PERFORMANCE ASSESSMENT METRICS FOR IN SITU BIOREMEDIATION OF DNAPL SOURCE ZONES

Gary Wealthall[1]; Peter Zeeb[2]

Resumo

Avaliação de desempenho das tecnologias de remediação in situ pode ser limitada por incertezas na descrição espacial da distribuição de contaminantes e pelos métodos interpretativos disponíveis para quantificar a depleção de massa. Um estudo de caso detalhado de biorremediação reforçada in situ (EISB) da região de origem de uma fase líquida densa não aquosa (DNAPL) solvente clorado fornece uma comparação de depleção de massa de DNAPL com redução de fluxo de massa de fase dissolvida. O estudo conclui que EISB é eficaz para reduzir a fonte de massa de DNAPL e que reduzindo a incerteza sobre se os objetivos correctivos foram atingidos requer crescente investimento em monitoramento de desempenho.

Abstract

Performance assessment of in situ remediation technologies may be limited by uncertainties in the spatial description of contaminant distribution and by the interpretative methods available to quantify mass depletion. A detailed case study of enhanced in-situ bioremediation (EISB) of a chlorinated solvent dense non-aqueous phase liquid (DNAPL) source zone provides a comparison of DNAPL mass depletion with dissolved phase mass flux reduction. The study concludes that EISB is effective at reducing DNAPL source mass and that reducing uncertainty in whether remedial targets have been reached requires increasing investment in performance monitoring.

Key words

Remediation, DNAPL, chlorinated solvent, performance assessment.

1 - INTRODUCTION

Chlorinated solvents have been used extensively in industry and are common groundwater contaminants. Their limited aqueous solubility often leads to the presence of dense non-aqueous phase liquid (DNAPL) source zones, which may persist due to mass transfer limitations from the DNAPL to groundwater [1]. Whilst recent research effort has been directed to the development of effective source zone remediation methods, considerably less attention has been given to establishing reliable methods to quantify the

[1]*Geosyntec Consultants, Inc. 130 Research Lane - Suite 2. Guelph, Ontario N1G 5G3. Canada. gwealthall@geosyntec.com*
[2]*Geosyntec Consultants, Inc. 289 Great Road, Acton, MA 01720, USA. pzeeb@geosyntec.com*

progress toward, and achievement of, remediation targets. Here we describe the development of uncertainty-based performance metrics for quantifying the treatment of a trichloroethene (TCE) DNAPL source zone.

2- SITE DESCRIPTION

A former chemical manufacturing plant in the UK was the focus for project SABRE. The site was occupied by a mono-chloro acetic acid (MCA) production plant that used TCE in the production process. The near-surface geology at the site comprises a variable thickness of fill over a sequence of alluvium (1 to 2.5 m thick) and gravels (3 to 5 m thick). The sediments rest on a significant thickness (>60 m) of mudstone bedrock, which is fractured and weathered near the surface [2]. The spatial distribution of the site-wide DNAPL source was used to guide the location of a 30 m long by 4 m wide cell (Figure 1) that was the focus for the EISB research study.

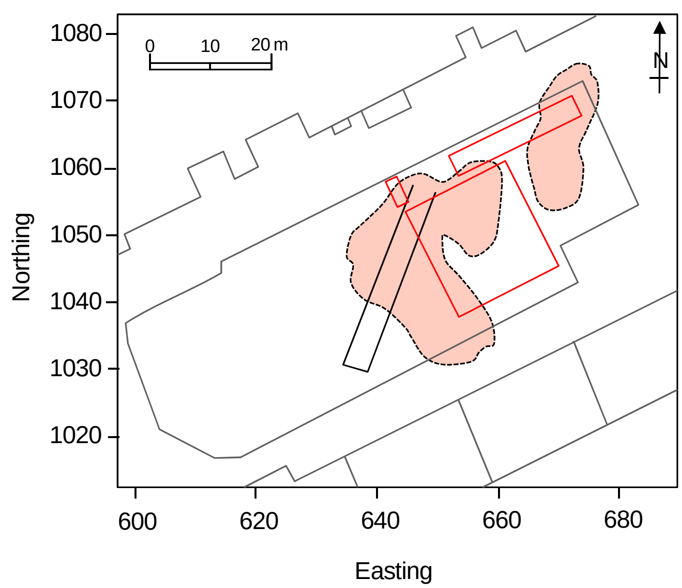

Figure 1. Extent of the DNAPL source zone is shown in dotted outline and shading. The elongated U-shaped bold outline identifies the location of the SABRE research cell.

3 - DNAPL MASS DEPLETION

The approach adopted in this study was to develop a methodology that simplified the description of contaminant distribution, yet allowed robust sensitivity analysis and quantification of uncertainty. The methodology is based on standard site investigation methods, simplifying assumptions regarding DNAPL distribution and statistical descriptions of DNAPL mass. The effect of variability in impacted aquifer volume and the distributions of DNAPL saturation and porosity were investigated using a modified bulk retention capacity expression. Monte Carlo simulations (10,000 realizations) were undertaken to determine the plausible range of DNAPL mass estimates (Table 1), both before and after treatment of the DNAPL source zone by enhanced in situ bioremediation.

Table 1. Summary of the mass estimates before and after remediation

Percentile values	10th	25th	50th	75th	90th
Pre-treatment mass (tonne)	0.27	0.49	0.94	1.76	3.13
Post-treatment mass (tonne)	0.14	0.24	0.45	0.85	1.51

4 - CONTAMINANT TRANSFORMATION

Monitoring of the test cell effluent provided a measurement of the total flux of chemicals through the cell. An ethene and chloride mass balance was conducted to determine the fate of TCE released from DNAPL during the test. The net discharge of each ethene and chloride was determined from the difference in cumulative mass discharge in the effluent and an estimate of the mass entering the cell based on influent groundwater monitoring data (Table 2).

Of the net discharge of 12,585 moles of chloride from the cell, 8,117 moles are accounted for based on dechlorination of TCE to cDCE, VC, and or ethene. The remaining 4,467 moles of chloride in the discharge is therefore likely the result of complete degradation of TCE. It is also possible that some of the excess chloride is associated with ethene that was lost to volatilization; regardless, the chloride balance suggests that 1,074 kg of TCE was lost from the cell through degradation and discharge.

Table 2. Relative proportions of the total TCE mass removed from the cell.

Constituent	Net Discharge (moles)	Free Cl- Created (moles)	TCE-Eq (kg)
PCE	0		0
TCE	1,108		146
cDCE	3,575	3,575	470
VC	1,455	2,910	191
Ethene	544	1,632	71
Total Ethenes in Effluent	6,682	8,117	878
Free Cl-	12,585	4,467	196
		Total TCE removed or degraded (kg)	1,074

5 - CONCLUSIONS

The following conclusions and recommendations are proposed:

- The study confirms the requirement for multiple site characterisation methods at DNAPL sites. As yet no single technique is available to characterise a DNAPL site.
- Multiple metrics may be needed, particularly at sites where fewer monitoring data (spatial and temporal) are available.
- Uncertainty-based methods are not standard tools, but are a key component in evaluating clean-up.
- Sophisticated SI tools are applied to reduce uncertainty in delineating DNAPL mass distribution, but even at highly-instrumented sites, remediation engineers expect to work with large mass ranges.
- The quantitative methodology has demonstrated that EISB is effective at reducing source mass (50% DNAPL mass depletion in two years).
- Using the median DNAPL mass values resulted in a low estimate of TCE DNAPL removed from the cell. Based on a comparison to the effluent mass discharge, the 75^{th} percentile was a more favourable value at this site.
- Reducing uncertainty in quantifying whether the endpoint is reached requires increasing investment in performance monitoring. Performance monitoring optimisation and cost-benefit analysis are emerging areas that warrant further research.

6 - REFERENCES

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