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Technology Screening and Remedy Selection at Large, Complex DNAPL Sites: Orica Botany Case Study

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Introduction

"Complex" sites, with large releases in heterogeneous subsurface environments, present technical and institutional challenges that may result in lengthy delays between discovery and implementation of a remedy, and even longer delays in achieving remedial action objectives defined by "restoration." The technical barriers to aquifer restoration at these sites are well established, where complex sites are defined by the magnitude of the release, the types of contaminants, and the geologic environment. At these sites, restoration in a reasonable timeframe is unlikely regardless of the remedial technologies applied, and a critical management decision during the remedy selection process is to identify appropriate short- and long-term objectives and appropriately screen remedial technologies in consideration of these objectives. This presentation uses the Orica Botany Groundwater Cleanup Project as a case study to discuss the linkage between remedial goals and remedy selection, the use of conceptual technology assessments to bound the tradeoffs between source treatment costs and remedy duration, and the practice of periodically revisiting project objectives to consider remedial modifications based on evolving site conditions and advances in the state of remediation technologies.

Botany Groundwater Cleanup Project (BGCP) - Overview

The Botany Industrial Park (BIP) chemical complex was formerly owned by Orica and is now occupied by a number of individual chemical manufacturing companies. Historical operations resulted in soil and groundwater contamination on and adjacent to the site. Investigation and remediation of contamination at the site have been ongoing since 1989.

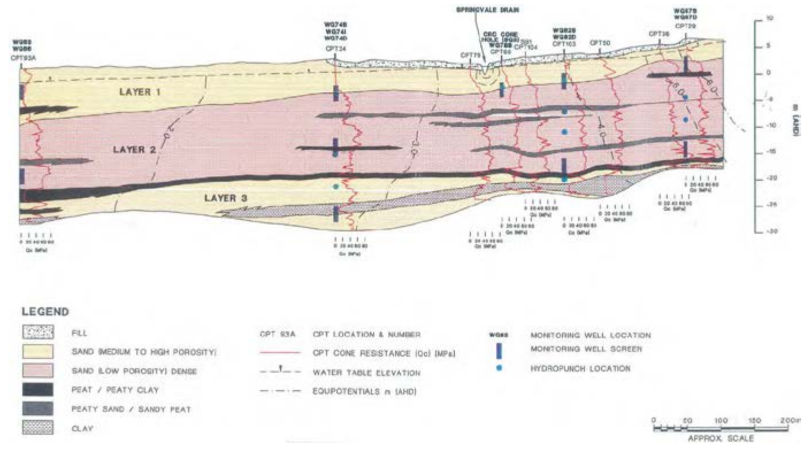

FIGURE 1: Geological cross-section (Woodward-Clyde, 1996).

Site geology (Figure 1) is characterized by relatively high transmissivity sand layers interbedded with layers of peat/peaty clay. The layers are highly variable in thickness and continuity across the site. Groundwater flow was historically variable, but is presently controlled by the operation of a groundwater extraction and treatment system.

Chlorinated hydrocarbons (CHCs) persist at the site as DNAPL, adsorbed to the aquifer matrix, and dissolved in groundwater. Multiple CHC sources are present, with elevated concentrations in groundwater extending to the Penrhyn Estuary (Figure 2). Estimates of CHC mass in the subsurface range from 9,600 to 19,400 tonnes.

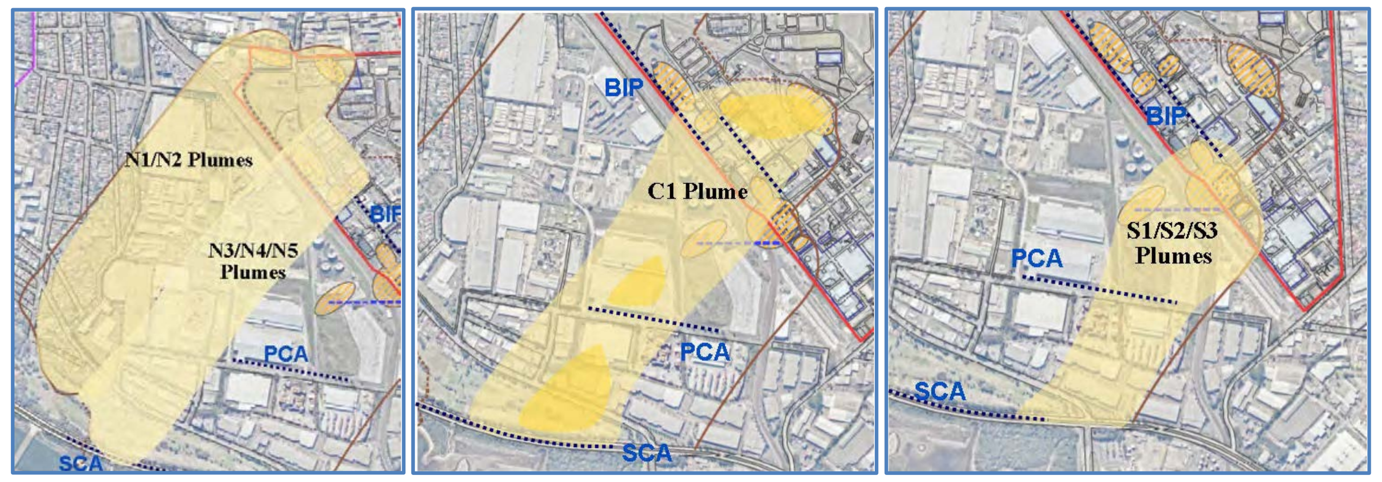

FIGURE 2: CHCs in groundwater downgradient of northern (left), central (center), and southern (right) sources (Orica, 2017).

Remedy Selection and Alternatives Screening

The initial BGCP remediation strategy included the following objectives:

1. Removal of DNAPL sources to extent practicable.
2. CHC plume containment and protection of human health and environmental receptors, including discharge into Penrhyn Estuary.
3. Monitoring the nature and extent of contamination to identify potential exposure pathways requiring management.

In consideration of Objective 1, two DNAPL source remediation technologies (steam injections, persulfate) were conceptually evaluated for implementability, cost, and likelihood of success to achieve restoration in context of site uncertainties and technical limitations.

Technology 1 – Steam Injection

Key conclusions:

- 70% mass removal potentially achievable over 11-year remedy duration at cost of $89M USD
- Key uncertainties – access to DNAPL beneath operating infrastructure, ability to reach mass removal objectives, impact on overall cleanup duration

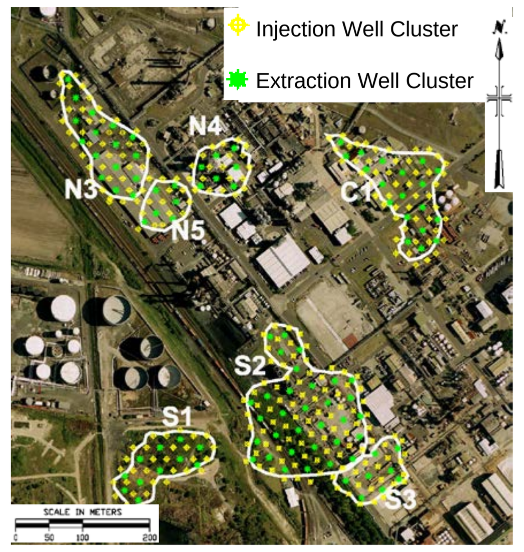

FIGURE 3: Conceptual layout, steam injections.

Technology 2 – Persulfate Injection

Key conclusions:

- Oxidant demand driven by contaminant demand; soil oxidant demand less than 5% (Table 1)

TABLE 1: Estimated persulfate demand.

DNAPL	Estimated DNAPL Mass (kg)	Mass of Persulfate Required (kg)
PCE	4,700,000	14,000,000
CTC	1,800,000	36,000,000
TCE	370,000	2,000,000
EDC	2,200,000	26,000,000
Subtotal	9,000,000	78,000,000
Persulfate Required to Satisfy SOD		3,000,000
Total Persulfate Demand		81,000,000

- Oxidant demand drives cost – estimated at $250M to $320M USD depending on access assumptions
- Technology not recommended – cost excessive compared to uncertainties

In consideration of Objective 2 and uncertainties regarding efficacy and benefit of DNAPL source removal, a revised strategy acceptable to regulator was developed, focusing on:

1. Hydraulic containment and *ex situ* treatment.
2. Hydraulic and chemical monitoring to assess remedy performance.
3. Periodic review of DNAPL and plume remediation technologies.

The current site remedy under a regulated cleanup program is groundwater extraction from 109 wells oriented in three transects perpendicular to the plume (Figure 4) with treatment and reuse of extracted water. Since startup, approximately 1,400 tonnes of CHCs have been extracted, although removal rates have been decreasing over time (Figure 5). Groundwater extraction has reduced discharge to Penrhyn Estuary below regulatory limits.

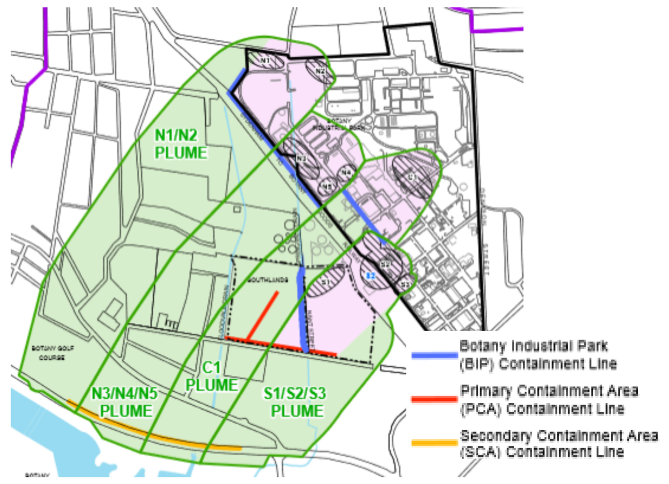

FIGURE 4: Groundwater extraction lines.

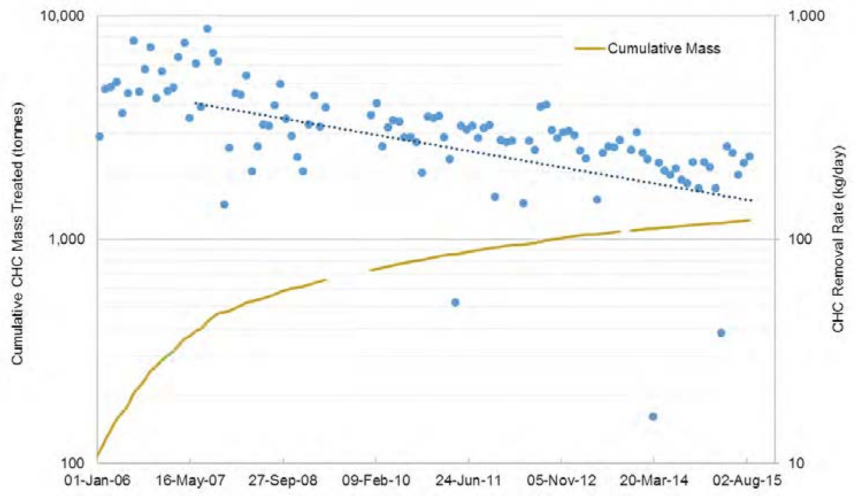

FIGURE 5: CHC mass removal (Orica, 2017).

Ongoing Expert Review

Consistent with regulatory requirements for the site, expert panels are periodically convened (~every three years) to evaluate potential technologies for CHC remediation (Table 2). Panel objectives include:

- Evaluating recent BGCP annual review reports and worldwide developments in site characterization and remediation technology
- Identifying promising current or emerging technologies for field trials
- Reaching consensus among stakeholders on efficacy of current remedial approaches and potential field trials of alternative technologies

TABLE 2: Partial list of technologies conceptually evaluated for DNAPL and groundwater plume remediation (2007-2017).

Technology	Evaluation Approach	Conclusions
ISCO (Persulfate)	Bench Test Cost Evaluation	Efficacy; cost ($300M) prohibitive
Direct Thermal Treatment (DTT)	Cost Evaluation	Recovery of up to 70% of mass (11 years, $90M); Not pursued – efficacy uncertain due to high groundwater flux and insufficient benefits for mass discharge reduction
Hydraulic Flushing	Conceptual Review	Not considered due to uncertainty in recoverable mass (1 – 1,800 tonnes)
Direct Recovery	Field Test	Test stopped due to low DNAPL recovery
ISCR (ZVI)	Bench Tests and major field trial of ZVI barrier	Limited ROI, clogging, excessive mass needed due to DNAPL
Source Containment	Calculations	Site limitations and uncertain effectiveness long term, long time frame
ISB	Lab tests, pilot tests, major field trial, limited scale-up assessment	Deserves closer look but limitations of biobarriers
Geochemical modification/pH adjustment to enhance attenuation	Qualitative evaluation	Challenges include injection well plugging and base demand; much greater return on investment if combined with bioremediation
STAR (Self-sustaining treatment for active remediation)	Qualitative evaluation	Requires delivery of air and evaporation of water; not currently practicable for depth of treatment required at Botany

Expert review conclusions to date (Orica, 2017)[1]:

- Current remedial strategy is technically appropriate and manageable
- Isolation or treatment of DNAPL sources is currently infeasible due to site constraints – partial DNAPL depletion is costly with uncertain benefits
- No transformative technologies for DNAPL treatment have been developed since 2007

Conclusion

Monitoring results collected to date suggest that the Botany remedy has been effective with respect to plume containment and control of CHC discharge to Botany Bay and Penrhyn Estuary. In addition, natural depletion of CHC sources since 2007 has exceeded expectations, suggesting the decision at the time to not immediately pursue source area remediation was appropriate. Although no transformative remedial approaches have been identified in the periodic reviews completed since 2007, the ongoing work to assess alternative approaches has resulted in a wealth of knowledge on natural source zone depletion rates and other factors that will inform future remedy modifications.

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1. 2017 Strategy Review available at: http://www.orica.com/Locations/Asia-Pacific/Australia/Botany/Botany-Transformation-Projects/Groundwater-Cleanup/publications-reports-and-reviews#strategy