Combined Remediation of Contaminated Soils and Groundwater at a Site on Cow Lane, Watford.

1. Site Description

The site comprised a former industrial facility with a long history of manufacture using non-chlorinated solvents. Being located in a predominantly residential area, the site had been identified as being ideal for a change to residential land use. The geology of the site comprises sandy gravels overlying The Chalk with the water table at approximately 11 metres below ground level (bgl) within The Chalk.

The contamination at the site was mainly confined to two distinct sources within the overlying sandy gravels with some localised hotspots in other areas. Previous site investigation works had revealed that the contamination from the two main sources had led to two distinct plumes of groundwater contamination which had remained fairly localised due to low levels of infiltration at the site during its industrial use. The suite of contaminants of concern were associated with light molecular weight hydrocarbons ranging from C_6 through to C_{16}, including aromatic and aliphatic classes.

Ecologia were requested to implement a remediation scheme that would minimise off-site disposal and would address the contamination issues whilst utilising a minimum area of the site during the remediation works so that other groundworks could be progressed concurrently. The scheme was required to address the two sources of contamination within the sandy gravels, the groundwater contamination and the various hotspots from around the site with a degree of flexibility to allow material that had not been identified during the site investigation to be treated as and when it was found during the groundwork.

2. Remediation Description

The scheme implemented by Ecologia included four distinct remediation technologies to remediate the site within the required timescale and in accordance with the client brief. The technologies that were implemented were:

- Soil Vapour Extraction (SVE) to remove contaminants from the larger of the two source areas, in the centre of the site;
- Ozone Sparging to treat contaminated groundwater beneath both distinct sources areas;
- Ex-Situ Bioremediation to treat material from the second source area and localised hotspots from around the site, and;
- Radio Frequency Soil Heating to improve the action of the SVE system in the centre of the main source area.

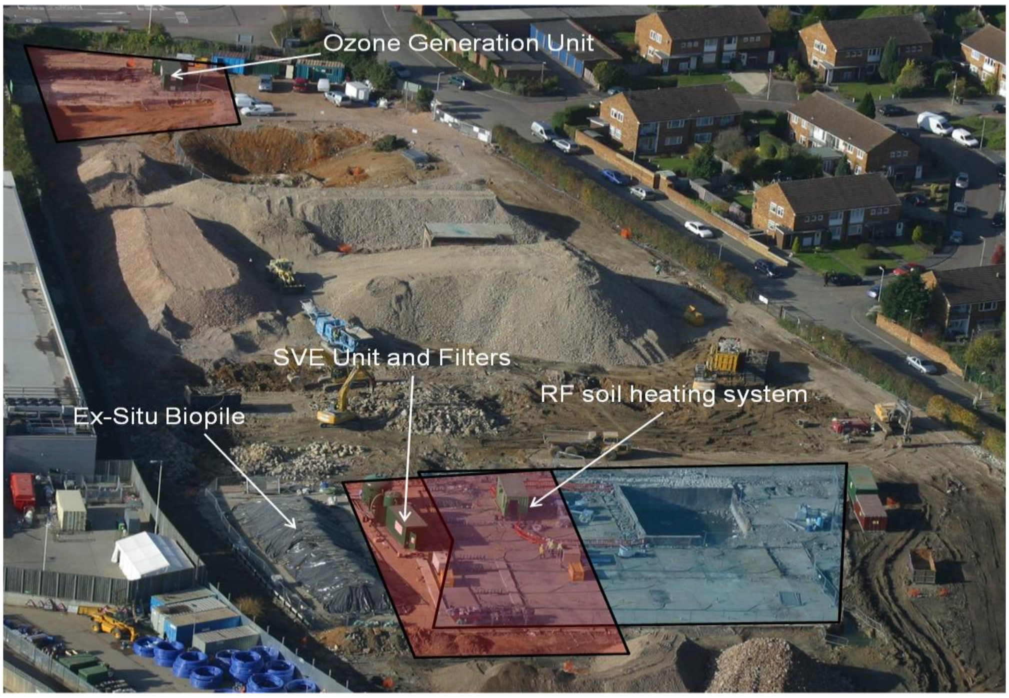

Figure 1. Aerial photo of the remediation layout during the remediation project – Areas in red underwent ozone sparging; the area in blue underwent soil vapour extraction.

Ecologia undertook all aspects of the remediation installation and operation and the following is a summary of each part of the scheme:

1. The SVE system comprised a total of 58 wells drilled to 8 metres bgl with a hollow stem auger technique to allow PID profiling of the contaminated zone. The SVE system was driven by a single vacuum pump system, designed and built in the UK by Ecologia. The system included Granular Activated Carbon (GAC) filtration of the off gases, comprising a two stage filter, the first with 12 tonnes of GAC and the second with 4 tonnes of GAC.
2. The ex-situ bioremediation system was constructed to treat material from the second source area and the hotspots identified around the site. The ex-situ biopile was continuously aerated using extraction pipework system coupled to the SVE unit and was covered for the duration of the treatment.
3. The Radio Frequency soil heating system was used in four batches to heat the centre of the central source area to approximately 50^{o}C, improving the rate of solvent desorption and subsequently improving the effectiveness of the SVE system. This reduced the programme timescale compared to undertaking the process using traditional ‘cold’ SVE.
4. The Ozone sparging system utilised an ozone generation system, designed and built in the UK by Ecologia, coupled to sparge points installed to 20 metres bgl using Ecologia’s sonic drill rig. The wells were designed to provide ozone to the top 10 metres of the saturated aquifer. The action of the ozone is designed to provide a chemical oxidative effect and also to oxygenate the aquifer to stimulate in situ bioremediation.

3. Health and Safety, Best Practice, Environmental Permitting and Stakeholder Acceptance

Prior to the commencement of the remediation operation, regulatory liaison was required in order to agree the deployment form and the inherent environmental monitoring and controls required therein. All the remediation plant used was fully automated with two way telemetric control allowing the project manager and maintenance engineers to be notified by SMS message of any faults or maintenance requirement.

- **Off gas monitoring –** Fugitive emissions of ozone were monitored continuously throughout the project with automated shutdown of the ozone generator in the event of any concentration of ozone being detected at ground level in either of the sparge zones.

  The outlet of the first GAC filter coupled to the SVE system was continuously monitored with an automatic data logging vapour analyser, designed and built by Ecologia, to ensure that no vapours were released to atmosphere; the second filter would always provide a backup in the event of breakthrough of the first filter, allowing with time to organise replenishment of the filter without system downtime.
- **Environmental permit (EP) –** The works were undertaken under the details of a deployment form submitted to deploy our EP ref: EAWML10088. Power for the system was provided by a generator. A noise survey was carried out prior to commencement of the remediation process to assess whether the noise from the generators and remediation plant could affect the nearby residential properties. Sound-proofing was subsequently installed around the generators to meet the Local Authority’s requirements.
- **Groundwater monitoring –** During the works a network of 20 groundwater monitoring wells was routinely sampled and tested for the contaminants of concern to provide validation data and to demonstrate, under the terms of the deployment form, that the remediation scheme was not causing an exacerbation of the groundwater pollution by spreading the plume of contamination, which is a genuine risk associated with sparge works.
- **Electromagnetic field generated by the RF system –** The electromagnetic field generated by the electrodes was fully contained within specialist Faraday cages, designed and built by Ecologia. In the event of trespass by unauthorised personnel into the treatment area or access to the Faraday cages, an infrared fence would shuts down the system automatically. The system was operated with daily attendance and it had additional safety systems associated with the on line soil temperature sensor array which will shut down the generator in the event of excessive heat produced near the electrodes or at the boundary of the treatment area.
- **Monitoring of the electromagnetic field -** The intensity of the electromagnetic level outside the Faraday cage is lower than that generated by a mobile telephone and below the most recent

guidance for time varying electromagnetic field for the general public published in the ICNIRP guidelines, 1998. This is the most restrictive guidance currently available.

- **Stakeholder acceptance –** In addition to the agreement of the relevant regulators the neighbouring business and residents were visited and the remediation scheme explained, particularly the health and safety protection measures that were implemented.

4. Remediation Performance - Reduction of the Pollution Burden

Ex-Situ Bioremediation

The process of bioremediation is designed to mineralise hydrocarbon contamination and therefore effectively remove the pollution burden form the contaminated site. Bioremediation is a well documented process and on this site the process was monitored on a weekly basis by gathering temperature measurements from thermocouples buried in the biopile and a suite of landfill gases measured from soil gas probes within the biopile. Respiration tests were carried out by switching the extraction system off line and determining the rate of oxygen depletion. This was an average reduction for 18% oxygen to 10% oxygen within 4 hours, demonstrating a good level of biological activity during the project.

Soil samples were taken on five occasions during the bioremediation with a reduction of all contaminants of concern to below the agreed soil target values without exception and no statistical analysis was required.

SVE

During the installation of the SVE wells a profile of contamination was recorded with field headspace tests using a hand held PID. This was undertaken to ensure that wells were being placed within areas that were contaminated and effort was not wasted extracting gases from ‘clean’ parts of the site. Wells found to be free from vapour during the installation works were abandoned or moved.

During the remediation process the performance was monitored on a daily basis by measuring the concentration of raw vapour at each extraction well with a hand held PID. This data was used to generate the plan view patterns exemplified in Figure 2. This information was used to communicate to stakeholders the effectiveness of the system within progress reports.

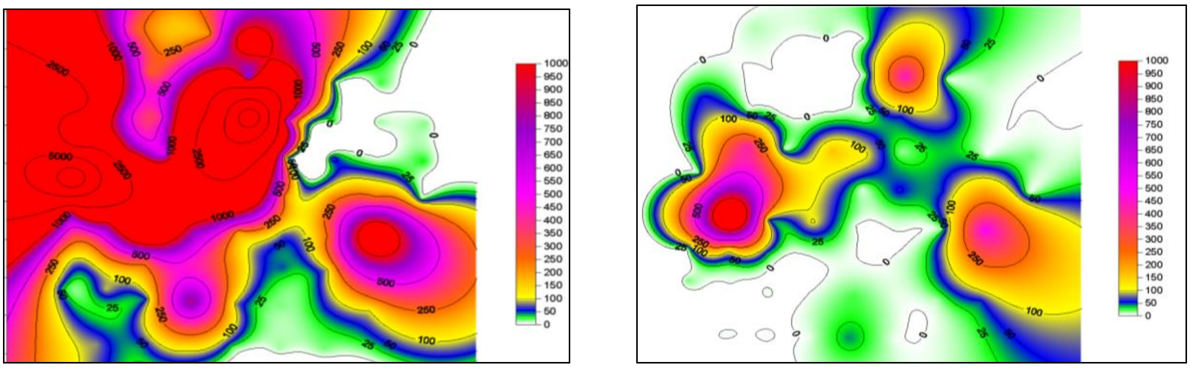

Figure 2: PID monitoring pattern at the start and end of the SVE works.

During the process the mass contaminant removal was also monitored with a datalogging automated volatile hydrocarbon analyser, designed and built by Ecologia. Approximately 3.5 tonnes of solvent vapour were removed from the ground and filtered from the off gases. Using the data from the PID monitoring and the mass removal data, an estimate of contaminant removal was made and soil validation samples were subsequently taken from the treatment area using a hollow stem auger technique. Samples were taken at three depths in the soil profile on a $10m^2$ grid, calculated using the method for hotspot detection provided in CLR4. Following the sampling of the soils a total of 6 samples returned elevated concentrations of two of the contaminants of concern. It was agreed with regulators that a US95 analysis of the data be undertaken and this revealed that the remediation had been successful.

RF Soil Heating

The RF heating process was monitored by measuring the temperature profile in three dimensions using thermocouples and fibre optic heat sensors. During heating the process was manned daily and once the desired temperature was reached the heating system was switched off line and moved to a new area or batch. Temperatures of an average of 50°C were reached within two weeks per 250m^3 and overall approximately 1000m^3 was heated in situ. Following heating, the mass recovery from the SVE system increased from approximately 10kg/day to over 50kg / day within the area that was heated.

Ozone Sparging

In-situ mass destruction was the aim of the sparging works rather than recovery of contaminants to the surface as is the case with a sparging / SVE combination designed to simply volatilise the contaminants. The sparging was not undertaken at a pressure required to volatilise the contaminants. The process at Cow Lane was monitored with groundwater samples, analysed for the contaminants of concern and dissolved oxygen within the sparge zone and downgradient of the sparge zone. Dissolved oxygen concentrations increased from an average 1.2 ppm to in excess of 4.5 ppm, demonstrating adequate oxygenation of the aquifer (figure 3). This increase occurred within three weeks. The contaminants of concern were reduced by 95%, with rebound monitoring revealing a true reduction of approximately 80% which was sufficient to reduce the contaminant load to below the agreed remediation target.

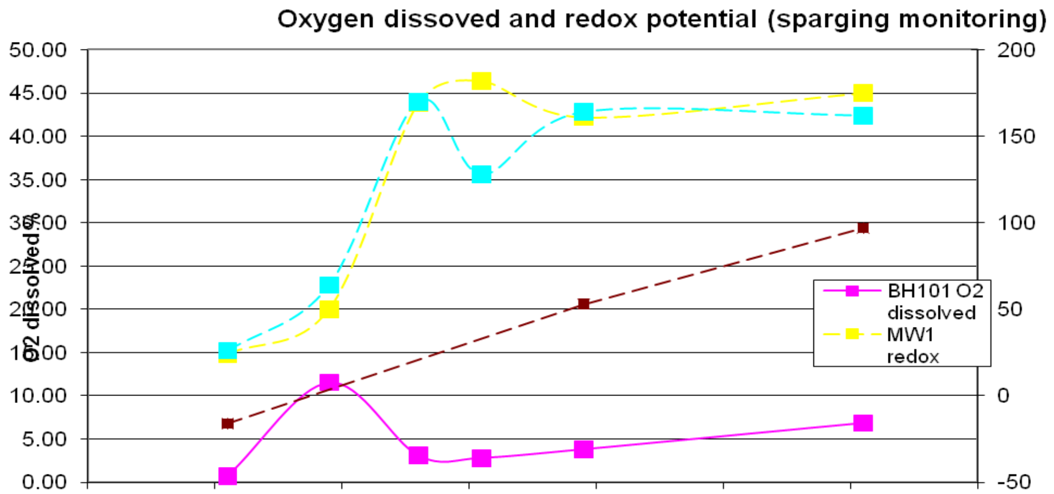

Figure 3 Increase in dissolved oxygen and redox potential during ozone sparging of the central area.

5. Cost effectiveness and Durability.

The overall scheme was priced at £410,000 and successfully treated approximately 21,500 tonnes of material within several months. In addition, two solvent groundwater plumes were effectively remediated by the ozone sparging presenting excellent value at approximately £19 per tonne for the unsaturated zone alone. The value of the project included the drilling works, remediation plant, monitoring and maintenance of the system. All the work was undertaken in situ or on site, thus haulage of contaminated soil and other material was not required, making the process more sustainable. Additionally, the use of an active process that induced genuine sub-surface mass transfer allowed the process to be undertaken and signed off within a reasonable timeframe, rather than long term monitoring of dissolution by natural aquifer processes.

The works were undertaken without the requirement for sub-contract which gave the client surety of contract and control over site operations.

During the works a total downtime of approximately 1 week was sustained. This resulted from the breakdown of a vacuum pump in the SVE system due to wear and tear which was replaced within four days; this rapid reaction was possible because Ecologia built the equipment in its workshops in Kent, allowing the engineers who built the system to repair it rapidly with stock items held at our premises. One further day of downtime was sustained when the GAC filter was replenished.

The durability of the groundwater remediation was demonstrated by the results of the groundwater monitoring following the ‘rebound period’. The remainder of the remediation works focussed upon the unsaturated zone and validation was undertaken with soil sampling, therefore no rebound period was applicable.