Challenges and Considerations for Assessing MNA Mechanisms, Plume Persistence, and Treatment Durations at Megasites

12 September 2019

Julie Konzuk, Ph.D., P.Eng.(ON)

Geosyntec consultants

Challenges and Complexities of Megasites

- Complexities:
  - Mixtures of chemicals with different fate and transport properties
  - Heterogeneous geological environments (e.g., layered systems with OOM variability in hydraulic properties, fractured bedrock, preferential flow paths)
  - Multiple competing attenuation mechanisms (sorption/desorption, diffusion/back-diffusion, DNAPL dissolution, volatilization, degradation, flushing and extraction)
- Challenges:
  - Multiple source areas, large, dilute plumes, co-mingled plumes
  - Primary (DNAPL) and secondary (sorbed/diffused) sources that constrain mass transfer to dissolved/vapour phase
  - $$$ spent annually → need to focus $$$ where it provides best value *(i.e., need to know where the best value is…)*

Keys Considerations for MNA

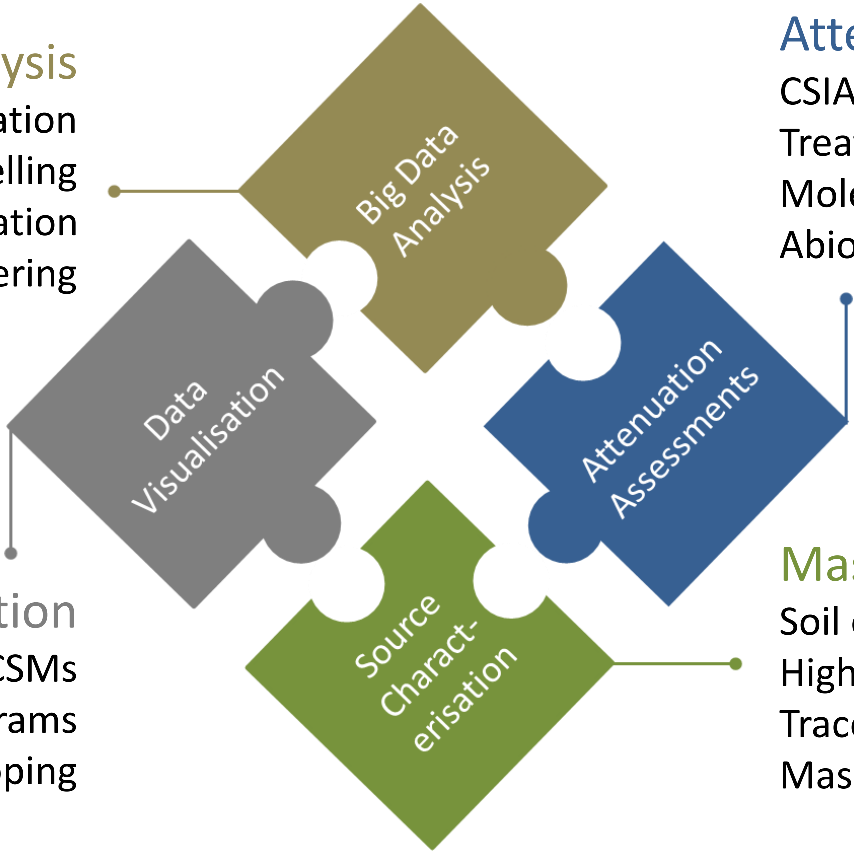
- Source dynamics:
  - Is NAPL present?
  - Will my contaminant preferentially sorb? Dissolve and flush away? Degrade? Diffuse into low permeability material?
- Plume dynamics:
  - Are there secondary sources that may be driving plume persistence?
  - What mass removal mechanisms are active/inactive? Extraction? Degradation? Sorption?
  - Are there preferential pathways for mass migration?
- Adapt to changing conditions
  - Plumes and sources evolve over time
- "Forensic" and high-detail characterization tools provide a means of gaining this insight

Tools in the Toolbox

Geosyntec consultants

Big Data Analysis

Trend evaluation
Predictive modelling
Uncertainty quantification
Multivariate Data Clustering



Attenuation Assessments

CSIA
Treatability studies
Molecular biological tools
Abiotic mineral characterisation

Data Visualisation

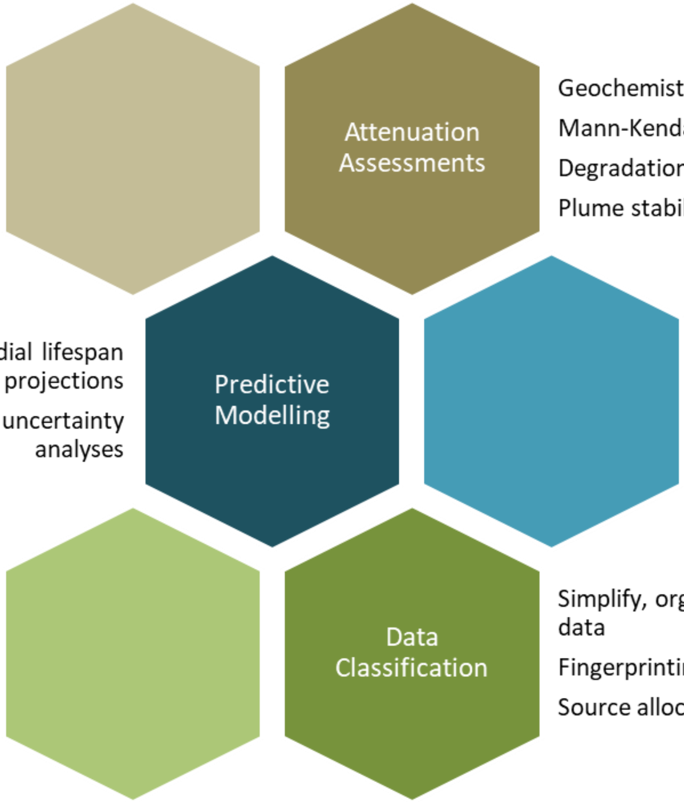
2D/3D CSMs
Radial diagrams
Interactive mapping

Mass/Flow Characterisation

Soil core sub-profiling
High-resolution tools
Tracer testing
Mass discharge/flux transects

Utilising “Big Data” Techniques to Understand our Site Dynamics

Big Data Analysis



Geochemistry radial plots
Mann-Kendall trend analysis
Degradation half-lives
Plume stability

Plume/remedial lifespan projections
Monte carlo uncertainty analyses

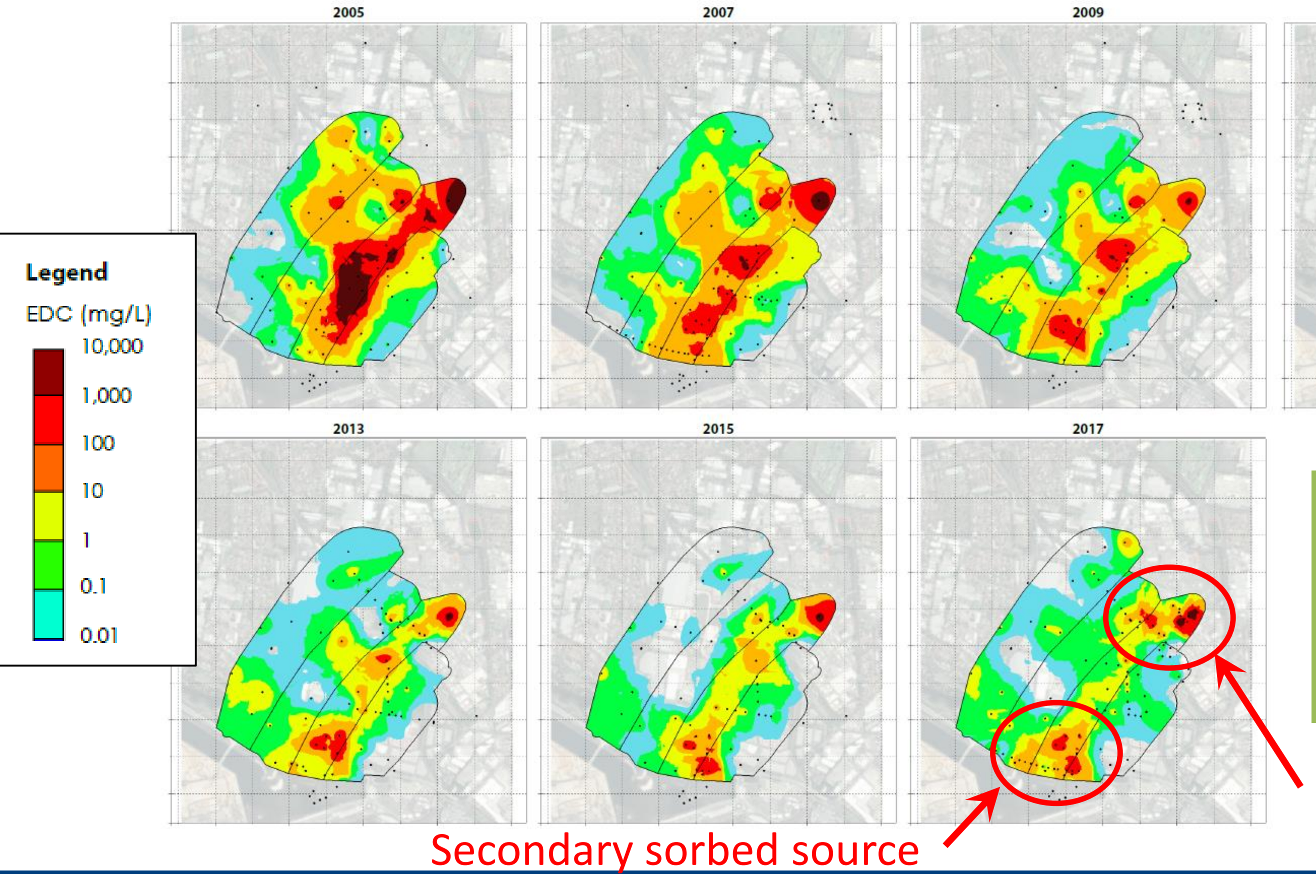
Simplify, organize and classify data
Fingerprinting
Source allocations

"Big Data" analyses can play a key role in the following:

- Developing the CSM
- Diagnosing remedial progress
- Understanding attenuation behavior to support MNA/ remedial design/no further action decisions
- Predictive modelling for cost-benefit analyses or uncertainty analysis

Visualising Plume Changes over Time

Geosyntec consultants

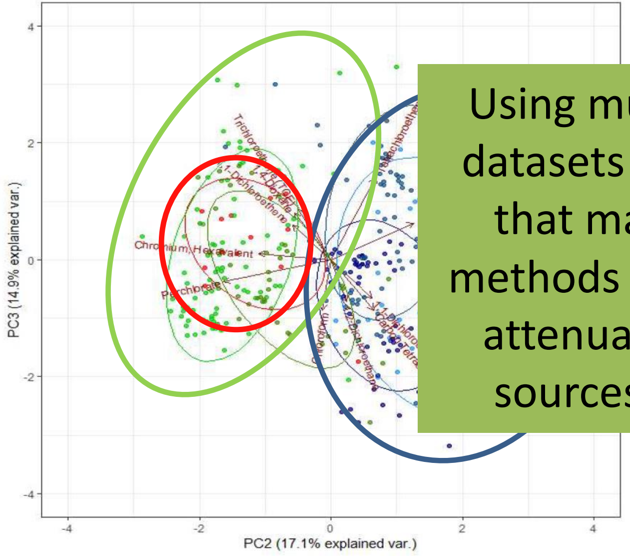


Mapping plume changes over time can provide preliminary insight into remedial drivers

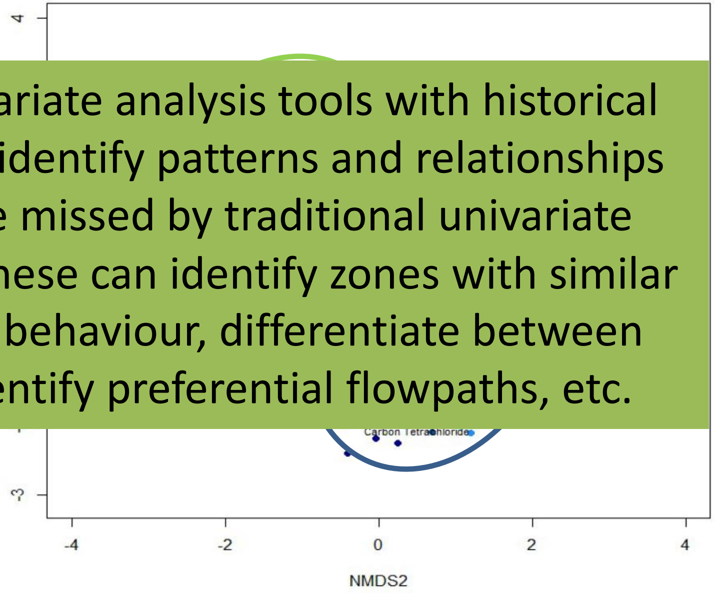
Advanced Data Analytics: Making Sense of Big Data at Complex Sites

Geosyntec consultants

Principal Component Analysis



Nonmetric Multidimensional Scaling

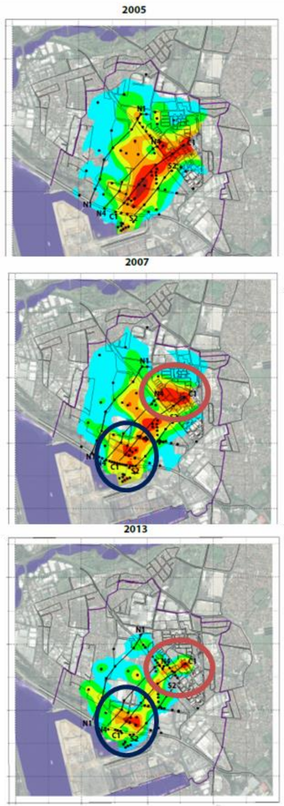


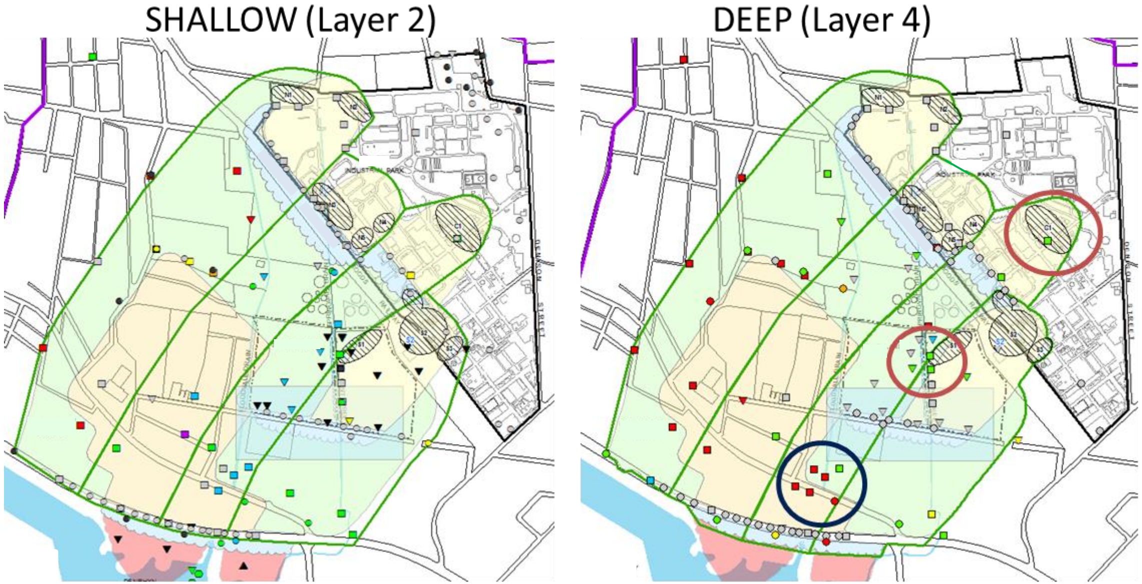
Using multivariate analysis tools with historical datasets can identify patterns and relationships that may be missed by traditional univariate methods → these can identify zones with similar attenuation behaviour, differentiate between sources, identify preferential flowpaths, etc.

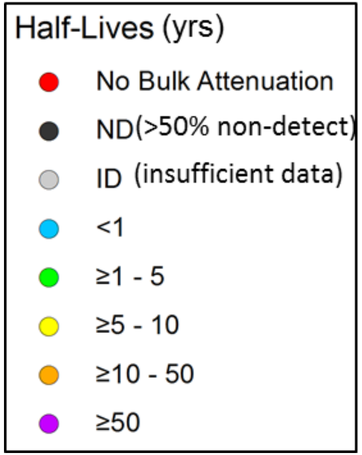
Multivariate statistical tools identified that a downgradient area was hydraulically connected to Source Area 1 and not Source Area 2

Source Area 1 — Source Area 2 — Downgradient

Identifying Areas of Mass Persistence



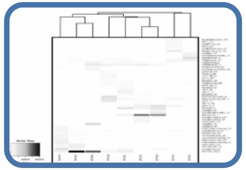




Higher value may be achieved by actively remediating plume toe

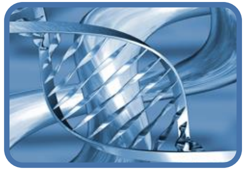
Identifying Dominant Attenuation Mechanisms

Characterising Biological Activity



Next Generation Sequencing

- Semi-quantitative, comprehensive community profiles (non-targeted analysis)
- Changes in microbial community profiles may indicate changing microbial activity, inhibition

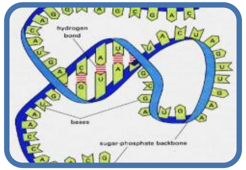


Quantitative Polymerase Chain Reactions (qPCR)

- Quantify concentrations of bacteria responsible for degradation of target contaminants (e.g., chlorinated solvents, aromatics, phenols, biphenyls, 1,4-dioxane) → targeted analysis

Functional Gene Assays

- Indicator of functional ability of bacteria (e.g., ability to degrade vinyl chloride; targeted analysis)
- Increasing number of commercially available tests for chlorinated solvents, BTEX, ethene, etc.

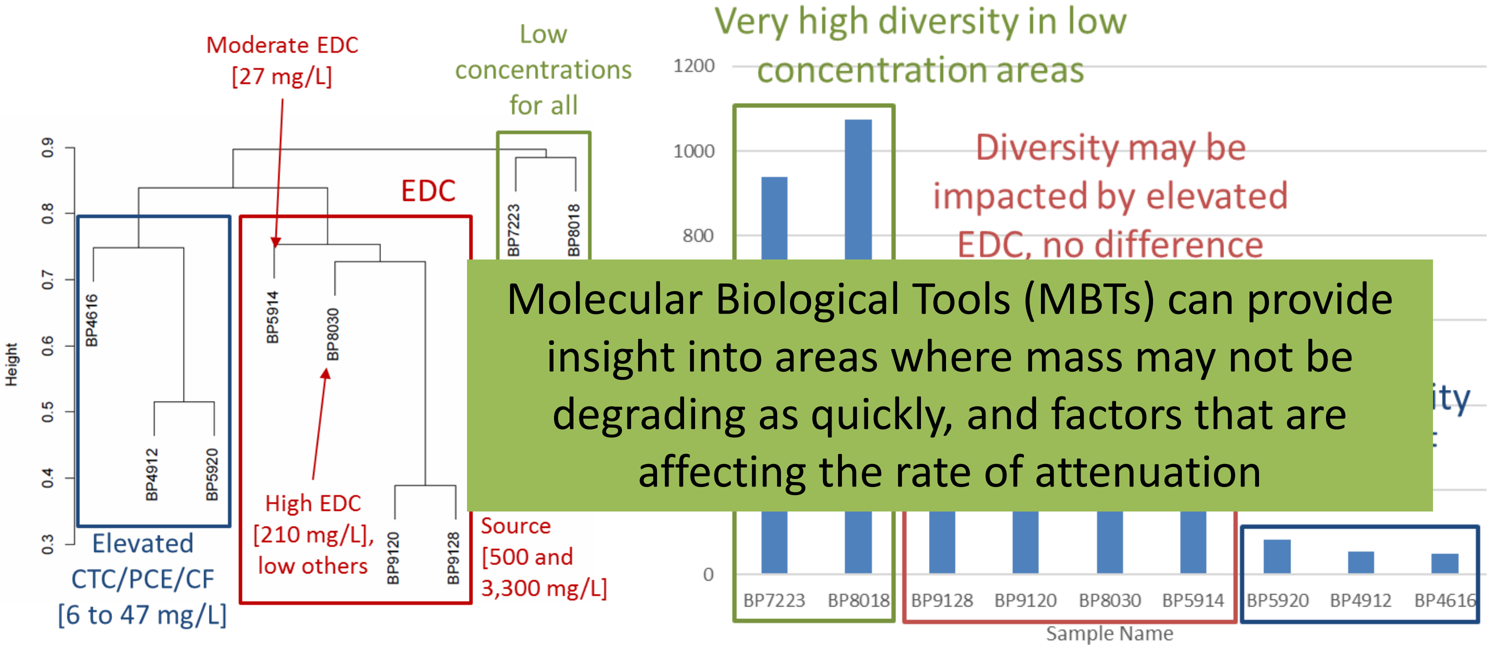


RNA Assays

- Indicator of bacteria activity levels (targeted analysis)
- Not commercially available, but may provide value at complex sites

Investigating Inhibitory Conditions Using NGS

Geosyntec consultants



Molecular Biological Tools (MBTs) can provide insight into areas where mass may not be degrading as quickly, and factors that are affecting the rate of attenuation

Fairly low biomass across the site

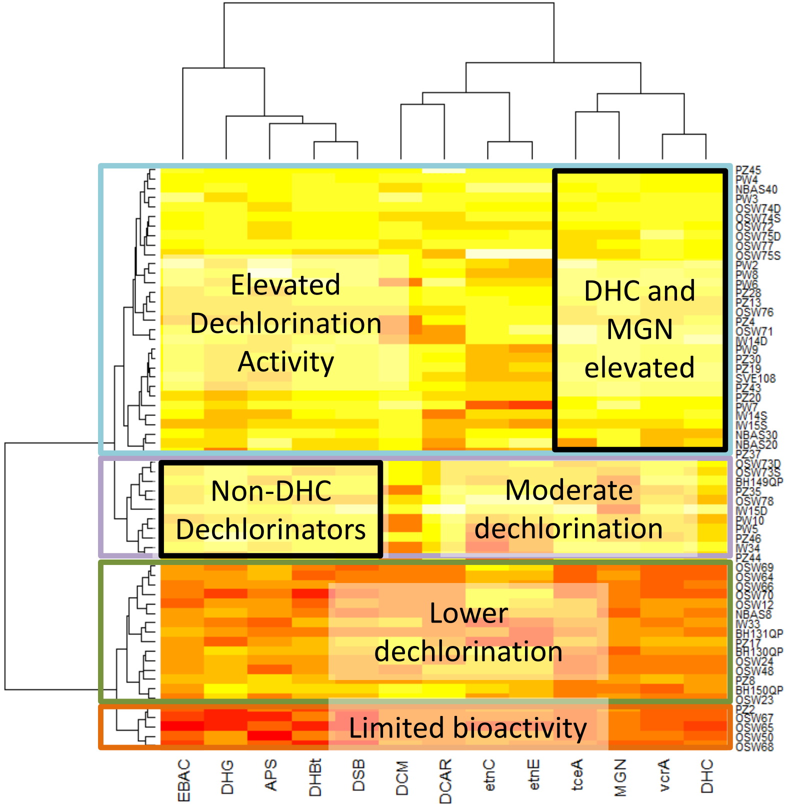
Common dechlorinators inhibited in CTC/CF source areas

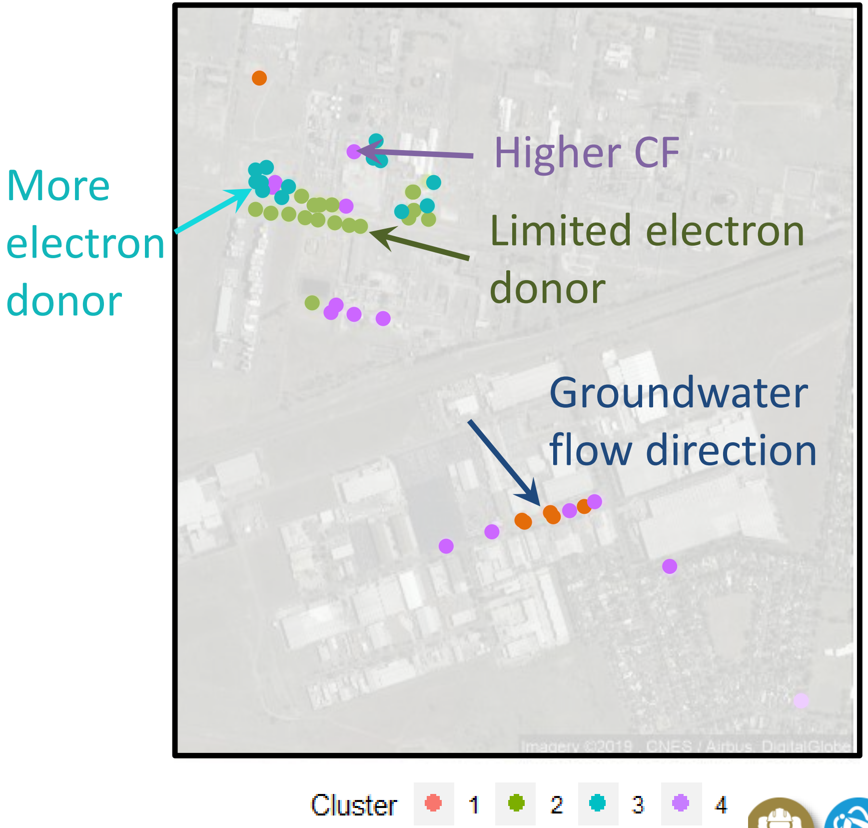
Dehalococcoides and *Geobacter* dominant for low [EDC] areas

Community shifts to sulphate reducers at higher [EDC]

Incorporating Multivariate Statistical Analyses and MBTs to Identify Bioactive Zones

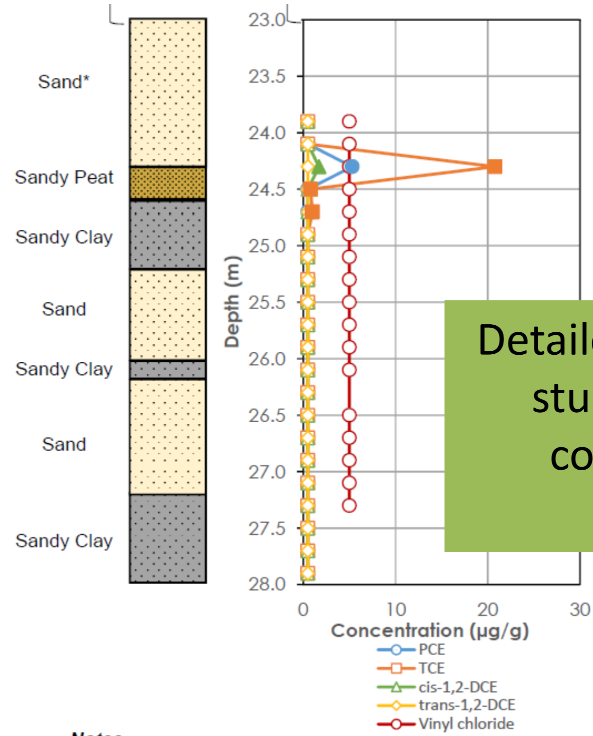
Geosyntec consultants



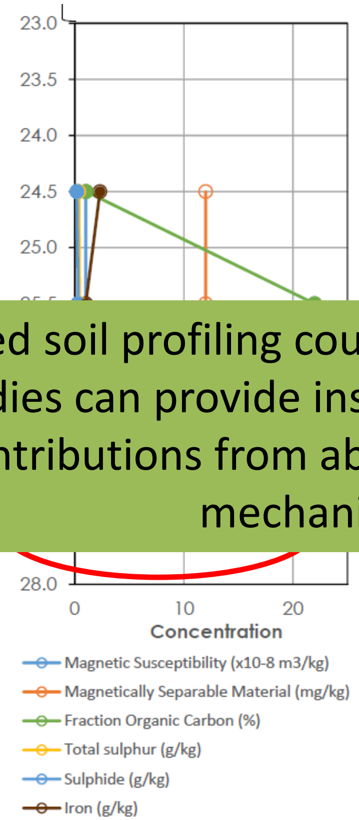


Characterising Abiotic Attenuation Mechanisms

Geosyntec consultants

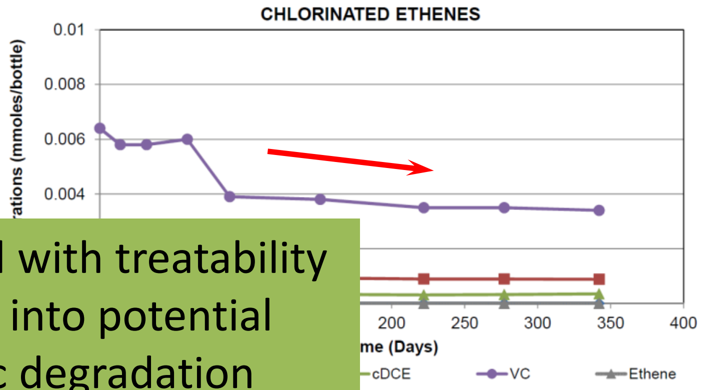


Notes
g - grams
kg - kilograms
m - metres
m^3 - cubic metres



sulph

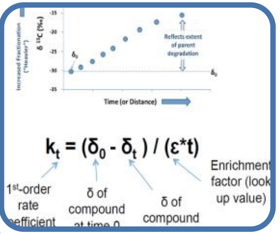
Treatability Study – Sterile Control



Detailed soil profiling coupled with treatability studies can provide insight into potential contributions from abiotic degradation mechanisms

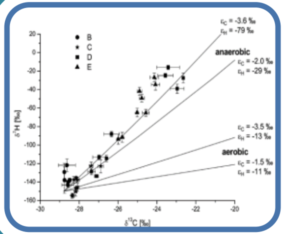
COC	Abiotic Half-Life
VC	1.0 yr
TCE	2.5 yrs
EDC	5 yrs

Compound-Specific Isotope Analysis



Single Compound-Specific Isotope Fractionation

- Can provide information with regards to the extent of mass destruction, degradation rates
- May be impacted by confounding factors (e.g., sequential degradation, other physical processes such as desorption masking degradation isotope signature)

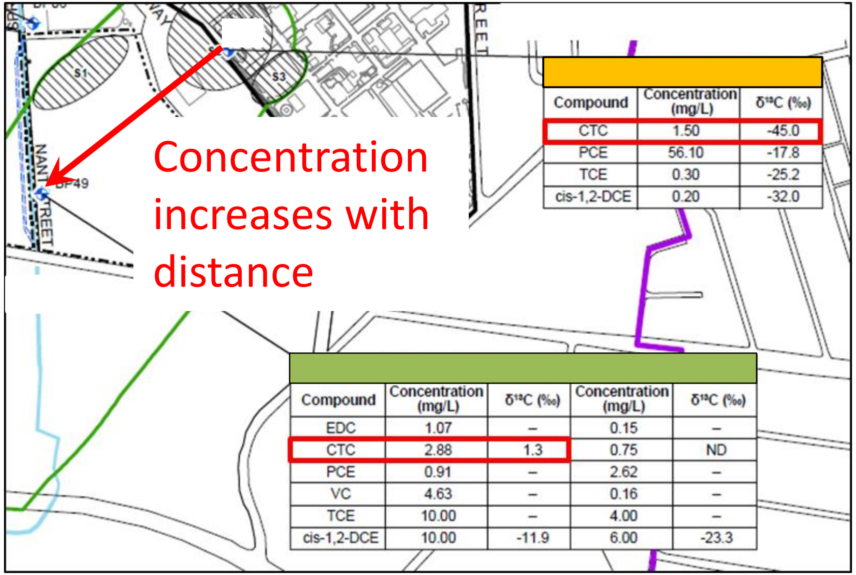


Dual/Triple Compound-Specific Fractionation

- May provide more accurate source identification
- Can better differentiate between different attenuation mechanisms (e.g. abiotic vs. biotic decay)
- Quantitative demonstration of degradation and other attenuation processes

Confirming Dominant Attenuation Mechanisms with CSIA

Geosyntec consultants



Compound	Concentration (mg/L)	δ13C (‰)
CTC	1.50	-45.0
PCE	56.10	-17.8
TCE	0.30	-25.2
cis-1,2-DCE	0.20	-32.0

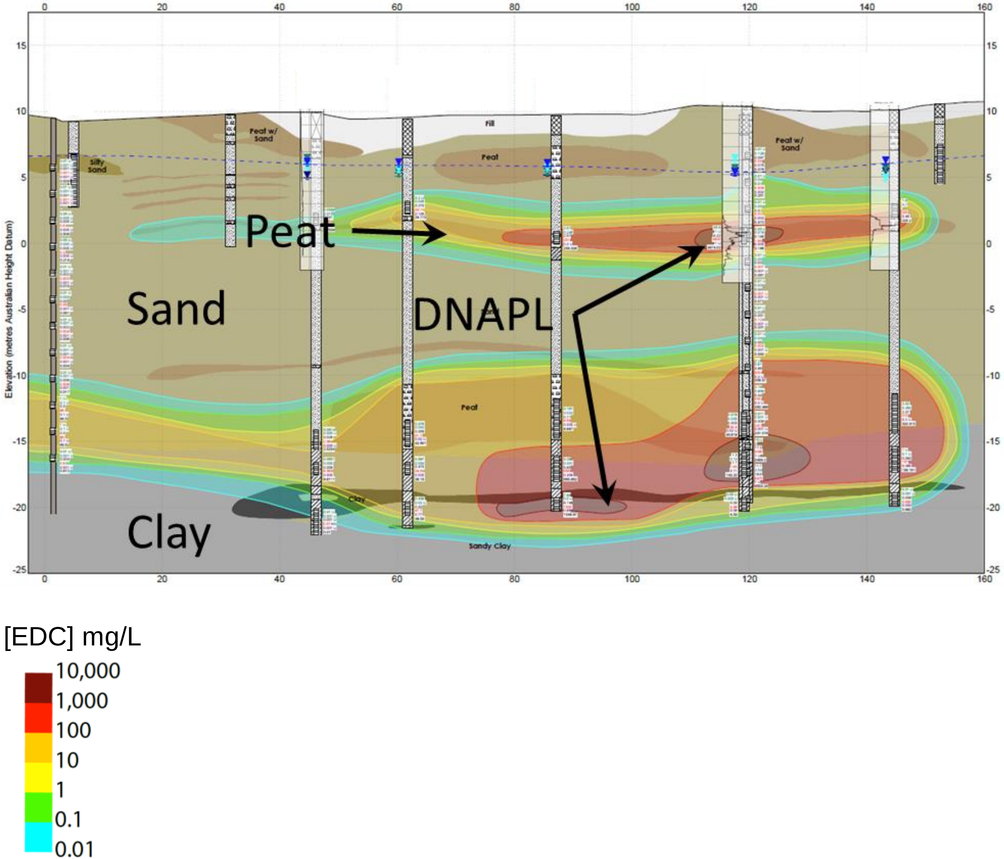
Compound	Concentration (mg/L)	δ13C (‰)	Concentration (mg/L)	δ13C (‰)
EDC	1.07	–	0.15	–
CTC	2.88	1.3	0.75	ND
PCE	0.91	–	2.62	–
VC	4.63	–	0.16	–
TCE	10.00	–	4.00	–
cis-1,2-DCE	10.00	-11.9	6.00	-23.3

	Rate (k)	Half-Life
Isotope-Derived Degradation	1.73 yr^{-1}	0.40 yr
Spatial Concentration-Derived Bulk Attenuation	N/A	N/A
Temporal Concentration-Derived Point Attenuation	1.24 yr^{-1}	0.56 yr

CSIA can provide insight into degradation behaviour separate from all of the other bulk attenuation mechanisms

Source Characterisation

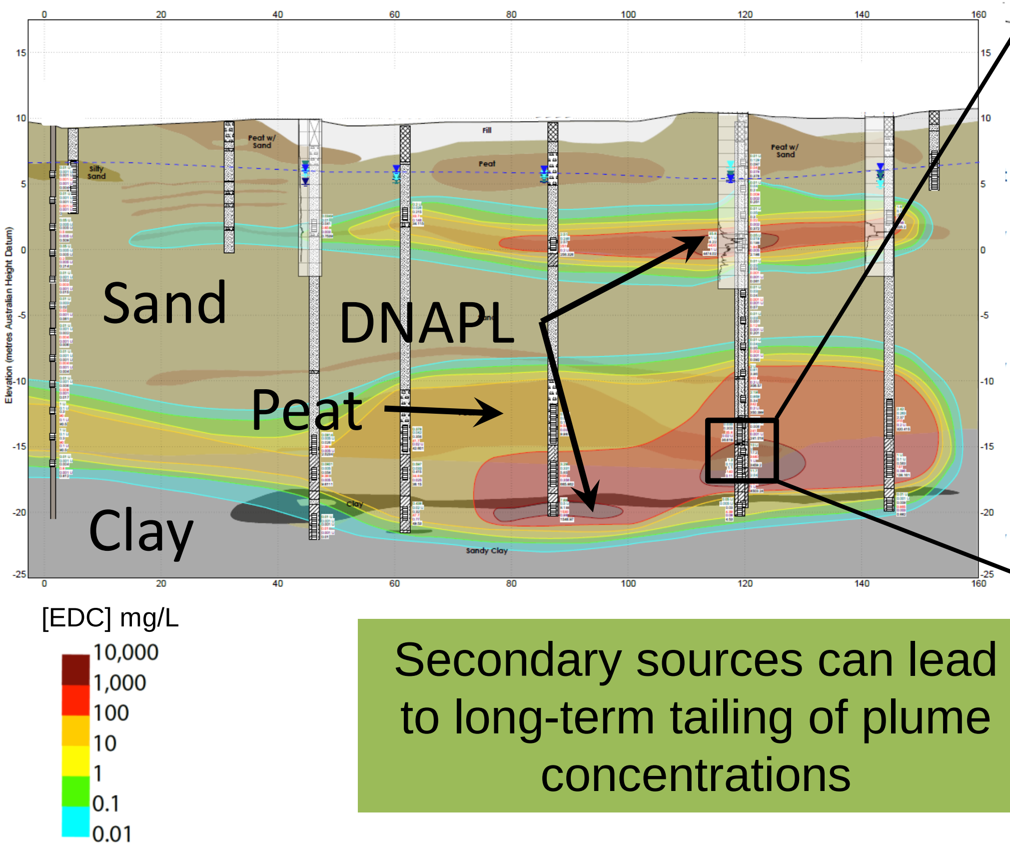
Persistence of Primary Sources – Mass Discharge

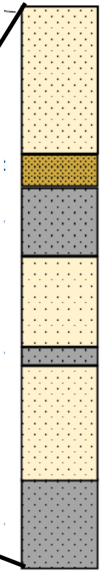


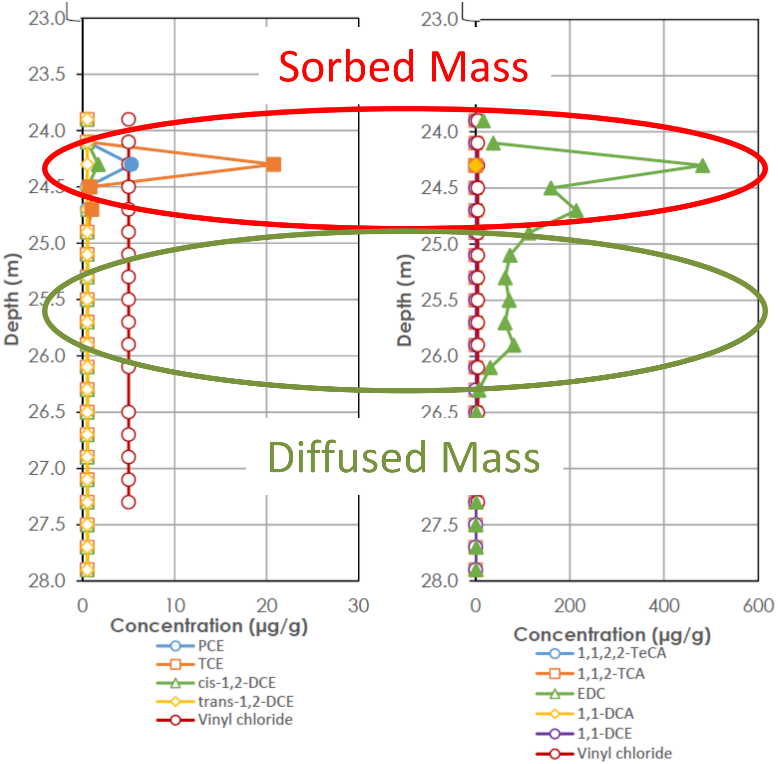
DNAPL Component	Mass Discharge (T_0)
EDC	>99%
PCE	<1%
Total (tonnes/y)	17

The change in mass discharge/flux from sources over time can provide insight into source decay rates and also identify areas where $$$ spent provides best value

Persistence of Secondary Sources



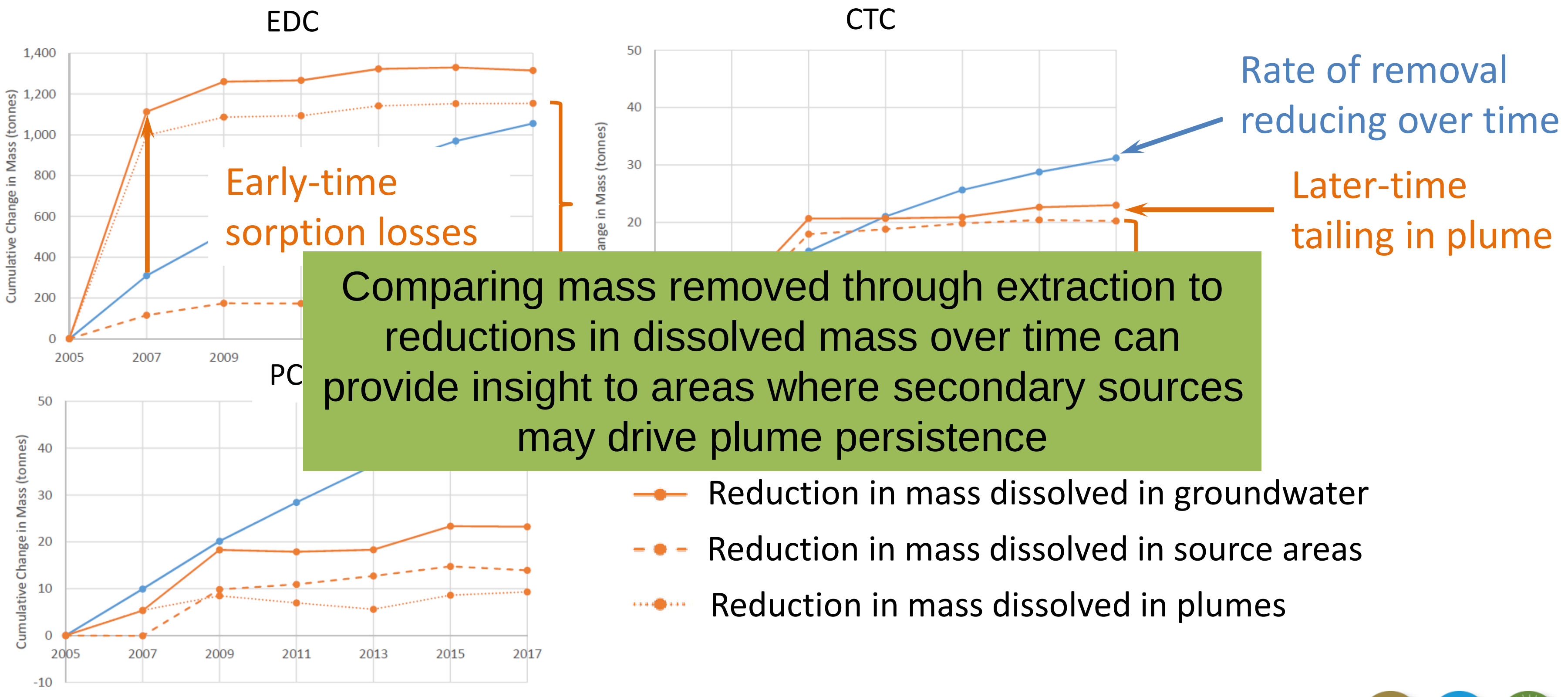




Secondary sources can lead to long-term tailing of plume concentrations

Long-Term Importance of Secondary Sources

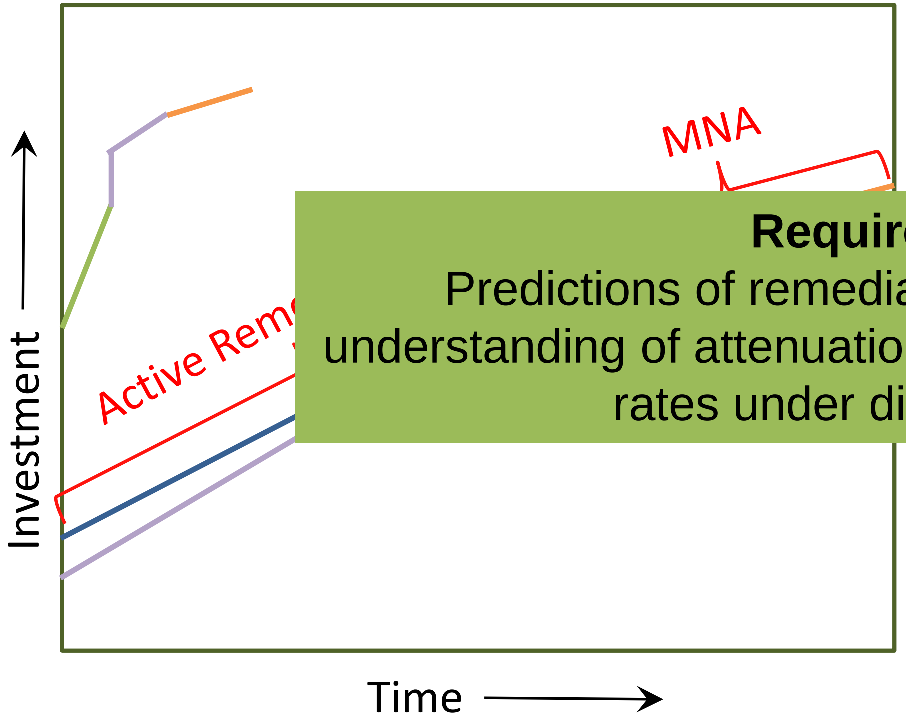
Geosyntec consultants



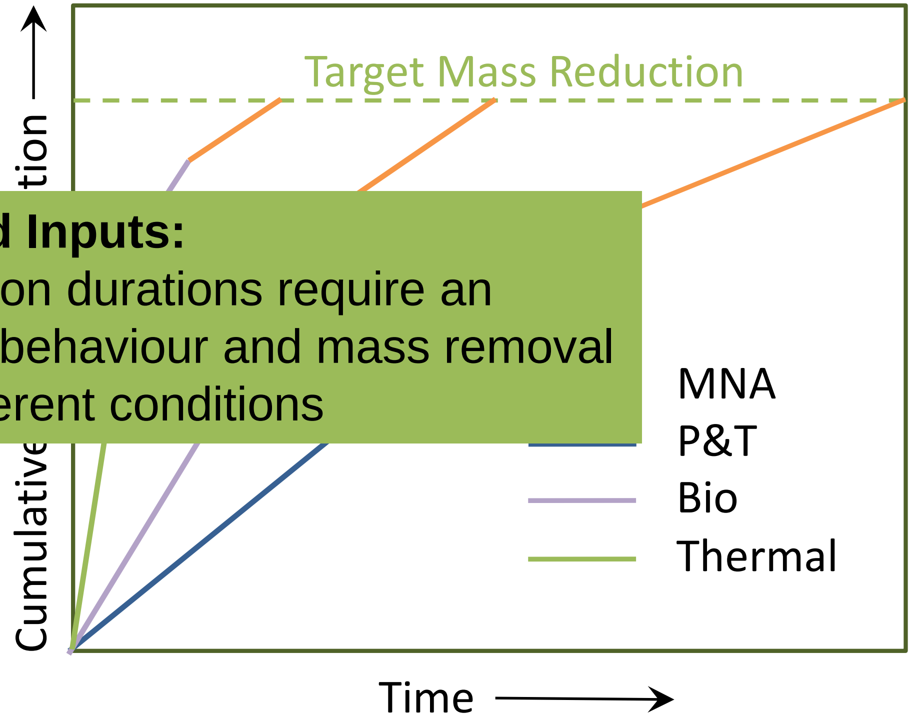
Comparing mass removed through extraction to reductions in dissolved mass over time can provide insight to areas where secondary sources may drive plume persistence

Tying it All Together into a Remedial Strategy

Remedial Strategy: Balance of Time and $$$

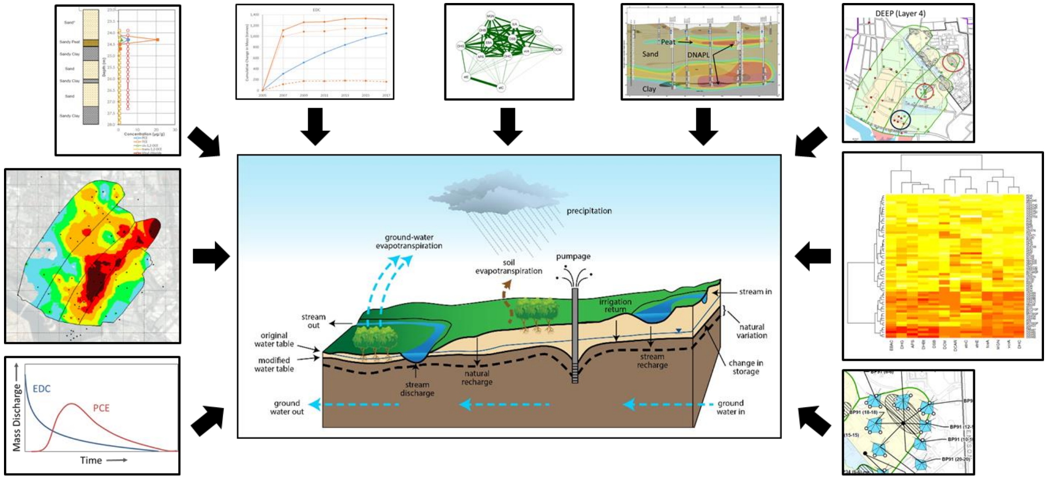


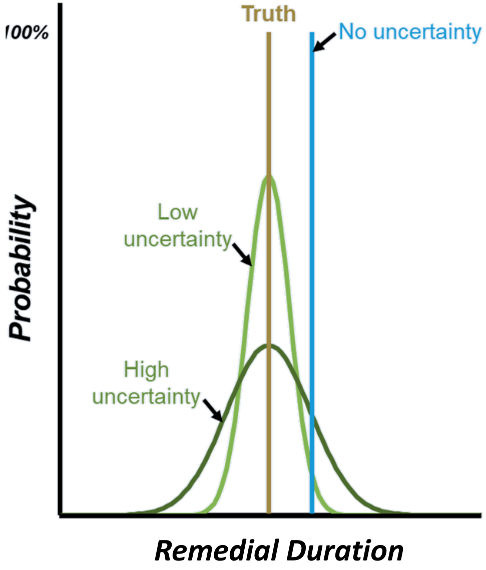
Required Inputs:
Predictions of remediation durations require an understanding of attenuation behaviour and mass removal rates under different conditions



Predictions of Remedial Durations

Geosyntec consultants





Accurate CSM is critical to accuracy of forward predictions of remedial durations

Final Takeaways

Geosyntec consultants

- Multiple lines of evidence is generally better when evaluating a site with complex chemistries, attenuation behaviour, and heterogeneity
- Accuracy of the CSM is crucial to optimising return on investment
  - Up front investment generally pays off in the end, but how do you prove that to the client?
- Do not forget the secondary sources – these may drive long-term plume behaviour
- Developing a remedial strategy may need to be an iterative process as conditions change in often unpredictable ways

Questions?

jkonzuk@Geosyntec.com

+1 416-637-8746