Using Stable Isotopes in a Multiple-Lines-of-Evidence Approach to Evaluating Sources and Degradation of Trichloroethylene

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Outline

- Context
- Assignment – Problem Formulation
- Site History
- Assessment Strategy
  - Hydrogeology
  - Groundwater Quality
  - CVOC Ratios
  - CSIA
- CVOC Degradation
- Conclusions

Context

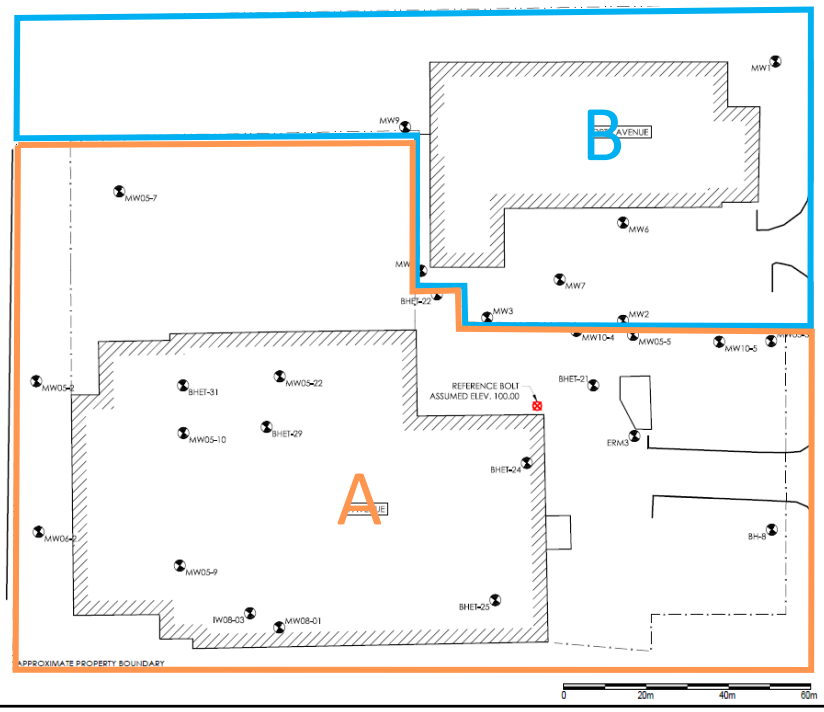
Legal action between adjacent property owners

- Diminution of property value
- Business interruption: delay of property sale
- Nuisance: alleging diminishment of the enjoyment, value, and beneficial use of the property

Assignment – Problem Formulation

- Property A is the alleged source of cVOC impacts to Property B.
- Assess whether impacts at Property B are attributable to the alleged source at Property A.
- Is it possible that this allegation is unfounded?
- How many lines of evidence are required on the balance of probabilities to prove or disprove the allegation?

Figure 1
Site Plan



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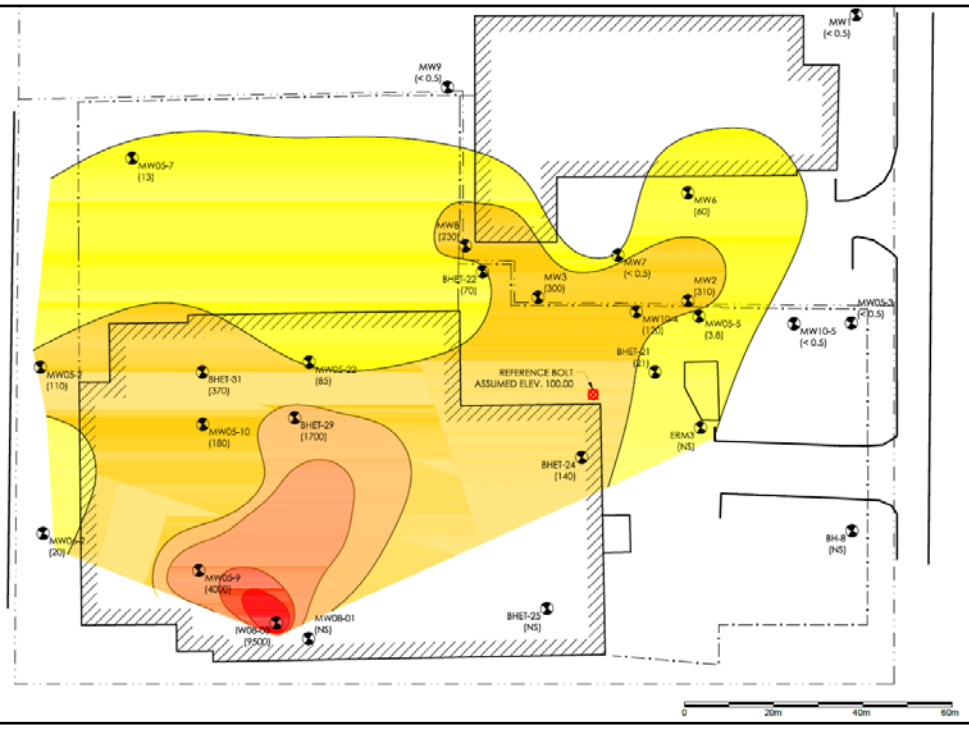
Site History

- Industrial operations since 1940s
- Manufacturer of automotive and aircraft parts
- Solvents and cutting oil used and stored at the Property (A)
- Adjacent property (Property B) initially used for warehousing then later sold to an automotive part distributor

Figure 2
Approximate Extent of cVOC Impacts to Groundwater



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Assessment Strategy

1) Hydrogeology:
   - Water level measurements
   - Survey both properties to common datum
   - Slug tests
2) Groundwater Quality:
   - 23 groundwater samples
   - Concentration profiles at Property A and Property B
3) cVOC ratios:
   - 15 sets of analyses
   - Comparison from Property A and Property B along the groundwater flow path
   - Ratios of TCE to daughter products
4) Stable Isotopes:
   - 15 sets of analyses
   - Variable enrichment/depletion of ^{13}C the flow path

Hydrogeology

- Two components of shallow groundwater flow direction; northeast and west.
- Principal direction of flow is toward Property B.
- Slug tests were conducted at several monitoring wells to estimate hydraulic conductivity.
- Groundwater flow velocities estimated to be 2 to 4 m/year.
- Estimated velocities are within expected range considering plume dimensions.

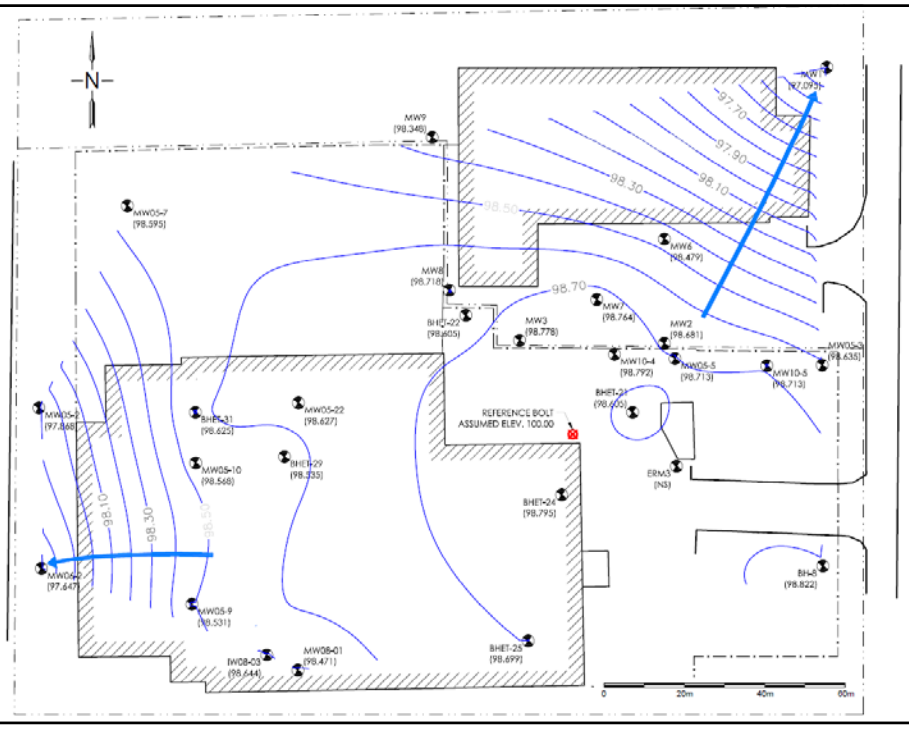


Figure 3
Interpreted Groundwater Flow Direction

Hydrogeology

- Two components of shallow groundwater flow direction; northeast and west.
- Principal direction of flow is toward Property B.
- Slug tests were conducted at several monitoring wells to estimate hydraulic conductivity.
- Groundwater flow velocities estimated to be 2 to 4 m/year.
- Estimated velocities are within expected range considering plume dimensions.

Groundwater Quality

- Groundwater samples collected at Property A (16 wells) and at Property B (7 wells).
- The nature, extent, and character of the cVOCs in groundwater were evaluated.
- The same cVOCs were documented at Property A and at Property B.
- Larger concentrations of TCE and cis-1,2-DCE were measured in groundwater at Property A compared to those measured in groundwater at Property B.

TCE: Degradation Compound Ratios

- The presence or absence of parent compounds and their breakdown compounds can provide evidence for source area identification.
- Parent-compound to daughter-compound concentration ratios of chlorinated ethenes are frequently stable within source zones, but will decrease as a result of natural attenuation along the groundwater flow path.
- Abrupt increases in parent-compound to daughter-compound ratios indicate a contribution from additional sources of chlorinated ethenes.

Figure 4
Select cVOC ratios: TCE to Degradation Compounds

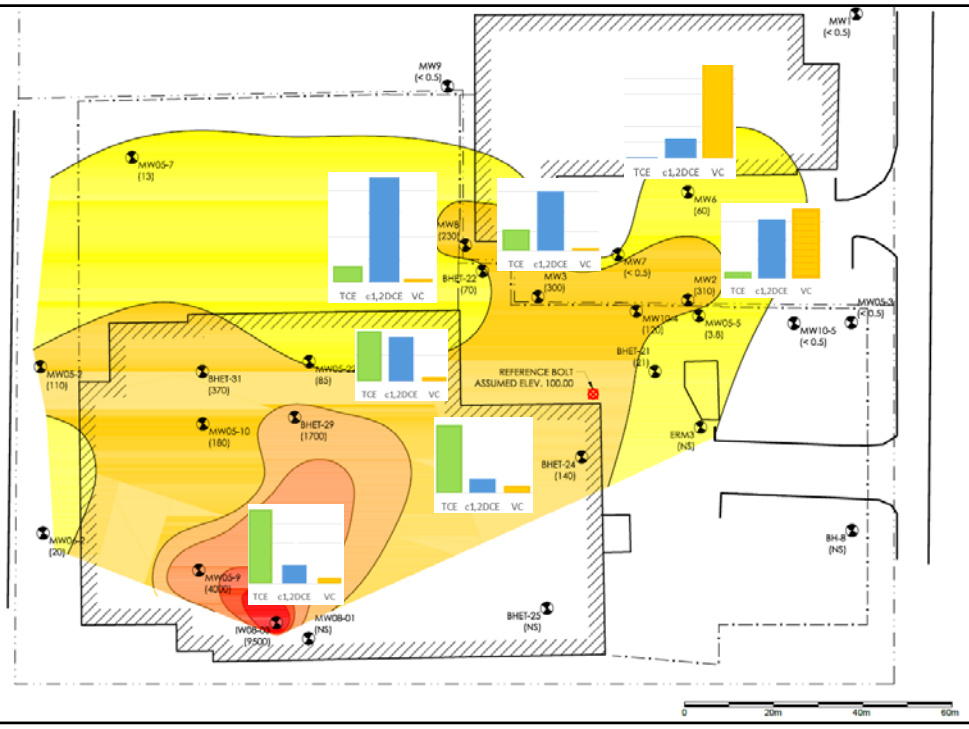
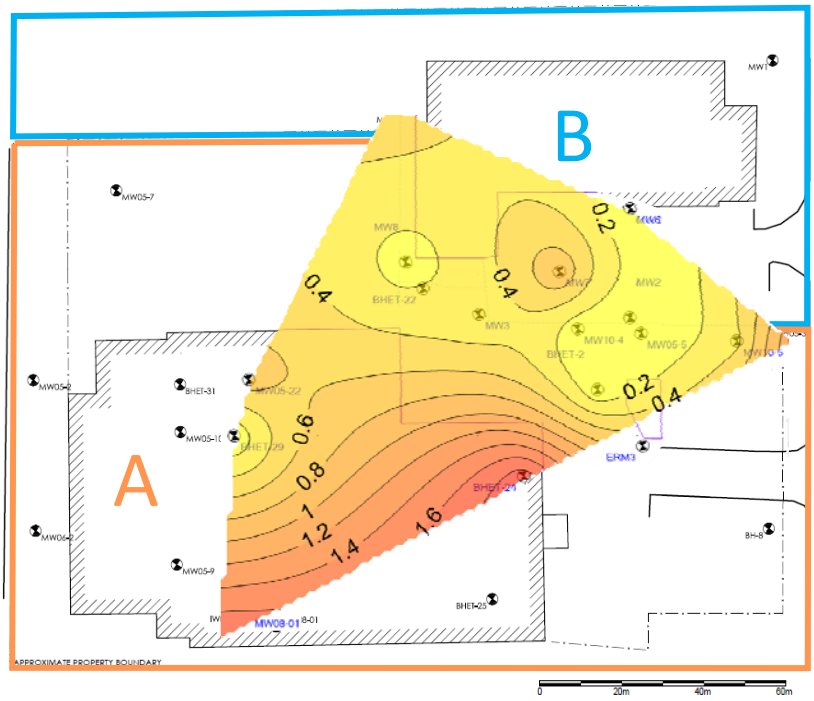


Figure 5
TCE – Daughter Compound Ratio Contours



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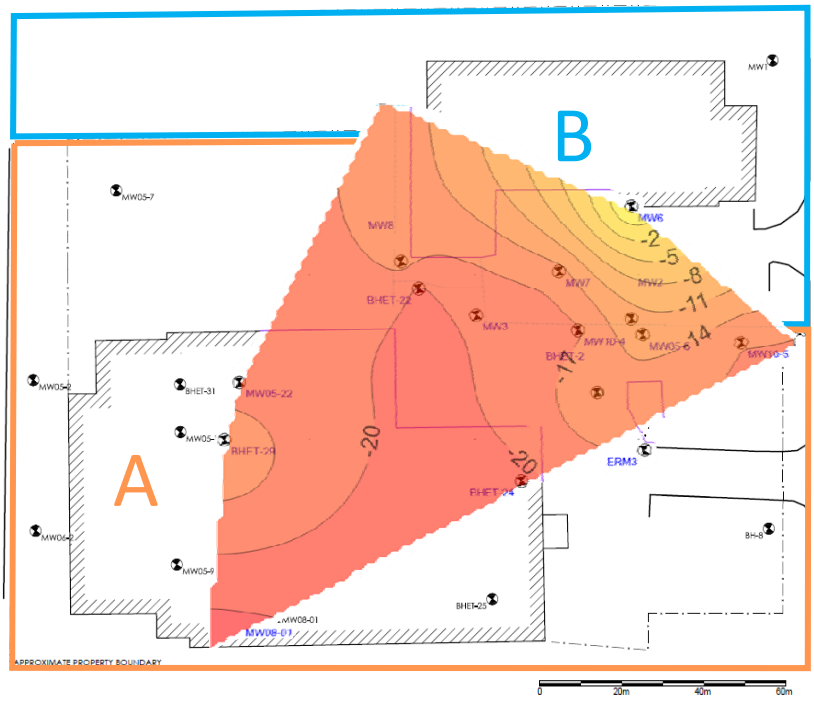
Stable Isotopes

CSIA Basics

- Carbon exists in stable form as ^{12}C and ^{13}C (radioactive ^{14}C not applicable in this study).
- With respect to its molecular weight, ^{12}C is lighter than ^{13}C.
- ^{12}C preferentially degraded: less energy to break the bond
- Over time, the isotopic ratio of ^{13}C to ^{12}C will change.
- Enrichment in the heavier isotope (^{13}C) is expressed as $\delta^{13}C$ in per mil notation (‰, parts per thousand), relative to a standard.
- Typical range of manufactured/un-degraded TCE $\delta^{13}C$ is -31.9‰ to -27.4‰.

Figure 6
^{13}C Enrichment Contours



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Stable Isotopes

- Lower (more negative) $\delta^{13}C$ values in the suspected source areas.
- Enrichment in the $\delta^{13}C$ along the groundwater flow path.
- Results indicated that it was unlikely that a source of TCE impacts to groundwater was at Property B.
- $\delta^{13}C$ values from TCE in samples from Property B were consistent with TCE degradation along the groundwater flow path from Property A.

TCE Degradation

- Mass reduction or dilution?
- Non-degradative processes do not fractionate
- TCE in groundwater from locations further down-gradient of the source areas may be expected to show increasing enrichment of ^{13}C and increasing $\delta^{13}C$ values in TCE, consistent with the increasing degradation of TCE to other cVOCs.
- Pattern can be masked or altered in situations where active remediation has degraded the parent compound TCE by chemical oxidation or reductive de-chlorination.
- Some degradation in the source area.

Conclusions

1) Plume extent consistent with groundwater flow direction and velocity.
2) Pattern of TCE and daughter products consistent with source area at Property A and migration along flow path to Property B.
3) Ratio of TCE to daughter products did not indicate secondary source at Property B.
4) Results of Isotope analysis did not indicate a secondary source at Property B.

Each line of evidence indicated that cVOC impacts to groundwater at Property A were the likely source of cVOC impacts at Property B.