CL:AIRE

CON 06
(November 2023)

Concawe bulletin

CL:AIRE's Concawe bulletins describe the deployment of sustainable remediation techniques and technologies on sites in Europe. Each bulletin includes a description of the project context and conceptual site model along with a sustainability assessment. This bulletin describes a sustainable remediation approach on a UK petrol station site.

Sustainable Remediation of a Petrol Release in a Chalk Aquifer

1. INTRODUCTION

The dissolution of unleaded petrol leaking from an underground storage tank system at a petrol station impacted a public water supply well in 2002. The petrol station was subsequently determined as contaminated land in 2004 under Part 2A of the Environmental Protection Act 1990. Remediation works were guided by a Part 2A remediation statement and sustainability was a key consideration in accordance with statutory guidance (Defra, 2012).

Initial investigation works were undertaken in 2003 with remediation works commencing in 2005. In 2013, AECOM took over ongoing risk management, remediation and verification works at the former petrol station and associated nearby residential properties. AECOM's objective was to manage risks resulting from the historical fuel release, and to achieve regulatory agreement to the cessation of remedial works for the petrol station and adjacent properties in accordance with the sustainable and risk-based approach used for contaminated land management in the UK.

Sustainability assessments were completed by AECOM at two stages of the project: firstly, to inform the future direction of remediation upon taking over the project in 2013; and latterly, to review compliance points in 2018.

2. SITE DESCRIPTION AND PROJECT CONTEXT

Methyl tert-butyl ether (MTBE) and tert-amyl methyl ether (TAME), both additives to unleaded petrol, were detected during routine analysis of drinking water quality from a public water supply well (supply well) in 2002. The supply well abstracted groundwater from the White Chalk Subgroup (Chalk) and the overlying Quaternary weathered chalk deposits. The Chalk, a calcitic limestone, is a Principal Aquifer and is widely utilised for groundwater abstraction in England. During the first year of monitoring MTBE concentrations were detected within the supply well at concentrations above the taste and odour threshold, but well below human health criteria.

The subsequent site investigations confirmed an active petrol station located 750 m from the supply well was the source of the MTBE.

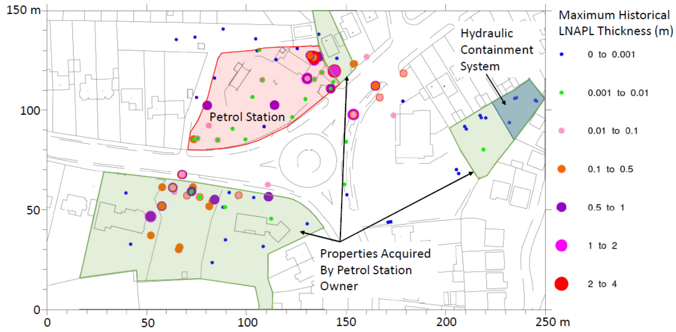

Figure 1: Site layout and historical LNAPL thickness.

Light-non-aqueous phase liquid (LNAPL) was identified beneath the petrol station which extended to off-site properties. Five of these adjacent properties were subsequently acquired by the petrol station owner to facilitate remediation activities. Figure 1 illustrates the historical LNAPL extent across the site and adjacent properties.

Dissolved-phase benzene, toluene, ethylbenzene, xylenes and naphthalene (BTEXN), MTBE and TAME were associated with the LNAPL. The BTEXN plume was primarily limited to the superficial deposits and extended a maximum distance of 80 m from the petrol station, in contrast to both MTBE and TAME, which were drawn into the abstraction and the plumes extended 750 m to the supply well. Figure 2 presents a schematic plan of the observed contaminant plumes extending from the petrol station to the supply well.

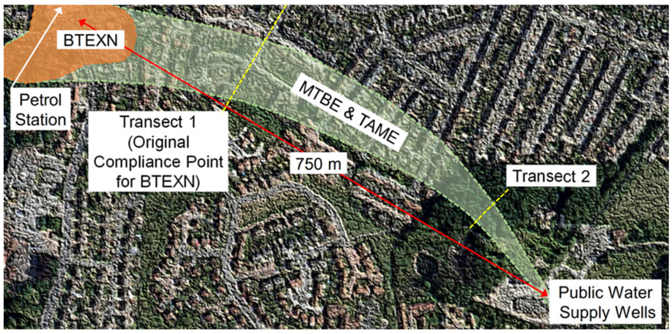

Figure 2: Schematic plan showing observed BTEXN and MTBE/ TAME plumes.

Concawe
Environmental Science for European Refining

For further information please contact the authors:
David Granger, AECOM Limited, david.granger@aecom.com
Lewis Jones, AECOM Limited, lewis.jones@aecom.com

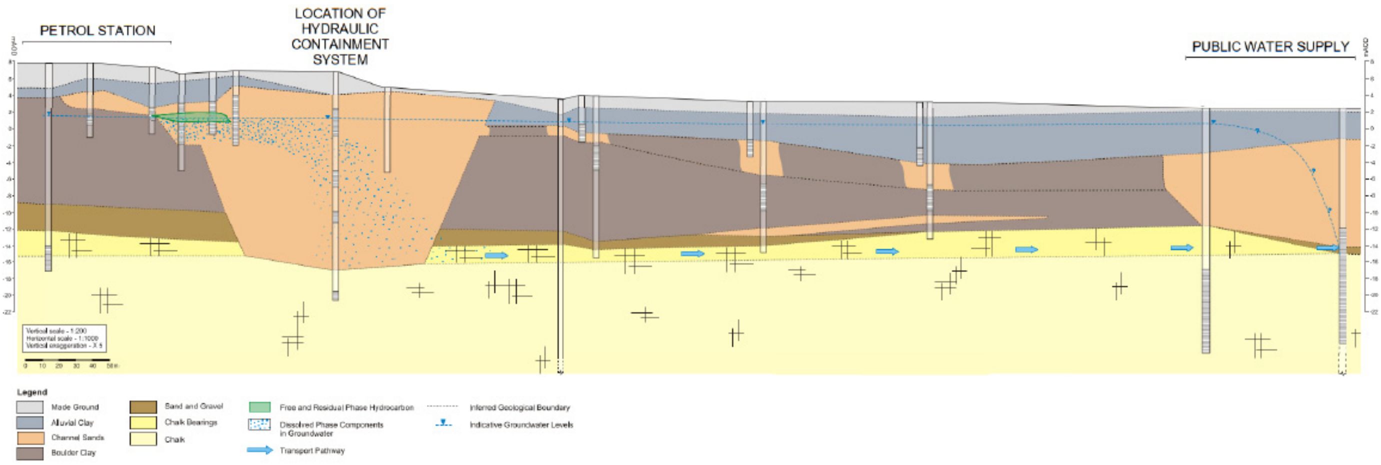

Figure 3: Conceptual site model (modified from Worley Parsons, 2012).

The site investigation and evidence of fuel leakage from the underground storage tank system led to the decommissioning of the petrol station in 2005 and removal of the tanks along with petroleum-impacted soil immediately surrounding the tanks.

3. CONCEPTUAL SITE MODEL

The petrol station was situated on made ground overlying the Devensian Till. Directly down hydraulic-gradient and adjacent to the underground storage tanks is a glaciofluvial channel comprising sands and gravels (referred to as the 'sand channel') which provides hydraulic connection between the petrol station and the underlying Quaternary weathered chalk deposits and the Chalk.

The primary potential groundwater transport mechanism between the petrol station and the supply well was downward movement through the sand channel into the weathered chalk deposits. The subsequent horizontal transport occurs via a relatively thin high transmissivity zone in the Quaternary weathered chalk deposits and is then captured by the supply well as illustrated in Figure 3.

4. REMEDIAL ACTIVITIES

A visual timeline of remedial activities is presented in Figure 4. Activities focused on source characterisation and pathway assessment, risk assessment, source remediation and pathway interception (to prevent further contaminant migration to the receptor).

Source remediation activities removed a significant volume of hydrocarbons through LNAPL skimming, soil vapour extraction and total fluids extraction on the petrol station and soil vapour extraction on one of the adjacent properties.

In 2010, an hydraulic containment system was installed approximately 100 m down hydraulic-gradient of the petrol station to break the pathway between the source and the supply well. The system was installed at a location where natural attenuation processes had already degraded the BTEXN and hence the abstracted groundwater (containing only MTBE and TAME) could be discharged to foul sewer.

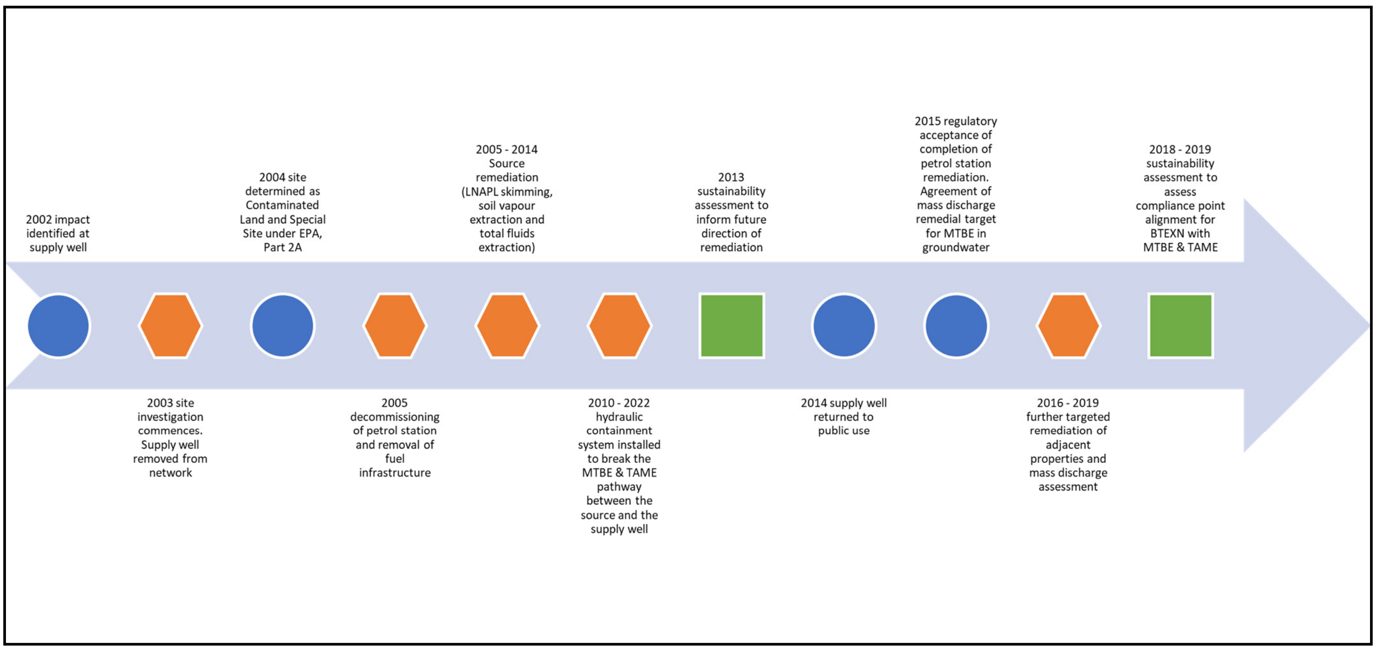

Figure 4: Timeline for remedial activities.

Upon commencement of the hydraulic containment system MTBE and TAME concentrations at the supply well rapidly reduced to below method detection limits within the year, and all abstracted water was able to be returned to public supply by 2014. The rapid reduction in concentrations at the supply well provided further support that the dominant migration pathway to the supply well was through the Quaternary weathered chalk deposits and not through the competent Chalk where matrix diffusion would have been expected to sustain the plume for a longer period following operation of the hydraulic containment system.

In 2012, remedial criteria were agreed with the Environment Agency which reflected the demonstrated natural attenuation capacity of the subsurface with respect to BTEXN. The subsequent focus of remediation was therefore on source reduction and ongoing pathway interception for MTBE and TAME.

5. INTEGRATION OF SUSTAINABILITY ASSESSMENTS WITHIN REMEDIATION

5.1 Initial sustainability assessment to support future remediation strategy

In 2013, a Tier 1 SuRF-UK-based sustainable remediation assessment was undertaken to identify the optimum risk management strategy to remediate the site. The principles of sustainable remediation were applied to the evaluation of the remedial options, which needed to meet three objectives:

- Achieving regulatory closure for remediation of the MTBE and TAME in the source area;
- Returning the petrol station site and associated acquired properties to beneficial use as soon as practically possible; and
- Mitigating any risks to human health, and to the future use of groundwater at the supply well based on taste and odour criteria.

Table 1 presents the five remedial options identified for achieving these objectives.

Table 2 presents the SuRF-UK sustainable remediation criteria, covering the three sustainability elements of environmental, social, and economic, which were chosen for the assessment.

Those criteria highlighted in bold were considered the most important by stakeholders but as this was a Tier 1 assessment the criteria were not weighted according to their importance. For each criterion, the assessment was based on comparison against an idealised situation or goal, (for example no emissions, minimise cost, maximise benefit), and the options were ranked accordingly from 1 (best) to 5 (worst). Where the differences between two or more options were marginal the options were ranked equally. The culmination of the assessment was therefore a comparison table which qualitatively ranked each option according to assessment criteria, together with the rationale for the ranking. The assessment was undertaken using a spreadsheet tool developed specifically for the assessment, and was latterly provided as the URS (a heritage AECOM company)-based SuRF-UK Tier 1 spreadsheet now available on the CL:AIRE website.

Implementation of the assessment process took place in two phases. The first assessment was completed by an Internal Stakeholder Team, consisting of the petrol station owner and their consultant URS. This assessment was then reviewed and amended by an External Stakeholder Team consisting of representatives from the Environment Agency, the Local Authority and the Water Company. The importance of stakeholder engagement was highlighted by the input from the External Stakeholder Team which increased the scoring associated with natural resources and waste, project lifespan and flexibility and ethics and equity for Option 1E (hydraulic containment only) resulting in this option moving from first to third place in the ranking of options. The increased scoring resulted from stakeholder concerns over the duration of this option and the ongoing discharge of groundwater to sewer from the containment.

Table 1: Remedial options evaluated.

Option	Details	Predicted duration of remedial activity (years)		
		Source mass recovery using soil vapour extraction and total fluids extraction	Groundwater remediation below three adjacent properties	Hydraulic containment system operation
1A	Continuing with the existing remedial systems	5	0	15
1B	As 1A, but reduced duration of active source mass recovery focusing on hot-spot areas	3	0	15
1C	As 1A, but more aggressive source area remediation (well replacement, increased vapour and groundwater abstraction, treatment and discharge)	2	0	10
1D	Continued operation of the hydraulic containment system combined with remediation of groundwater below three of the adjacent residential plots (well installation, total fluids abstraction, treatment and groundwater discharge)	0	2	5
1E	Stopping source-area remediation and continuing only with hydraulic containment system operation	0	0	20

Concawe bulletin

Table 2: Criteria used to assess sustainability of options.

Environmental	*Economic*	*Social*
Emissions to air (minimise; air quality impact dominated by power consumption)	**Direct economic costs and benefits** (minimise cost, maximise benefit)	**Human health and safety** (maximise site safety and minimise potential for spills; hazard removal preferable to long term risk management)
Soil and ground conditions (maximise improvement in soil quality)	Indirect economic costs and benefits (return of properties to use in shortest time)	Ethics and equity (minimise transfer of impacts to future generations)
Groundwater and surface water (maximise improvement in groundwater quality)	Employment and employment capital (maximise)	Neighbourhoods and locality (minimise impact, maximise benefit)
Ecology (prevent deterioration in ecological systems)	Induced economic costs and benefits (minimise time for inward investment)	Communities and community involvement (maximise functionality of the impacted properties)
Natural resources and waste (minimise resource usage and waste generation)	**Project lifespan and flexibility** (most robust, most flexible, permanent solution, minimum operation period)	**Uncertainty and evidence** (minimise uncertainty and maximise quality of evidence)

The ranking of the options is illustrated graphically in Figures 5 and 6. Considering all 15 criteria, Options 1C and 1D were the highest-ranking (lowest scoring) option. Option 1D (targeted source reduction on adjacent residential properties combined with continued hydraulic containment system operation) was ranked highest when only the priority criteria were considered, hence it was selected as the preferred option.

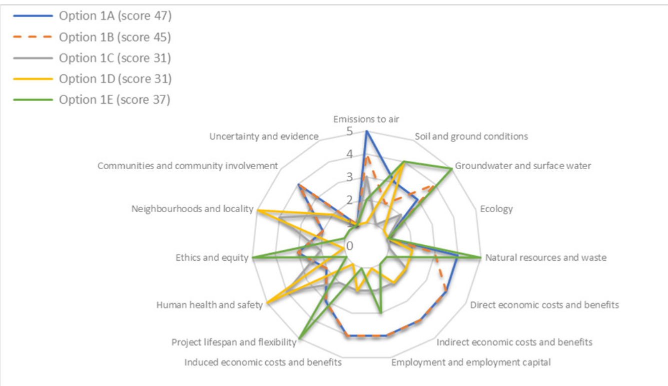

Figure 5: Individual and cumulative scores for all criteria – 2013 assessment. NB: low scores = most sustainable option.

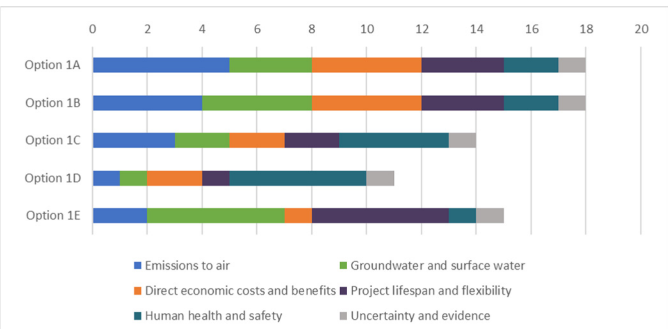

Figure 6: Cumulative scores for six priority criteria – 2013 assessment. NB: low scores = most sustainable option.

From the radar plot for each option it can be seen that Option 1D is highly ranked (lower scoring) in all criteria with the exception of the criteria for soil and ground conditions, human health and safety and neighbourhoods and locality. The sustainability assessment indicated that the additional improvement in these criteria provided by the alternative options was not justified by the additional benefits or impacts defined by the other criteria.

5.2 Implementation of Option 1D remediation solution

Cessation of active remediation on petrol station

In line with Option 1D, the soil vapour extraction and the total fluids extraction systems were removed from the petrol station site in 2014, once asymptotic recovery was reached. Regulatory approval for completion of remediation at the petrol station was received in 2015, following one year of post-remediation validation monitoring and confirmation that remedial criteria for the petrol station had been met.

Continued operation of the hydraulic containment system

Whilst the remedial targets were met for the petrol station, there was a continued need for operation of the hydraulic containment system to manage the remaining MTBE and TAME plume which was sustained by impacts that had migrated beyond the petrol station boundary.

Between 2014 and 2015 works focused on updating an existing numerical groundwater flow and contaminant transport model to assess the performance of the hydraulic containment system under a range of likely future abstraction regimes. The modelling supported field observations that the hydraulic containment system would continue to capture the dissolved MTBE and TAME plume as illustrated in Figure 7. It was therefore proposed that mass discharge at the hydraulic containment system provided a better metric than source zone groundwater concentrations to determine when concentrations of MTBE and TAME no longer presented a risk to the

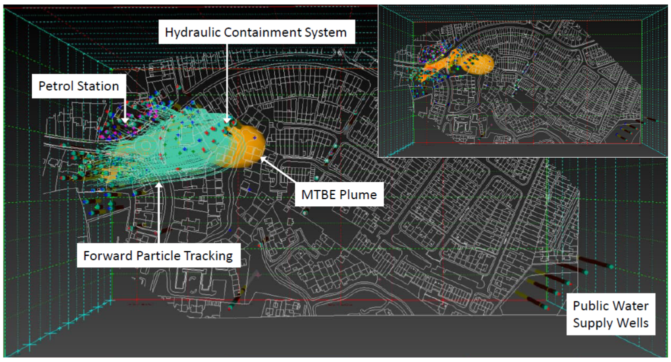

Figure 7: Modelled hydraulic containment system capture zone and MTBE plume.

public water supply. Continued operation of the hydraulic containment system was coupled with routine monitoring of groundwater quality within the source area, at the hydraulic containment system, at wells along two transects downgradient of the hydraulic containment system and at the supply well.

Mass discharge remedial targets for assessing remedial close-out for MTBE (and latterly TAME) were developed adopting the 10th percentile abstraction rate for the public water supply (i.e. 90% of the time the public water supply will be pumping at volumes greater than assumed target rate) and an agreed ceiling concentration based on conservative taste and odour thresholds within the blended public water supply. The MTBE target was agreed with the regulators and stakeholders, including the water supply company, in July 2015. The Environment Agency confirmed this was the first time a mass discharge remedial target had been agreed with them.

Since 2010 the hydraulic containment system has operated successfully with an operational efficiency of over 99%. By 2018 approximately 690 kg of MTBE and 315 kg of TAME had been removed in the discharge as a result of its operation and MTBE and TAME concentrations have continued to be below method reporting limits in the supply well.

Groundwater remediation below adjacent properties

The other element of Option 1D comprised the remediation of groundwater below three of the adjacent properties to accelerate the improvement in groundwater quality for MTBE and TAME to reduce the operational duration of the hydraulic containment system. Based on residual source concentrations and historical concentrations detected at the supply well, MTBE posed the dominant residual risk to the supply well. Focused short-duration source zone remediation works were undertaken at one of the adjacent residential properties in 2016 using total fluids extraction. Whilst the initial MTBE recovery rate was above that for the hydraulic containment system, within two months the mass recovery rate declined to rates of recovery below that achieved by the hydraulic containment system.

To focus further remedial activities the mass discharge of MTBE was assessed across a series of transects through the source area in 2017.

5.3 Further sustainability assessment to assess compliance points

A second sustainability assessment was completed in 2018 and looked specifically at whether the hydraulic containment system could be switched off once the MTBE mass discharge remedial targets had been met (Option 2A) or whether the hydraulic containment system should continue to be maintained to prevent periodic exceedances of BTEXN at a compliance point located upgradient of the supply well at transect 1 (Figure 2) (Option 2B). It should be noted that the supporting groundwater modelling and historical groundwater quality data at the supply well did not predict an exceedance for BTEXN at the supply well.

Both options included further short-duration targeted MTBE mass recovery from the one remaining residential property where MTBE mass discharge was calculated to exceed the mass discharge remedial target together with passive sulfate injection across the source area to stimulate anaerobic biodegradation of residual hydrocarbon mass.

Fifteen criteria across the three sustainability elements were selected again, and this time some of the criteria were supported by quantitative estimates of costs and benefits based on existing knowledge of system operational cost. A pairwise comparison of the two options was made with the options ranked again from 1 (best) to 5 (worst). The output of the Tier 1 assessment is presented in Figures 8 and 9.

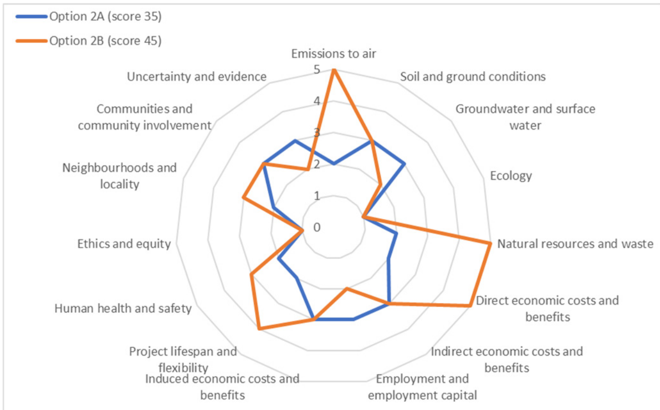

Figure 8: Individual and cumulative scores for all criteria – 2018 assessment. NB: low scores = most sustainable option.

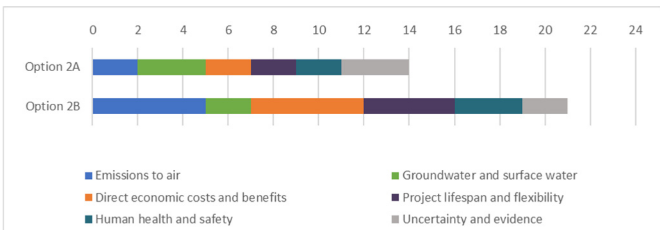

Figure 9: Cumulative scores for six priority criteria – 2018 assessment. NB: low scores = most sustainable option.

Considering all 15 criteria, Option 2A was the highest-ranking (lowest scoring) option. From the radar plot for each option it can be seen that Option 2A scored equal or better than Option 2B in all criteria with the exception of the criteria for groundwater and surface water, employment and employment capital and uncertainty and evidence. The sustainability assessment indicated that the additional improvement in these criteria provided by the alternative option (continuing to run the hydraulic containment system post-achievement of the mass discharge remedial target) was not supported by the additional benefits or impacts defined by the other criteria. The high scores for Option 2B were related to emissions to air, natural resources and waste, direct economic costs and benefits and project lifespan associated with continuing to run the hydraulic containment system. Impacts on these criteria relate to the electricity consumption, discharge of groundwater to sewer and operational and maintenance costs associated with the extended operation of the hydraulic containment system.

The results of this assessment were used to align the compliance point for BTEXN with that for MTBE and TAME i.e. the supply well. This approach was accepted by the regulators.

5.4 Additional remediation to support return of acquired properties to beneficial use

In accordance with Option 2A, further focused short-duration source zone remediation works were undertaken at the one adjacent residential property exceeding the MTBE mass discharge remedial target in 2018 using total fluids extraction. Similar to the previous trial, the MTBE recovery rate declined to rates of recovery below that achieved by the hydraulic containment system within 6 weeks of commencement. Given the additional water treatment required for abstracted groundwater from these pilot trials (due to the presence of BTEXN) as opposed to groundwater abstracted from the hydraulic containment system (predominantly BTEXN free as a result of natural attenuation), further source zone remediation of MTBE mass present below properties adjacent to the petrol station was not considered sustainable. In addition, the residual MTBE mass discharge from this property post-trial was calculated to be below the mass discharge target.

Following the reduction of MTBE within the source area, passive injection of sulfate was carried out to further stimulate anaerobic degradation of the residual hydrocarbon mass in this area to increase the availability of other electron acceptors for MTBE biodegradation (Figure 10).

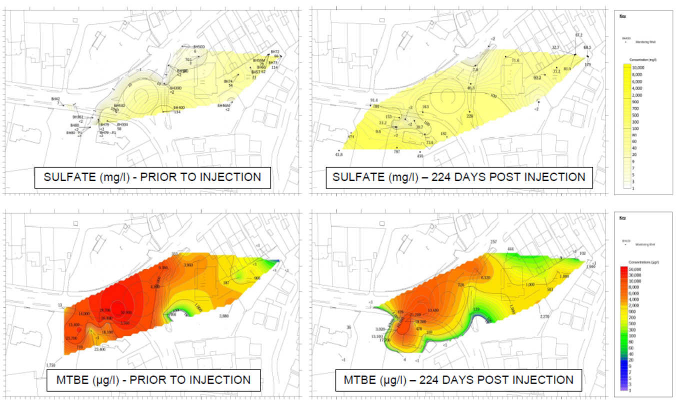

Figure 10: Sulfate and MTBE concentrations in groundwater prior to, and post, passive injection of sulfate.

Sulfate solution was successfully injected under gravity into selected wells to promote the attenuation of dissolved-phase hydrocarbons via biodegradation. Background sulfate concentrations were relatively low prior to the addition of sulfate. Approximately 6 weeks after completion of the sulfate injection, wells located outside of the main hydrocarbon impacted area where sulfate had been injected reported sulfate concentrations above background concentrations. The persistence of sulfate concentrations in these wells was inferred to be due to the lack of hydrocarbons restricting the activity of sulfate reducing bacteria.

In contrast, groundwater samples collected from wells located 5-10 m downgradient of the injection wells and located in areas of high concentrations of BTEX detected very low concentrations of sulfate. The low concentrations are understood to be a result of sulfate being utilised for the degradation of hydrocarbons by sulfate reducing bacteria. This was further supported by quantitative analysis of sulfate reducing bacteria and decreases in BTEX concentrations in these wells.

Concentrations of aerobic MTBE degrading bacteria were detected at locations across the project area but were clearly predominant in areas where BTEX concentrations were low or below the laboratory method detection limit. This indicated that where BTEX were not present to utilise oxygen for aerobic degradation the aquifer was sufficiently aerobic to support MTBE biodegradation by specialised MTBE degrading bacteria, which are already present within the aquifer. This was confirmed in laboratory microcosm experiments.

5.5 Regulator acceptance of source-zone remediation on acquired properties

MTBE mass discharge was assessed below four of the acquired properties to demonstrate whether the mass discharge target had been met. The hydraulic containment system was located on the fifth property and hence remediation continued at this property. The TAME mass discharge target had already been met at the hydraulic containment system and hence did not need assessment on a property-by-property basis.

The achievement of mass discharge targets for MTBE and TAME together with the achievement of concentration-based remedial targets for BTEXN below the four acquired properties led to regulator agreement that no further monitoring or remediation works were required at these properties. Each property could then be divested by the petrol station owner and returned to residential use.

5.6 Ongoing operation of the hydraulic containment system

The hydraulic containment system continued to operate to protect groundwater quality at the supply well from MTBE. To facilitate closure of the system, AECOM completed a review of historical MTBE attenuation between the petrol station and the supply well and developed a clear road-map for closure which was accepted by the Environment Agency.

6. PROJECT HIGHLIGHTS

Key project highlights include:

- Regulator-endorsed closure of remedial activities on the petrol station through attainment of concentration-based remedial targets;
- Innovative use of mass discharge remedial targets to achieve regulator-endorsed closure of remedial activities on all four properties adjacent to the petrol station, thereby allowing a return to beneficial use;
- Application of sustainability assessments to inform future remedial strategy and to review the appropriate adoption of compliance points; and
- Use of historical attenuation data to establish a road-map for closure of the hydraulic containment system.

7. LESSONS LEARNED

Sustainability forms part of the overall solution in complex cases - and often forms part of a final exit strategy. Prior to implementation the site conceptual model needed to be thoroughly understood through detailed on and off-site investigation, modelling and risk assessment - and closure could not have been achieved utilising sustainable assessment without this foundation.

These cases rarely are fast - and in the same way as traditional solutions they are not fit and forget. Successful implementation takes robust site characterisation, stakeholder engagement, adjustment and strategic flexibility.

8. CONCLUSIONS

Sustainability assessments were applied to identify the most sustainable remedial solution to address impacts to groundwater associated with the historical operation of a petrol station that had impacted a public water supply.

Tier 1 SuRF-UK-based sustainable remediation assessments were completed at two stages of the remediation works to identify the optimum risk management strategy for achieving regulatory closure for the ongoing remediation works, based upon the principles of sustainable remediation. The first assessment applied the principles of sustainable remediation to the assessment of five broad options for meeting remedial objectives. The second assessment was completed to evaluate the sustainability of additional remediation required to protect groundwater quality upgradient of the supply well. The assessments resulted in the adoption of the most sustainable remedial solution, were endorsed by the regulators and led to the cessation of monitoring and remediation works on the affected properties.

Key takeaways include:

- Proper characterisation of the situation is vital - closure cannot be achieved without good assessment and conceptualisation;
- Sustainability comes only after the situation is well understood and remedial options have been assessed;
- Stakeholder engagement is critical in shaping and ultimately endorsing the assessment findings; and
- Sustainability is an integral part of contaminated land management - from start to end, it was reassessed and all parties need to be kept engaged during this process.

REFERENCE

- Defra, 2012. Department for Environment, Food and Rural Affairs, Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance, April 2012.