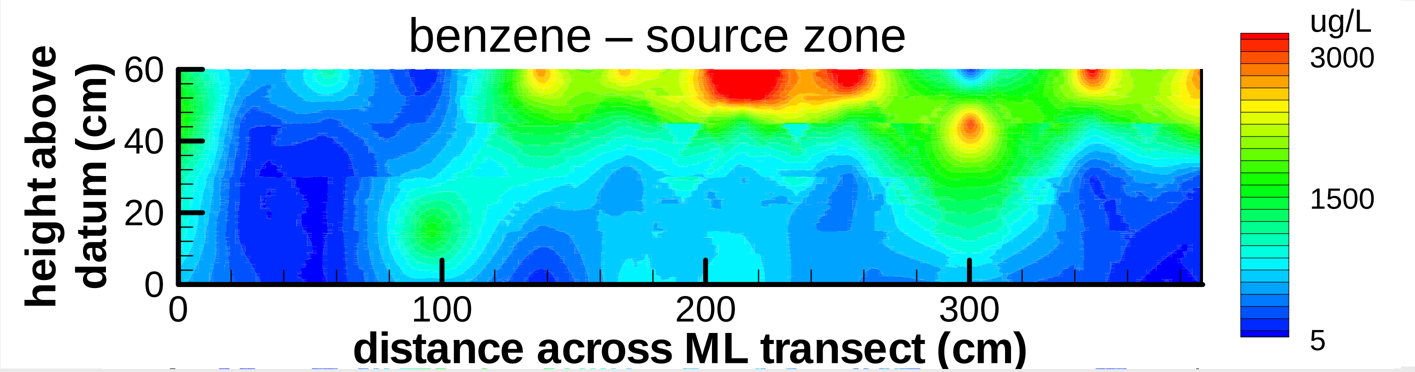
Increasing interest in robust performance assessment

- Asking more challenging questions:
  - **why** is treatment working?
  - **why** is treatment not working?
  - are key processes **sustainable**?
  - is sufficient mass reduced?
  - what do concentrations mean?
  - **how accurate** are performance estimates?



Source zone characteristics

- Spatially complex hydrogeology
  - complex NAPL mass distribution
  - complex dissolved plume architecture
- High concentration gradients
  - NAPL dissolution is pore scale process
- Spatially discrete demands on treatment systems

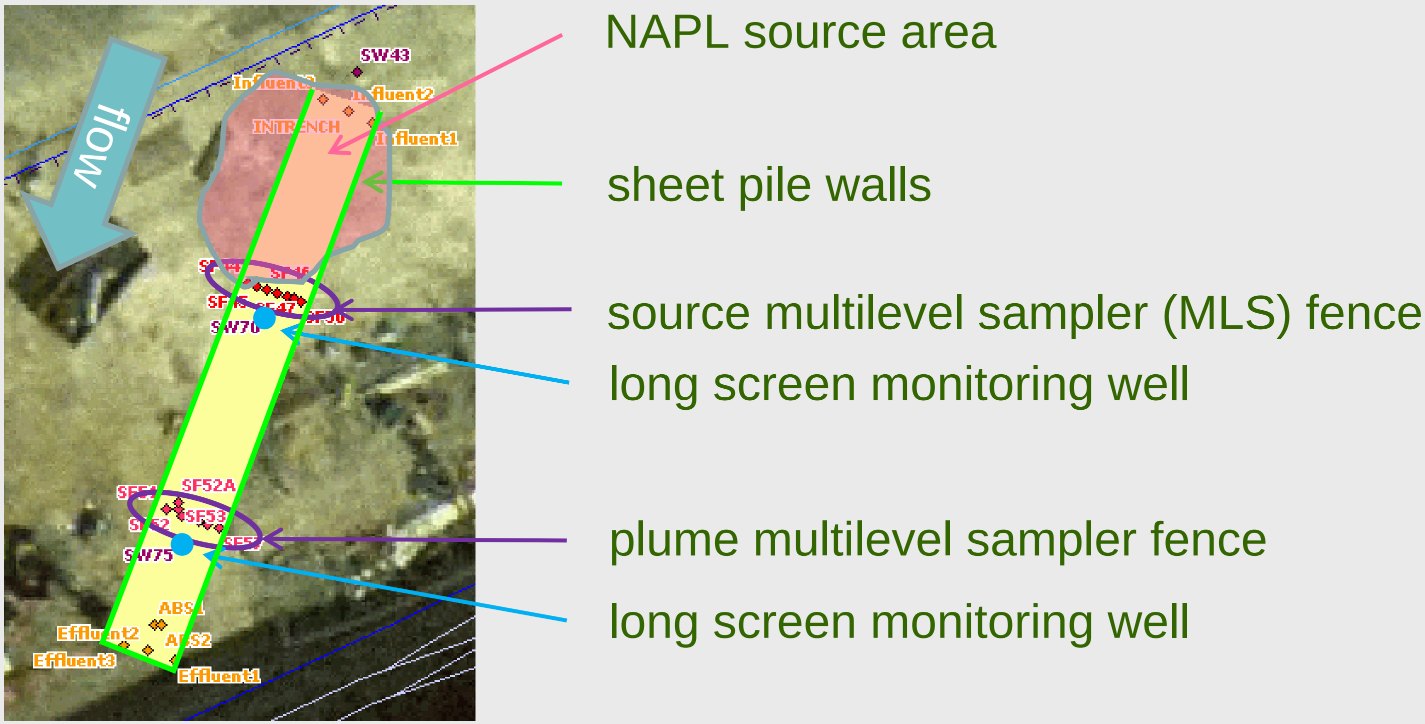


PA metrics for source zones

- Start/end **mass difference**
  - core extractions, PITTs
- Primary and secondary chemistry
  - concentrations at control points
  - remedial process resolution
- Spatial concentration distributions
  - **mass flux** changes
  - **spatial process resolution**

Example: biostimulation/bioaugmentation of chlorinated solvent NAPL source (SABRE)

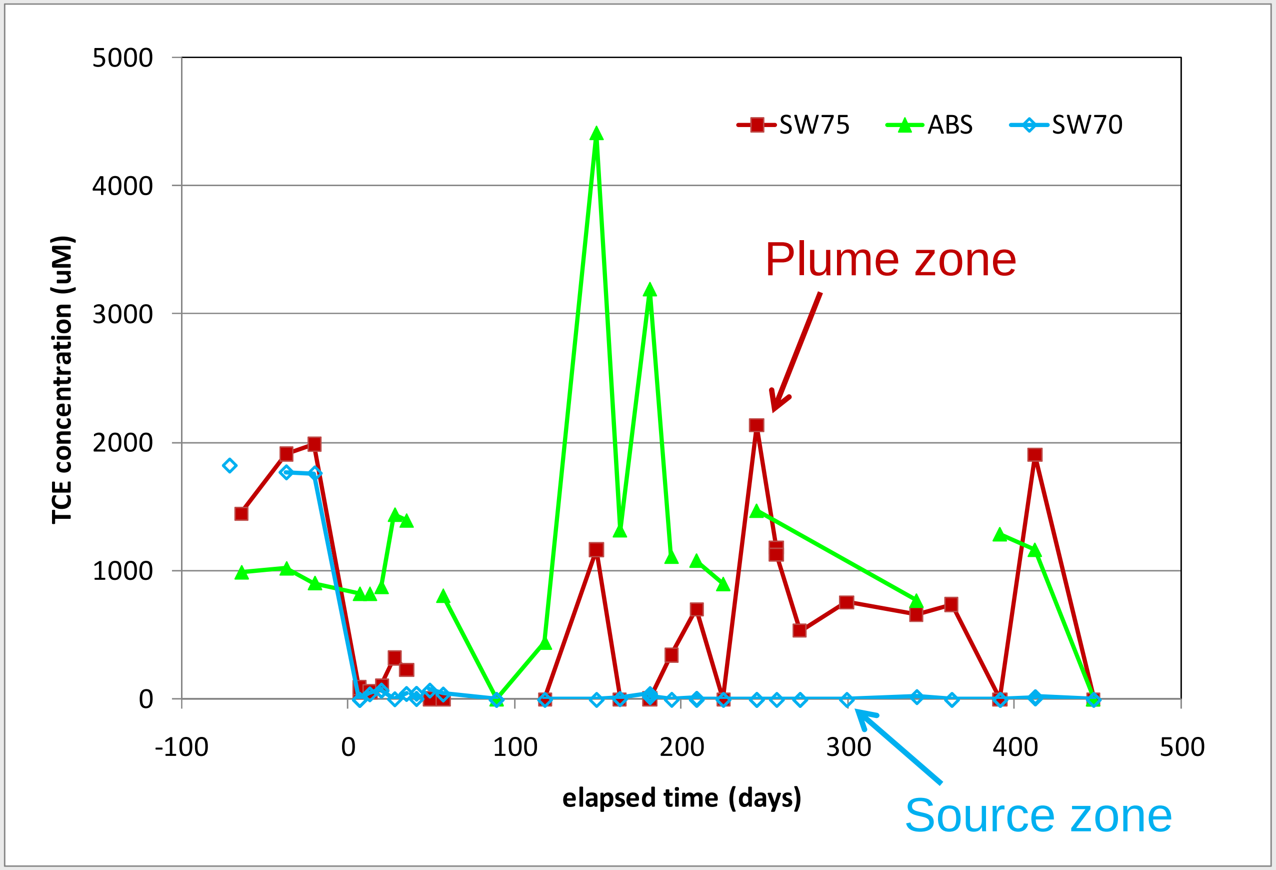
- controlled experiment in isolated portion of aquifer



Performance metrics

- **chemistry from long screen monitoring wells**
- **mass flux change between MLS fences**
- start/end NAPL mass balance
  - estimated from core samples

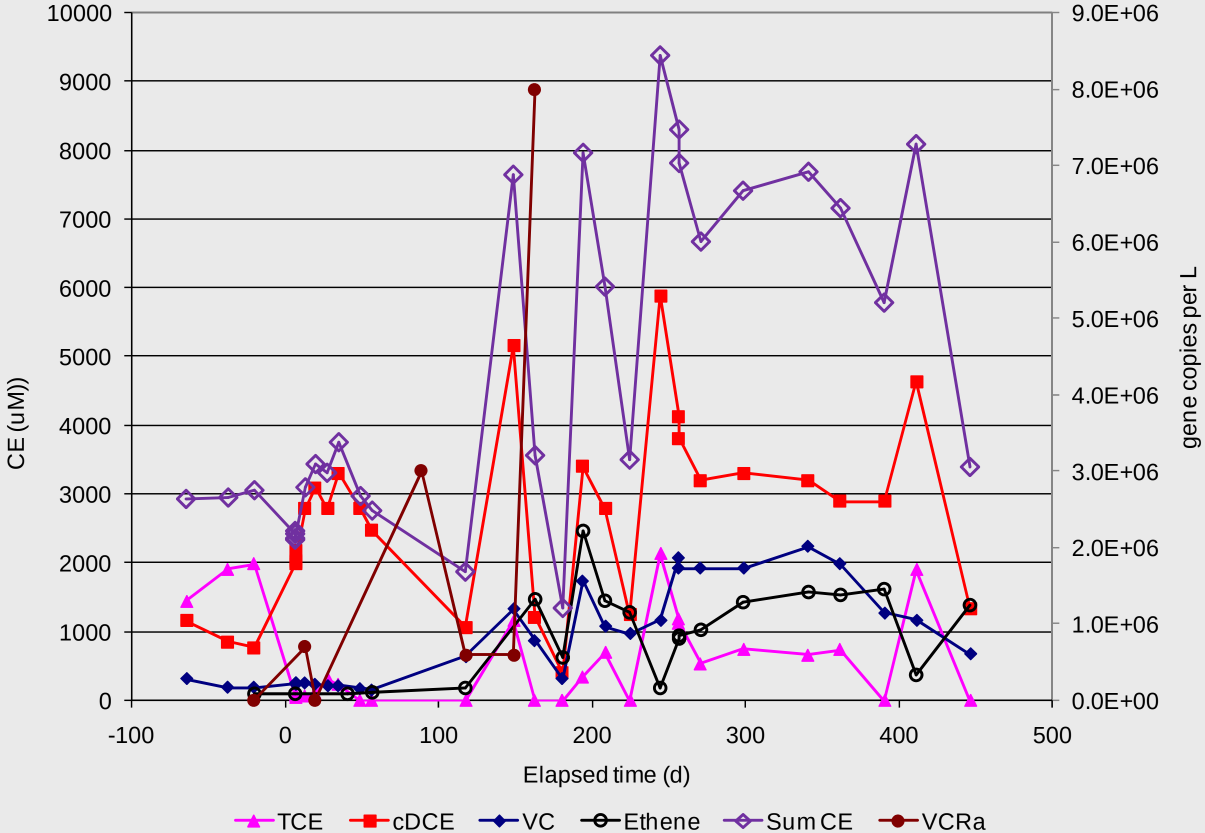
TCE in long screen monitoring wells and cell abstraction well



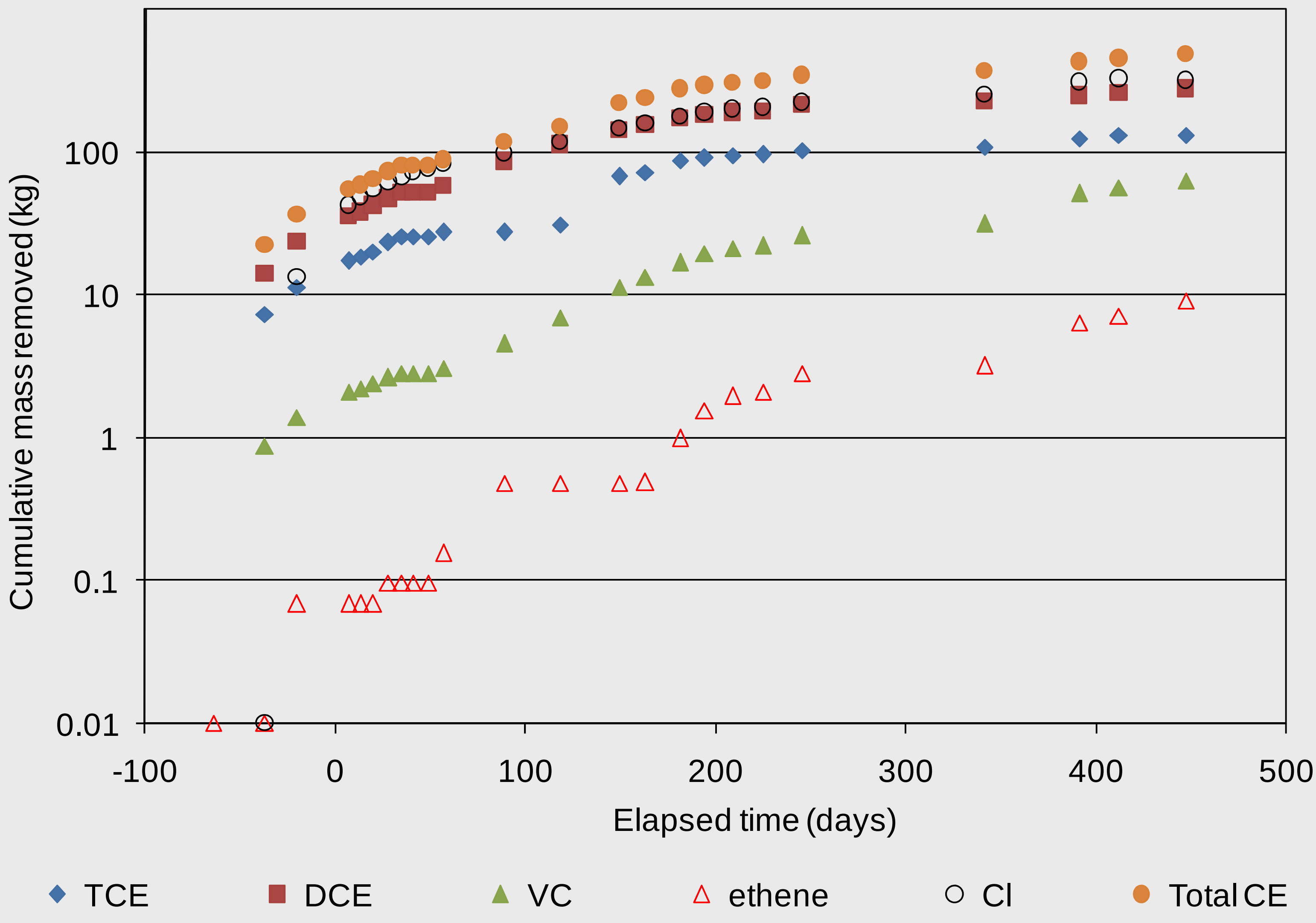
TCE in SW75, but not in SW70 – suggests each samples a different flow path

What do long screen MWs indicate?

- Considerable noise
- Temporal trends
- Indication of degradation processes

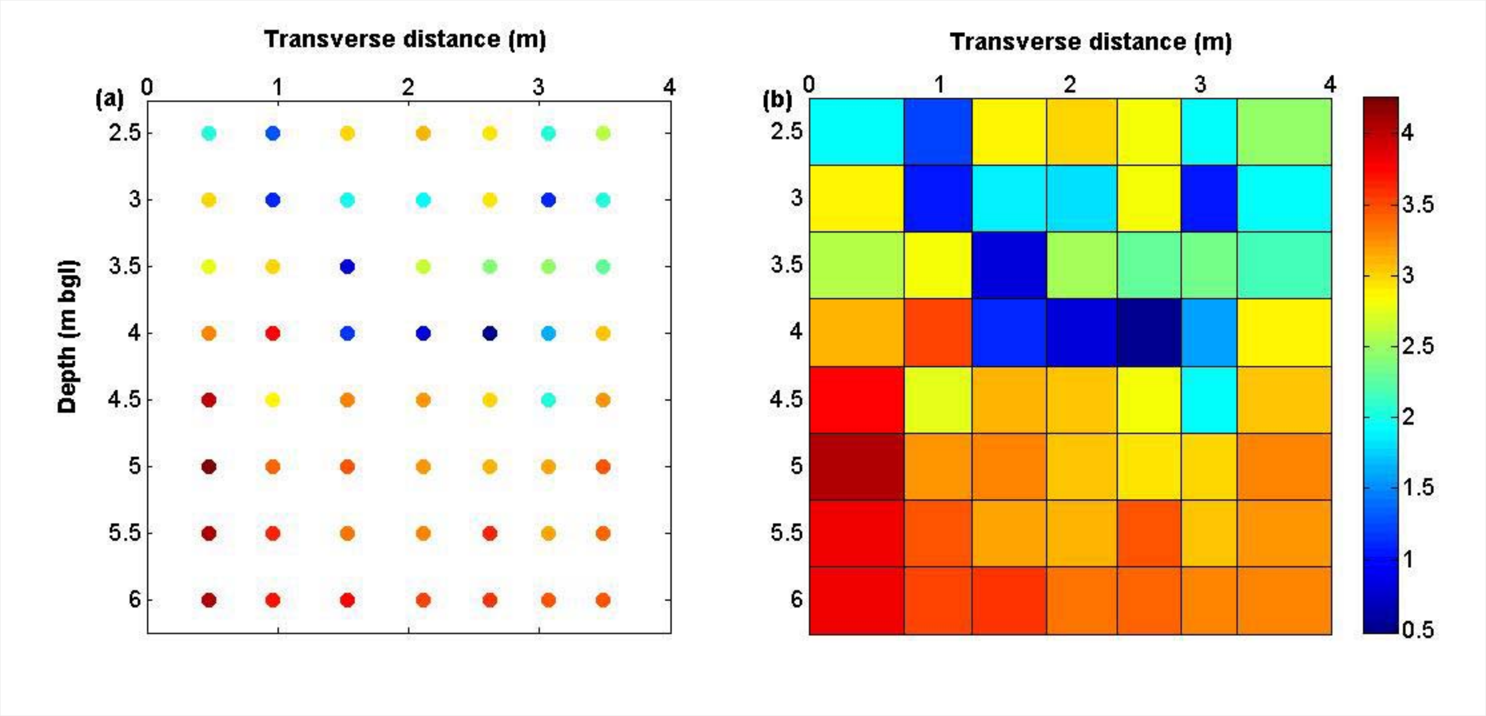


Total extracted mass from ABS



Mass flux estimation method I

- Simple: Theissen Polygon method

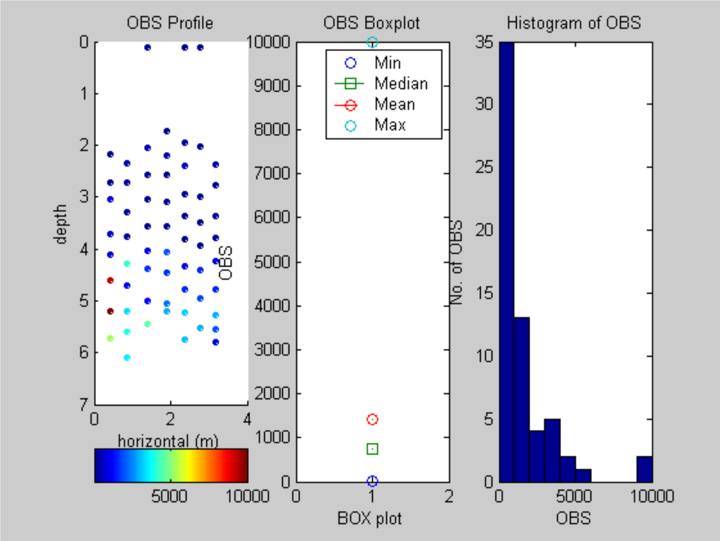


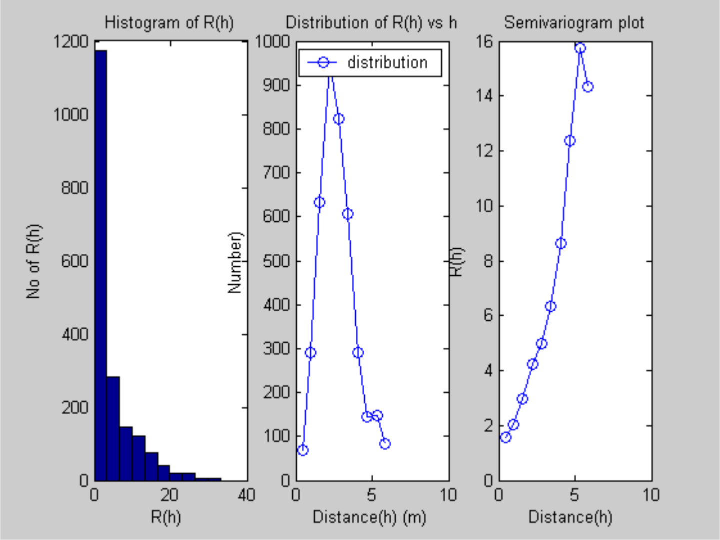
from hydraulic conductivity

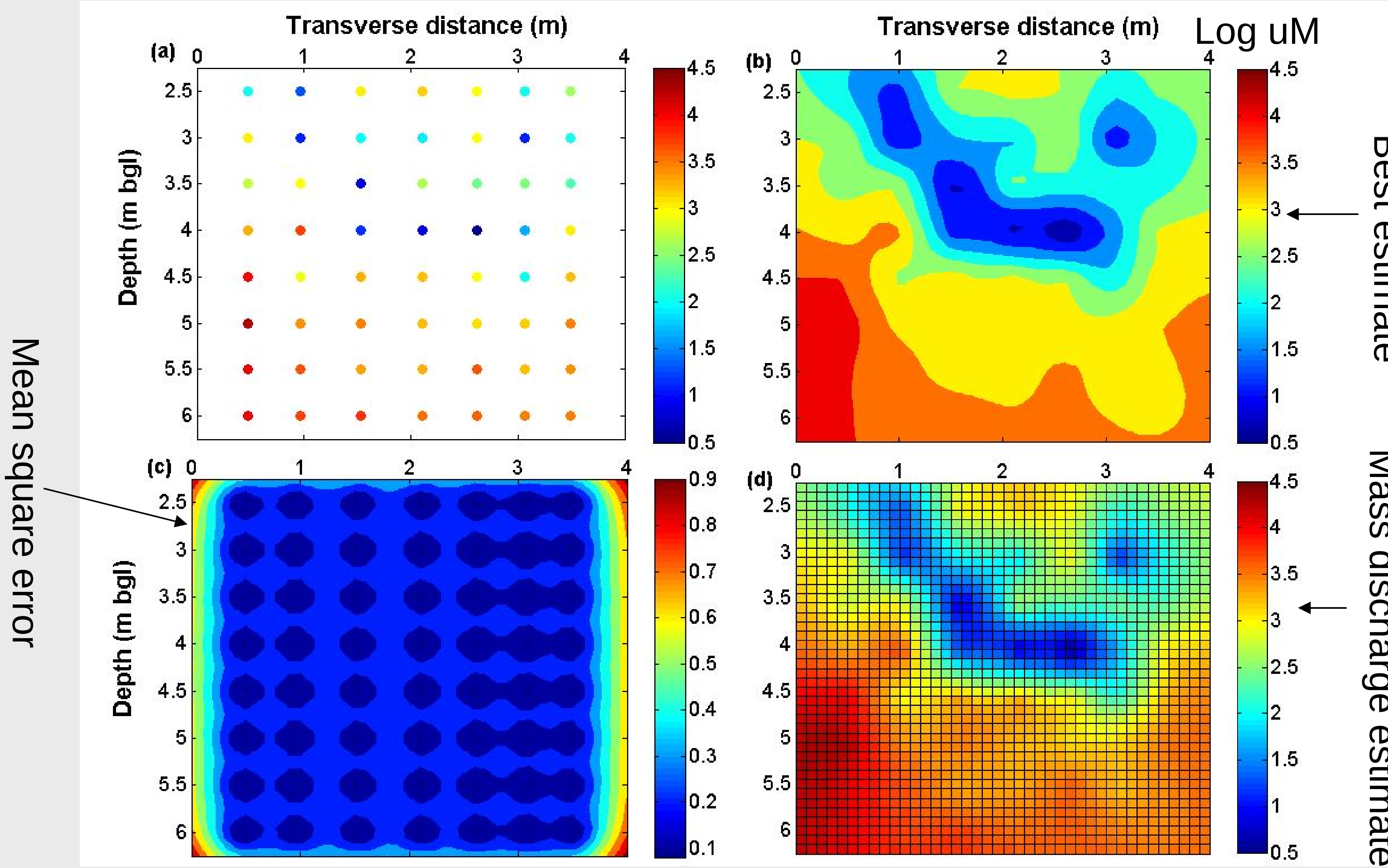
$$M_d = \sum_{i=1}^{N} M_{d,i} = \sum_{i=1}^{N} C_i q_i A_i = \sum_{i=1}^{N} C_i Q_i$$

Mass flux estimation method II

- Rigorous: geostatistical method
  - construct data histogram
  - analyse spatial data structure → semivariogram
  - use semivariogram to krig data
    - gives mean square error





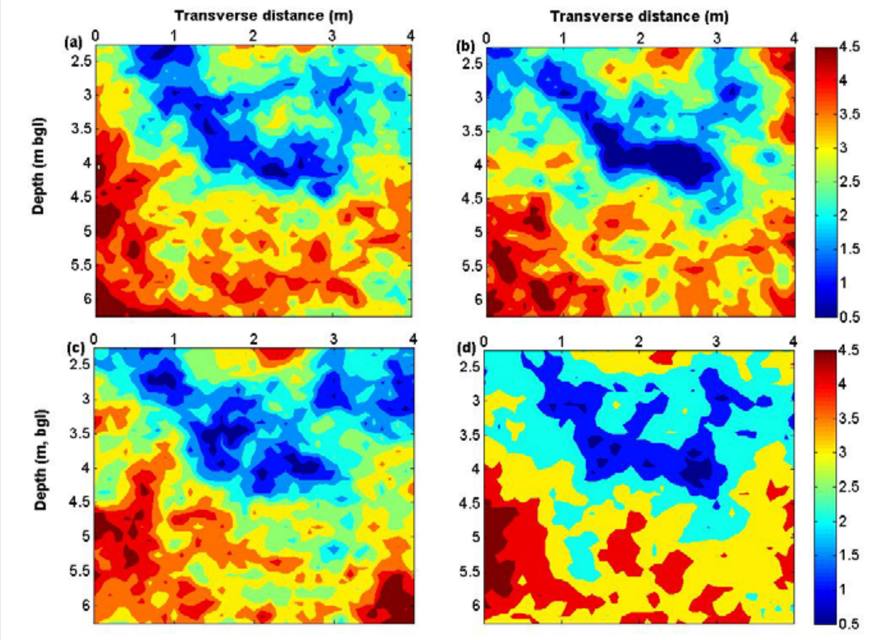


from hydraulic conductivity

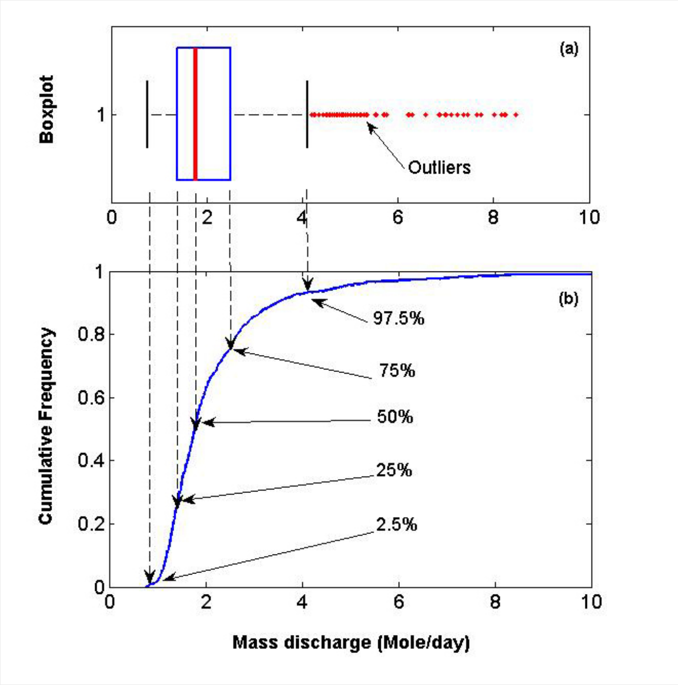
$$M_d = \sum_{j=1}^{M} M_{d,j} = \sum_{j=1}^{M} C_j q_j A_j = \sum_{j=1}^{M} C_j Q_j$$

M>>N (number of OBS)

- Use semivariogram statistics to perform conditional simulations (~1000) to generate uncertainty estimate

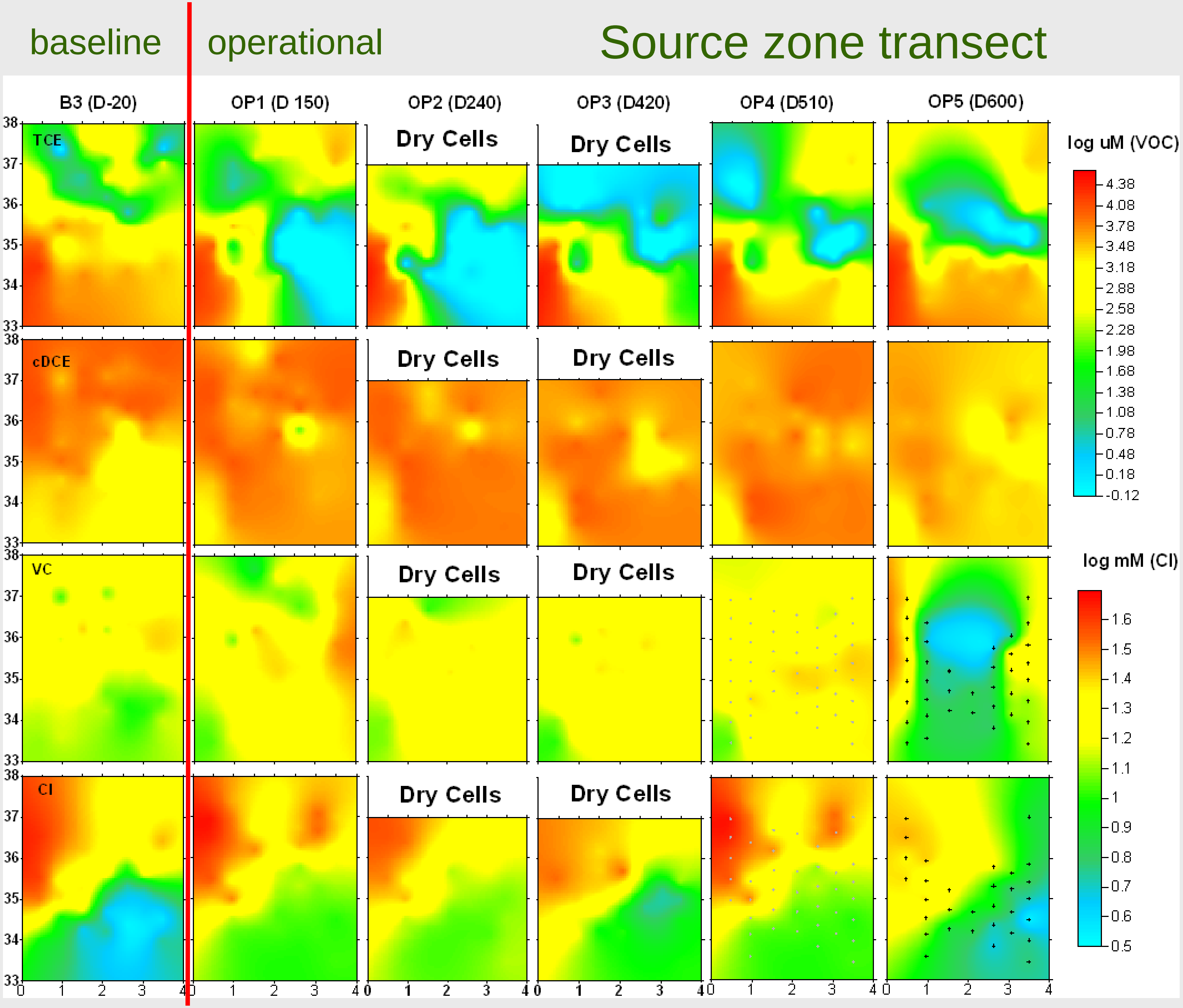


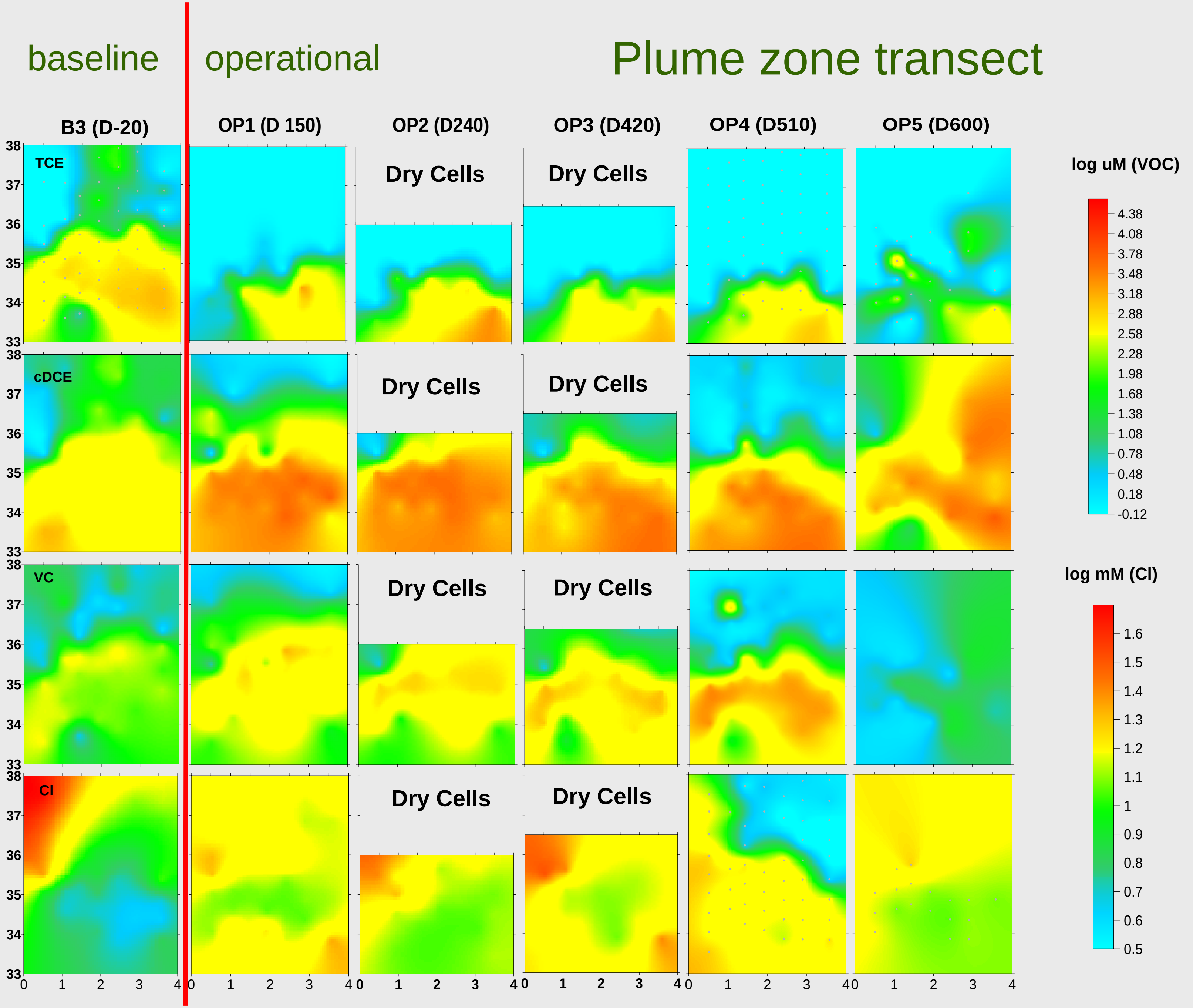
4 realisations of possible concentration profile from conditional simulation



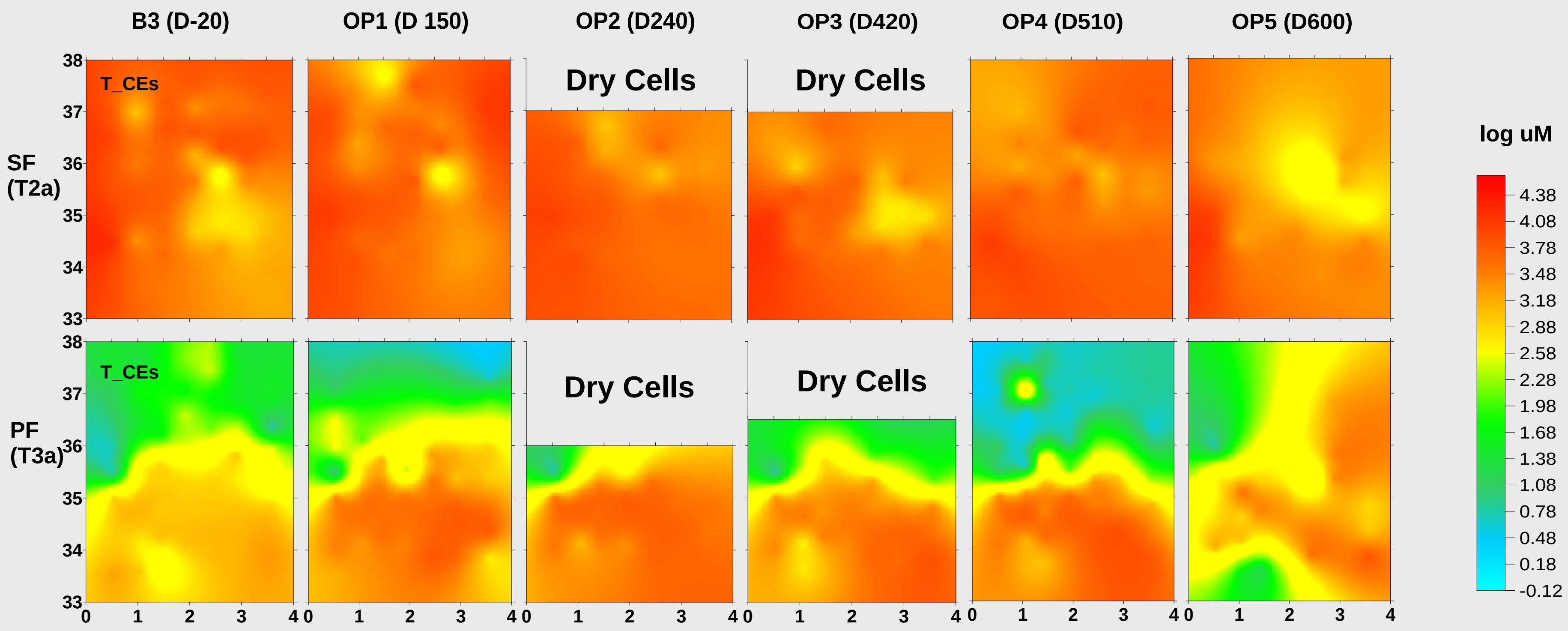
best mass flux estimate and confidence intervals

Source zone transect




baseline
operational
Plume zone transect
B3 (D-20)
OP1 (D 150)
OP2 (D240)
OP3 (D420)
OP4 (D510)
OP5 (D600)
TCE
cDCE
VC
Cl
Dry Cells
log uM (VOC)
4.38
4.08
3.78
3.48
3.18
2.88
2.58
2.28
1.98
1.68
1.38
1.08
0.78
0.48
0.18
-0.12
log mM (Cl)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
38
37
36
35
34
33
0
1
2
3
4

Total Chlorinated Ethenes

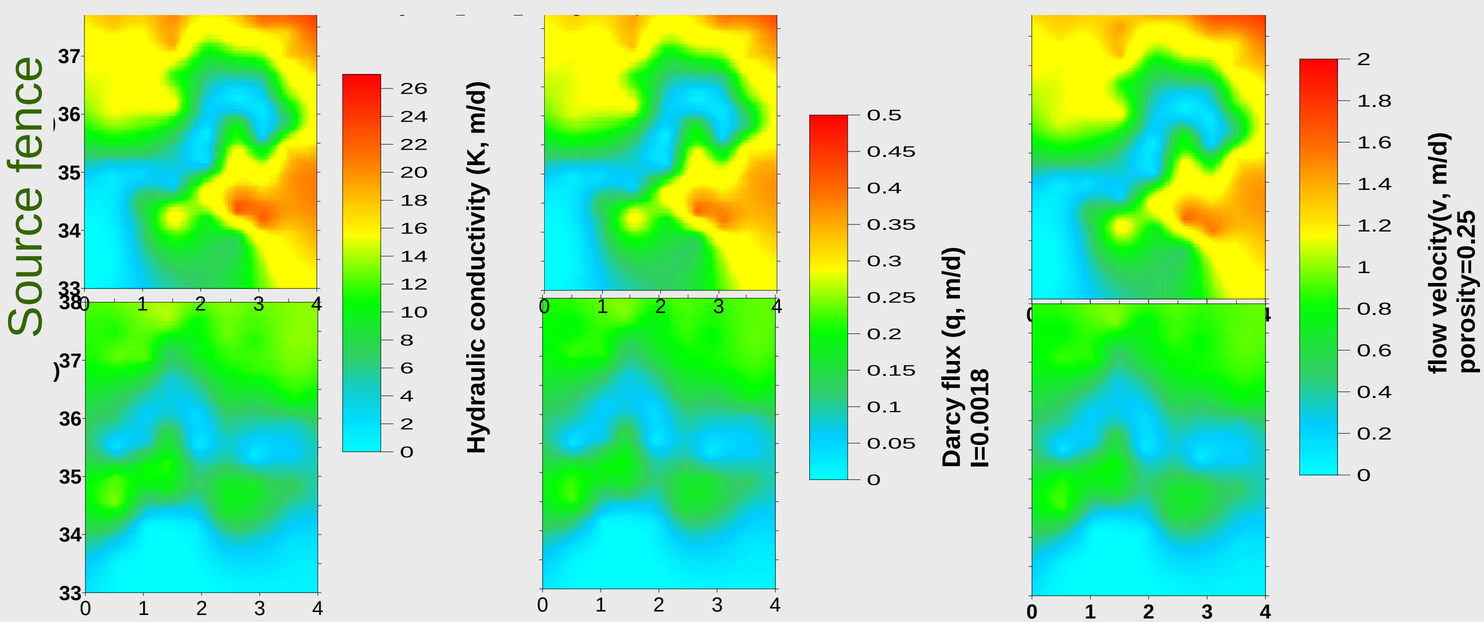


What about the q?

from hydraulic conductivity

$$M_d = \sum_{j=1}^{M} M_{d,j} = \sum_{j=1}^{M} C_j q_j A_j = \sum_{j=1}^{M} C_j Q_j$$

- Accurate mass flux requires q (Darcy flux) field
  - using uniform q is = assuming uniform K
- Obtained K from each MLS point from falling head tests



Compare F from uniform/variable v

uniform velocity = 0.36 m/d

Moles/day				source fence – T2a				
Day	TCE		DCE		VC		Tot CE	
-20	4.7		3.2		0.6		8.7	
150	2.1		5.8		1.5		10.0	
240	2.3		7.3		1.1		9.7	
420	2.9		6.0		0.9		9.7	

using kriged velocities from K tests

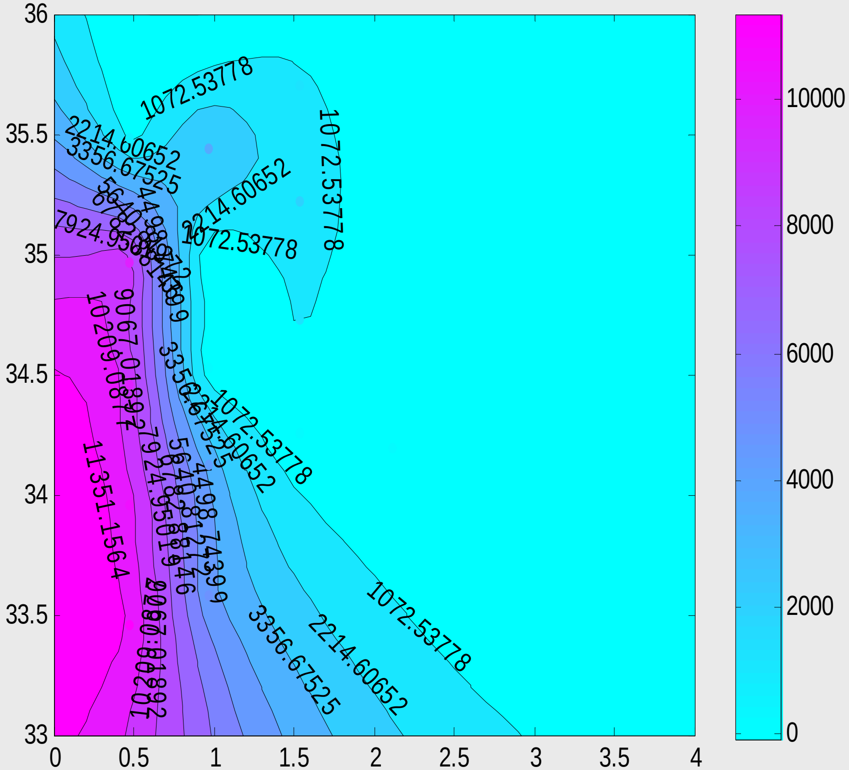
Moles/day				source fence – T2a				
Day	TCE	% difference	DCE	% difference	VC	% difference	Tot CE	% difference
-20	5.5	17	4.6	44	1.0	67	11.6	33
150	0.6	-71	10.8	86	3.8	153	15.8	58
240	0.6	-74	14.7	101	2.2	100	15.8	63
420	0.9	-70	10.7	78	1.6	78	13.6	40

Can also produce mass flux maps

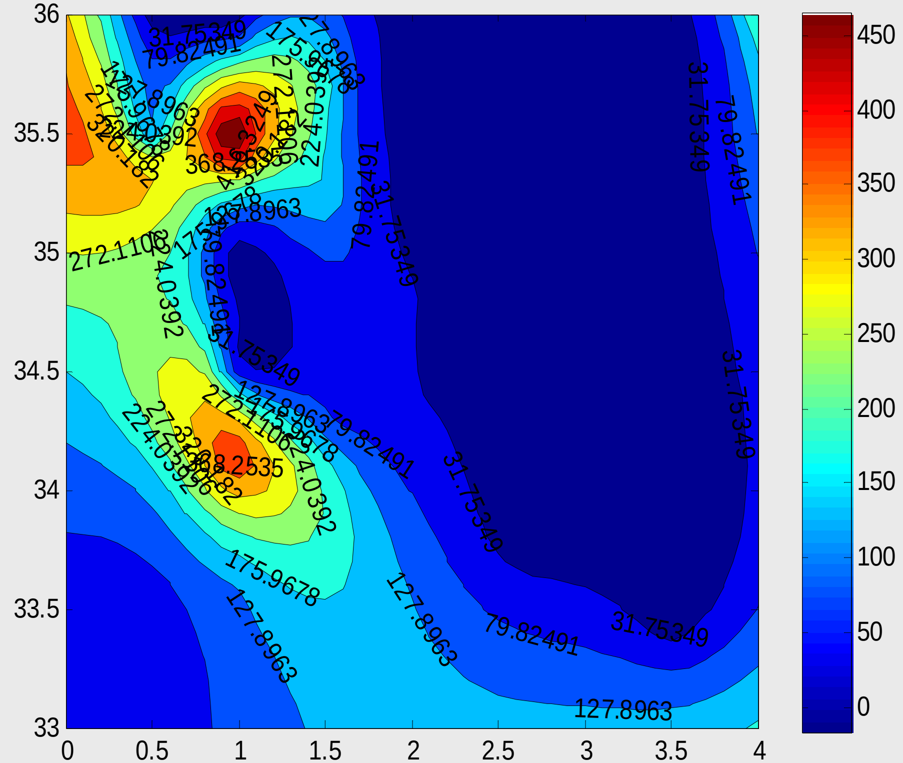
- Product of C and q
- Kriged using same geostatistical method
- High flux does not always equal high C
- Indicator of upstream mass
- Indicator of bioactive flowpaths

TCE

Concentration uM/L



Mass Flux mmoles/d/m^2

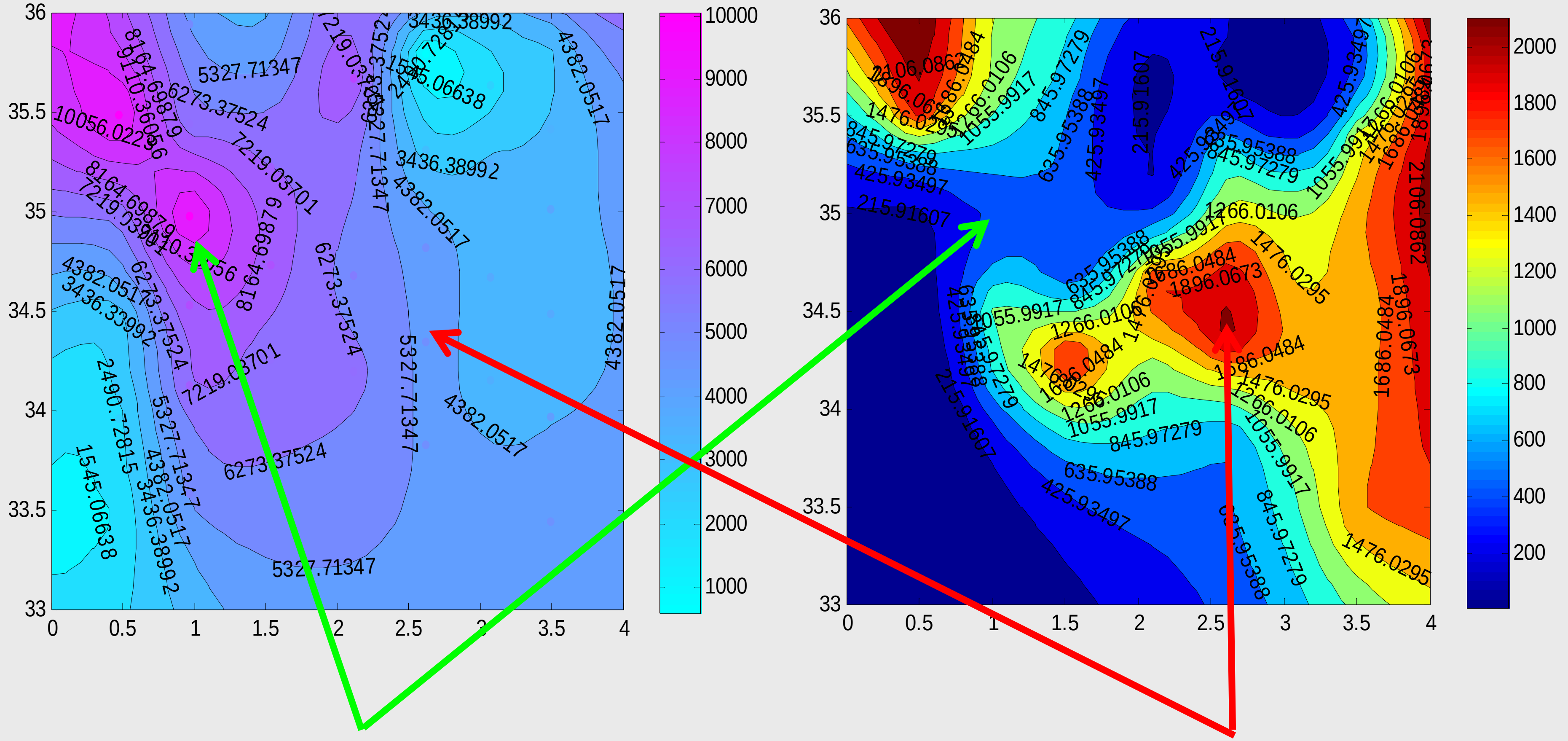


TCE flux appears highest on fringes of suspected NAPL zone

cDCE

Concentration uM/L

Mass Flux mmoles/d/m^2



Highest concentration regions do not correspond to highest mass flux

Conclusions

- MWs pick up **temporal** information not represented in MLS transects
- MLS transects highlight **spatial** distribution of mass
- Mass flux maps highlight process **location**
- **Uncertainty reduced** when K field resolved
- **Both** methods used together is more robust