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REMEDIATION OF A SUBSURFACE HYDROCARBON PLUME AT A MANUFACTURING FACILTY IN ALBERTA USING A VACUUM ENHANCED RECOVERY SYSTEM

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Abstract

The subject property is an industrial site located in the southern Alberta. Several subsurface investigations have revealed the presence of free-phase gasoline and a dissolved phase groundwater plume underlying the site and adjacent properties. The source of the petroleum hydrocarbons was identified as two former underground storage tanks on the Site. The extent of the free-phase plume was estimated to be approximately 2,300 m^2 in area.

An assessment of remedial options was conducted to identify the most cost-effective method to mitigate the subsurface contamination within the schedule and site management requirements of the client. The selected remedial strategy included excavation and disposal of off-Site impacts and in-situ treatment by Vacuum Enhanced Recovery (VER) of on-Site impacts.

Off-Site remediation began in October 2002 and included excavation of contaminated soil to a depth of 7 m over an area of 850 m^2 on the adjacent street and commercial property. Excavation works involved the support of an adjacent building, and removal and replacement of underground utilities including storm and sanitary sewers, a water line, a gas line, telephone cables and electrical wiring. Off-Site excavation work was completed in December 2002.

On-Site remediation began in October 2002 with the installation of approximately 60 recovery wells located inside an existing building and in outside locations. Recovery wells were grouped into seven networks of underground pipes leading to a custom-designed VER and treatment system. Installation of the VER system was complete in December 2002 and system operation began in January 2003.

Introduction

Golder Associates Ltd. was retained to provide consulting services associated with the investigation and remediation planning and monitoring for an industrial site in southern Alberta.

The subject site covers an area of approximately 5.4 hectares and is occupied by several buildings including process, packaging, shipping and storage facilities and office space. The area surrounding the building is predominantly graveled with some paved areas for employee parking. The surrounding adjacent properties are a mix of commercial and light industrial businesses.

Background

The Site has been the subject of several environmental investigations since 1996. The previous studies indicated that on-Site petroleum hydrocarbon impacts in the soil and groundwater extended off-Site to the west beneath a road and onto a commercial/industrial property. The source of these impacts was determined to be two underground storage tanks containing diesel and gasoline, which were formerly located in the central portion of the Site. These tanks were removed from the Site in 1997. During the tank removal in 1997, impacted soils were encountered, but were left in place. A risk management plan including monitoring of on and off-Site wells and manual bailing of free-phase product from on-Site wells was implemented following the tank removal. However, the discovery of free-phase product in off-Site wells in October 2001, prompted the Site owner to re-evaluate this approach.

Geology and Hydrogeology

Soil conditions on the Site and adjacent properties primarily consist of asphalt or gravel overlying native deposits of silty sand and silty clay, with some intermittent seams of fine-grained sand. The silty clay soil had a hydraulic conductivity ranging from 2×10^{-5} to 3×10^{-7} m/s.

In areas of underground utilities, asphalt or gravel is underlain with sand and gravel fill to a depth ranging from 3.7 to 5.8 m, overlying fine-grained sand surrounding the utility.

The water table occurs at depths ranging from 4.4 to 7.2 m below ground surface. However, based on a review of historical groundwater monitoring data, groundwater levels as high as 2.9 m below ground surface were measured in 1998. Historical and current groundwater elevation data suggest that the groundwater flow gradient is towards the west.

Defined Nature and Extent of Petroleum Hydrocarbon Impacts

Golder undertook and additional environmental investigation of the Site, a municipal street and an adjacent commercial property in May 2001. Based on the findings of this investigation and previous investigations, the area of free-phase gasoline and the areas of soil and groundwater impacts above the provincial guidelines were determined. The areas of soil and groundwater impact were defined based on the Alberta Environment (AENV) 2001 "Risk Management Guidelines for Petroleum Storage Tank Sites" (AENV Guidelines). A summary of these areas is presented in Table 1 and Figure 1:

Figure 1: Site Plan and Estimated Extents of Impact

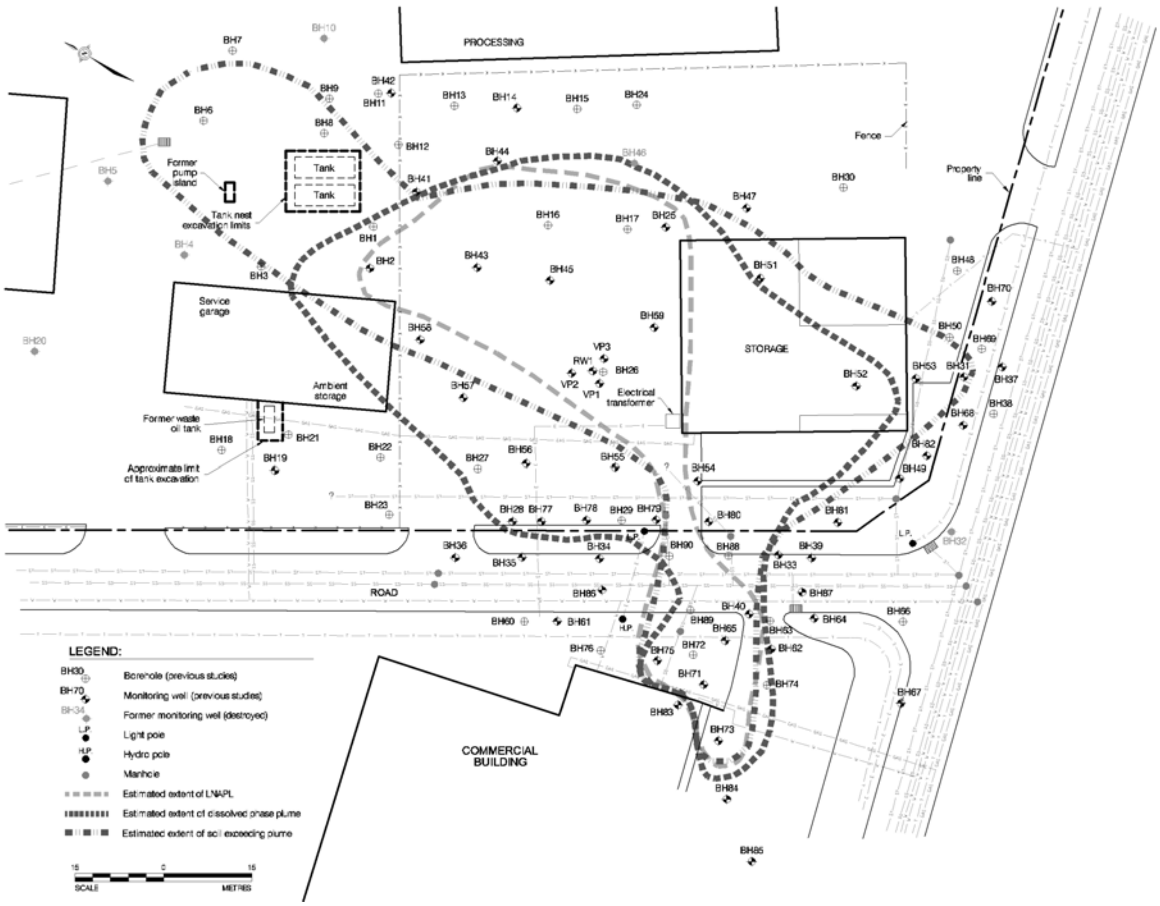


Table 1: Estimated Extents of Impact

Location	Area of Soil Impact	Area of Groundwater Impact	Area of Free-Phase Hydrocarbons
Subject Property	4,740 m^2	4,630 m^2	1,900 m^2
Road	260 m^2	300 m^2	100 m^2
Commercial Property to West	300 m^2	370 m^2	300 m^2

Based on the distribution of the free-phase hydrocarbons towards the southwest and the location of several utility corridors that converge on the municipal street, the primary off-Site migration pathway was evaluated to be the Site's private utility corridor, which intersects with the municipal utility corridor. Based on the historical groundwater monitoring well data, it is anticipated that the majority of the contaminant migration off-Site occurred in 1998 and 1999 while the groundwater table was at the same depth as the private utility corridor. The May 2001 investigation confirmed that contaminants have not migrated along the municipal utilities and rather crossed the road through another private utility corridor on the southwestern commercial property.

The maximum thicknesses of free phase product on and off-Site were 1.0 m and 0.4 m respectively. Based on soil sample head-space measurements, analytical results and historical data, the depth of soil impact ranged from 2.5 m to 6.0 m below ground surface.

Assessment of Remedial Options

Subsequent to the completion of the 2002 contaminant delineation work, Golder proceeded to develop a remedial action plan for the Site and adjacent properties. Several short, medium and long term conceptual strategies were evaluated to determine which would best match the remediation objectives for all three impacted properties (Site, road and commercial property) and the business management strategy for our client. Following this evaluation, a remedial action plan was selected and consists of the following two elements:

1. Excavation and off-Site disposal of subsurface impacts on the road and adjacent property; and

2. Installation and operation of a high vacuum extraction/treatment system on the subject site, pending a pilot study.

Golder Associates Innovative Application Ltd. ("GAIA") was retained to remediate the impacted soil and groundwater on the street, adjacent commercial property and on the subject property. Golder was retained to provide geotechnical and environmental consulting services associated with this work.

Off-Site Remediation

Remedial activities began in November 2002. Excavation work was completed on December 22, 2002. A total of approximately 2,565 tonnes of impacted soil was excavated and transported off-Site to a permitted facility.

Soil excavation surrounding the adjacent property building was conducted in a series of slots. The excavation target was to remove impacted soil within 1 m of the adjacent building to a depth of 6.0 m. To minimize the potential for undermining the building foundation, excavation and validation sampling was accomplished using a "slot" excavation and backfill method. Alternating slots were excavated out from the building and immediately backfilled with quick-setting 2-5 MPA fillcrete. No measurable settlement of the building occurred during the remedial activities. Validation samples collected at the extents of the excavation were analyzed for benzene, toluene, ethylbenzene and xylene (BTEX) and petroleum hydrocarbon (PHC) fractions F1-F4 and concentrations were all below the applicable AENV guidelines.

Following excavation activities on the adjacent commercial property, impacted soil beneath the municipal street was excavated. This excavation began on December 10, 2002 and was completed on December 12, 2002. The water supply, sanitary sewer and storm sewer utilities located beneath the road were completely removed during the excavation and later re-constructed. The water line in the road was isolated during the excavation activities. The storm sewer was temporarily disconnected, during the excavation activities. The sanitary sewer was disconnected and service was managed using one existing and one temporary manhole as sumps with centrifugal pumps to transfer fluids to an undisturbed portion of the sewer system south of the impacted area. A gas line was also temporarily re-routed.

Validation samples collected at the extents of the excavation were analyzed for BTEX and PHC F1-F4 and concentrations were all below the applicable AENV guidelines. Prior to backfilling the excavation, a geomembrane line was placed along the eastern boundary of the excavation. The purpose of the geomembrane was to provide a vapour barrier and secondary containment against migration of untreated dissolved or free-phase hydrocarbons from the subject Site onto the road.

A post excavation groundwater monitoring and sampling program was conducted in May 2003 and consisted of monitoring 4 wells on the road and adjacent commercial property. All concentrations were below the applicable guidelines. Golder has since submitted these results to AENV to request a letter of compliance.

VER Technology

Vacuum enhanced recovery (VER) is well established as a de-watering technique in construction projects. This strategy can also be applied to LNAPL recovery and groundwater remediation. VER involves applying a negative pressure to a recovery well system in order to increase the groundwater flow rate into wells. The negative pressure created in the well results in an increased hydraulic gradient and transmissivity which are two principal factors influencing the movement of water into wells. These principals are equally applicable to subsurface LNAPL recovery. In contrast to conventional groundwater pumping techniques, which create a hydraulic gradient to solicit product flow, vacuum enhanced pumping creates a cone of reduced pressure (Vacuum) around the well resulting in a pressure induced gradient from the relatively higher pressure areas in the formation beyond the well to the lower pressure zone inside the well. Flow conditions under these conditions can be greater than flow enhancement induced be hydraulic means.

In VER, soil gas and liquid are conveyed from an extraction well to the surface within the same conduit, referred to as the “drop tube”. The drop tube is typically set at the water/product interface within the recovery well. The vacuum induced negative pressure zone in the well promotes product flow toward the well and also draws product trapped in small soil pore spaces above the water table. When the LNAPL level declines slightly in response to pumping, the drop tube begins to draw in vapours. This removal of vapours promotes air movement through the unsaturate zone, increasing oxygen content and enhancing bioremediation. When mounding due to the introduces vacuum causes a slight rise in the water table, the drop tube cycle back to the removal of product and groundwater. This cyclical process minimizes water table fluctuations and therefore reduces the potential for “smearing” of contaminants by groundwater drawdown.

VER Pilot Test

In August 2002, a pilot test study was conducted on the subject property to confirm the feasibility of VER for the Site. Based on the observed radius of influence and recovery rates, an optimum operating vacuum of 10" of mercury at the unit and up to 10" of mercury in the recovery well was selected. At this vacuum, the water pumping rate ranged from 1.4 to 2.7 L/min and air extraction rates up to 36 scfm were measured. An average conservative best fit was then generated from measured vacuums in surrounding observation wells. A radius of influence of 8.5" of water at a distance of 1 m to 2" of water at a distance of 10 m was observed. The selected radius of influence for design purposes was 6.0 m and is based on a response of 4" of water in the surrounding wells.

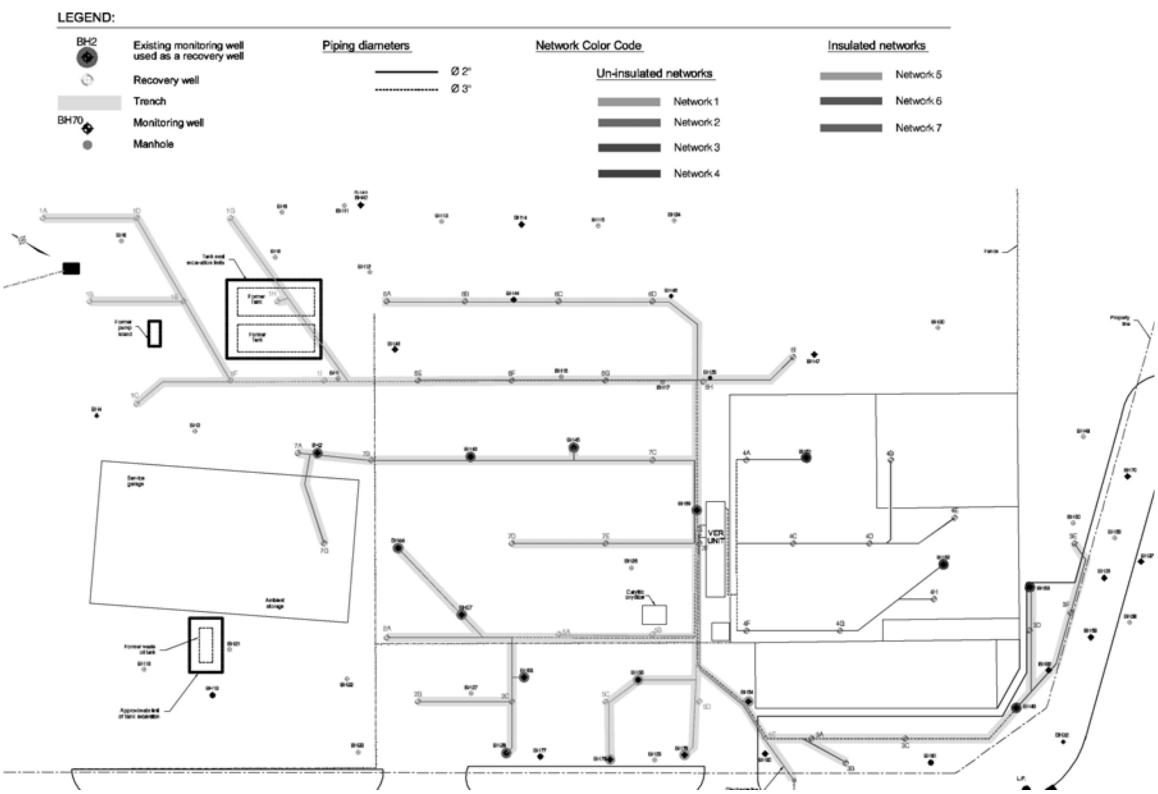
Site Preparation

Site preparation activities for the installation of the VER system were conducted between October and December 2002. These activities included the drilling of forty-seven new wells, installation of recovery well heads on these new wells and sixteen existing wells, excavation of approximately 540 m of recovery trenches and placement of recovery lines. The recovery wells were standard 5 cm (2") diameter monitoring wells. The depth of the wells ranged from 5.75 to 6.75 m below ground surface. All wells were constructed with flush-joint, threaded schedule 40 PVC pipe and factory slotted screens. The well screens were installed such that they straddled the water table, with sufficient screened portions above and below the water table to allow for potential seasonal fluctuations. For wells in traffic areas, concrete manholes with steel covers were used to protect the well. In the landscape areas, plastic protective boxes were used and within the buildings, steel plates with beveled edges were placed flush with the concrete floor surface over the well.

In addition to protecting the well, the protective coverings house the well head piping that leads to the VER unit. The well head piping includes a 2.5 cm (1") drop tube which is inserted into the well through an opening in the well seal. The protruding portion of the drop tube was connected to either a 5 cm (2") or 7.6 cm (3") main collector line for the network, which was located adjacent to the well.

The sixty-three recovery wells were grouped into seven separate recovery networks. Each network consists of seven to eleven wells. The two recovery networks located in the center of the product plume and the recovery network along the western property boundary were heat-trace and insulated, so that they could be operational year round. As a cost controlling measure, the remaining four networks were not heat traced or insulated. However, one of these networks is located within a heated storage building and will also be operation year round. All of the recovery networks lead to a trailer that houses the VER and treatment units.

Figure 2: VER Recovery Well Layout

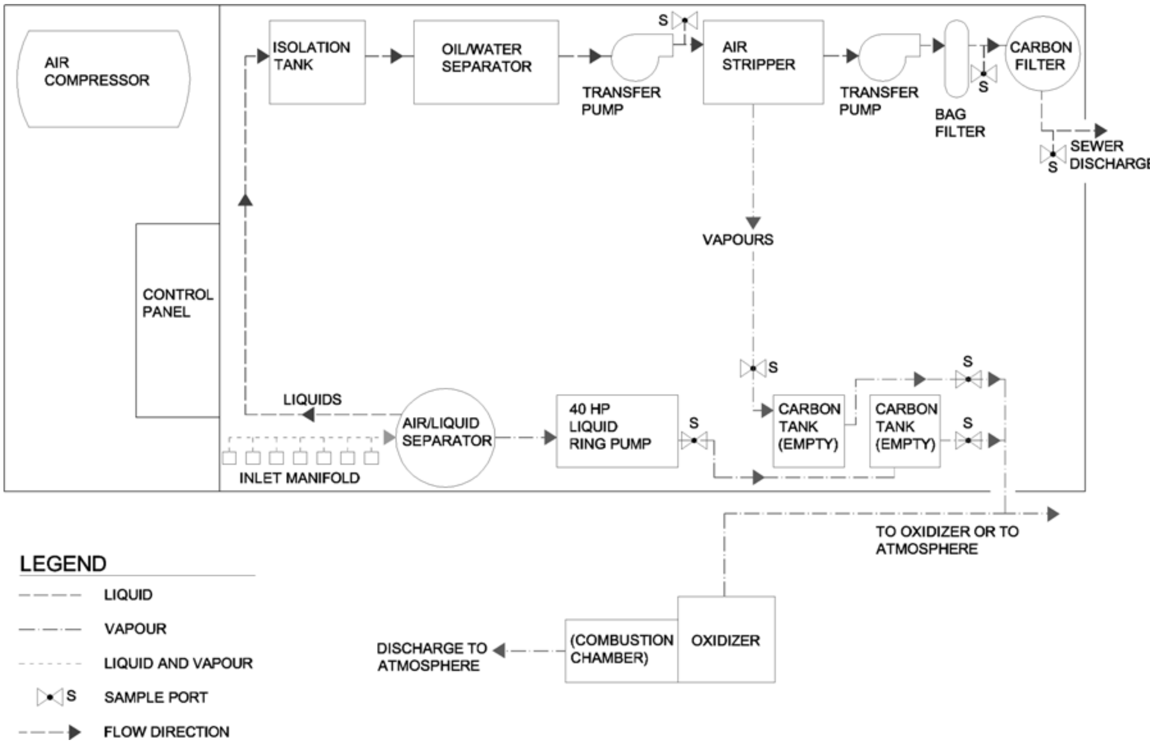


VER Unit

The VER unit was manufactured by GAIA and transported from Montreal, Quebec. The unit is currently situated along the north side of the storage building on-Site and is mounted on steel skids. The shell is constructed of steel and aluminum framing which is covered with aluminum sheathing.

The unit is divided into 2 compartments. The smaller compartment houses the electrical panel, assorted electrical equipment and the compressor. The second and larger chamber houses all of the process equipment. The primary process components are as follows: 40 Hp liquid ring vacuum pump; inlet manifold, sedimentation and air/water separation tank; oil/water separator, air stripper, water phase carbon treatment vessel, air phase carbon treatment vessel and associated transfer pumps. Treated water is directed to the municipal sanitary sewer system. A schematic of the VER and treatment unit are shown in Figure 3.

Figure 3: VER and Treatment Unit Process Flow Diagram



Results of the pilot tests conducted in August 2002 were used to predict untreated ambient air concentrations that could be expected near the air intakes of the on-Site buildings. Based on the calculated concentrations, the client requested that recovered air be treated prior to discharge to the atmosphere. Anticipated hydrocarbon concentrations during the first few months of operation were evaluated to be sufficient to warrant the use of an oxidizer unit. Therefore, GAIA has supplied a gas fired thermal/catalytic soil vapour oxidizer. The oxidizer is able to achieve destruction efficiencies in the order of 99.5 to 99.9 % for VOCs.

Operation and Maintenance Program

The operation and maintenance requirements were developed for the site and are completed by GAIA personnel as part of regularly scheduled visits. During each visit a regular list of tasks are completed.

Performance Monitoring Program

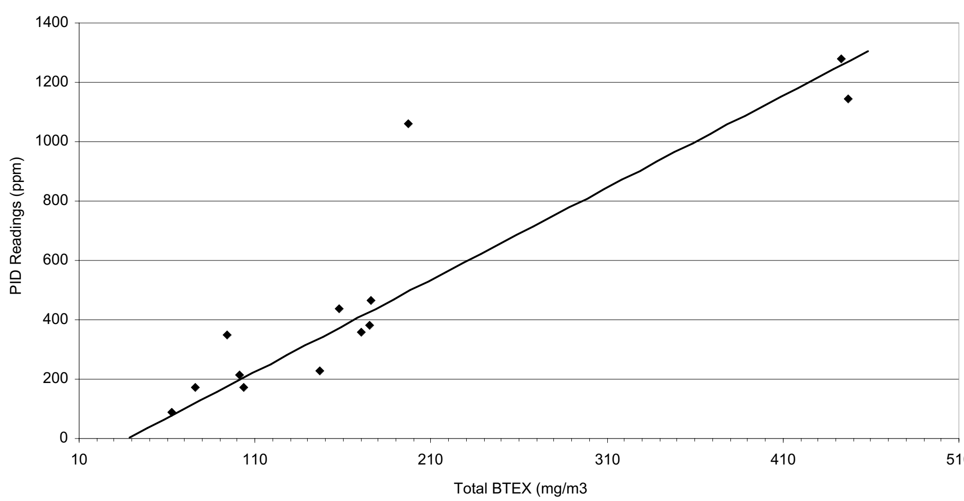
Start-up of the system began in January 2003, with recovery from one of the central insulated networks. A bi-monthly environmental monitoring program is conducted at the Site that includes the collection of influent and effluent vapour and water samples, measurement of influent vapour concentrations with a photoionizing detector and measurements of recovered volumes of air, water and LNAPL. In addition to the bi-monhtly visits, groundwater levels and vacuum measurement will be collected four times during the year. Groundwater samples will be collected from select monitoring wells at least twice during the year and effluent water samples from the treatment system will be collected quarterly to assess compliance with the sewer discharge permit.

Information collected during the environmental monitoring is used to assess the performance of the system and to estimate rates and quantities of hydrocarbons removed.

Performance Results and Analysis

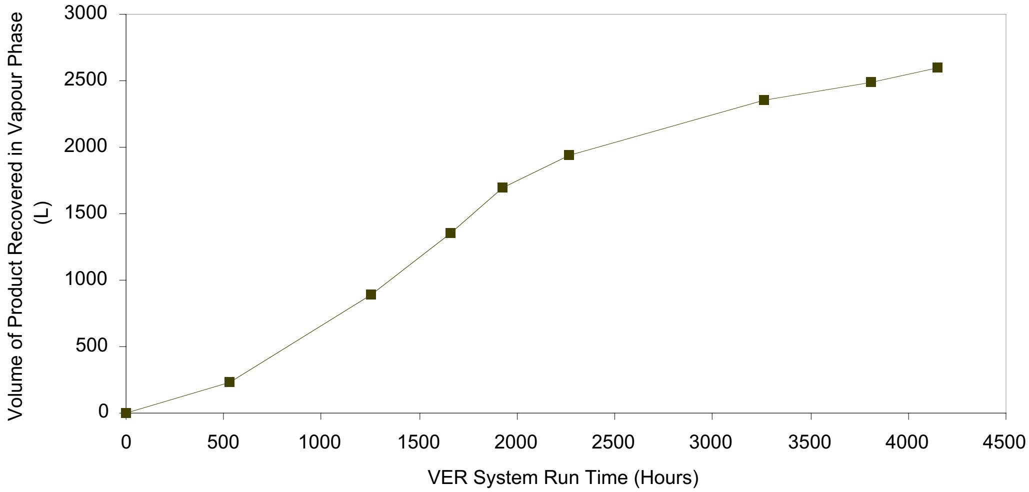
The average airflow recovery rate for each network is 500 scfm, or 45 to 70 scfm per well. Pre-treatment vapour analytical results were compared to field measurements collected using a mini-rae photoionizing detector, to develop a correlation of field measurement to actual mass of hydrocarbons removed in the vapour phase. The correlation data is presented below in Figure 4.

Figure 4: PID Vapour Measurements Versus Total BTEX Concentrations



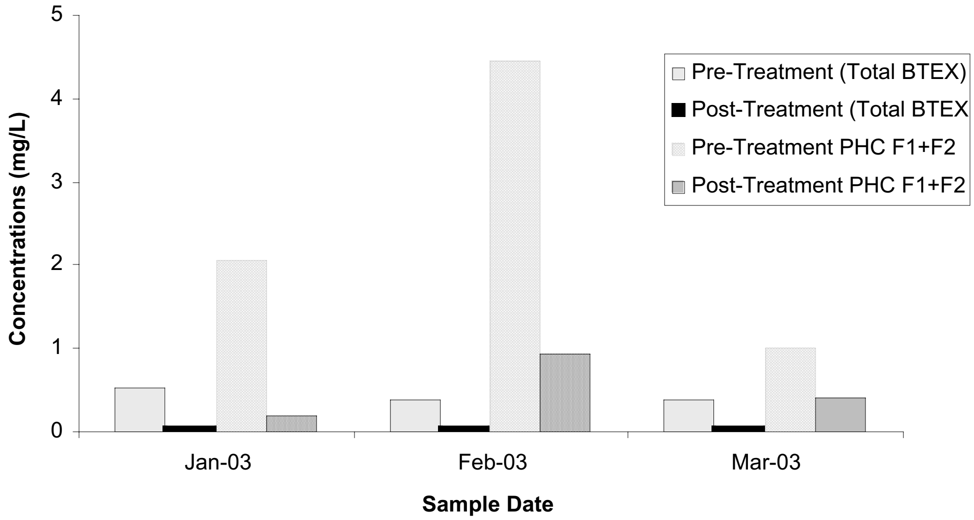
The total volume of product recovered in the vapour phase, since the start up of the system, is approximately 2,600 L. This total was calculated based on the measured airflow rates and estimated concentrations of BTEX based on analytical results and field vapour measurements. The evaluation is based on an average of 14.5 % of BTEX in the product and a density of the product of 0.77 kg/L. The total hydrocarbon recovery in the vapour phase versus elapsed time is shown in Figure 5.

Figure 5: Total Volume of Product Removed in Vapour Phase versus Run-Time



A total of approximately 11,410 L of groundwater was recovered, since start-up of the system. Groundwater recovery flow rates have ranges from 0.1 to 5.0 L/min. The recovered groundwater is collected and passed through a treatment system prior to discharge to the municipal sewer system. The effectiveness of the groundwater treatment system can be determined by the comparison of the total BTEX and total PHC Fraction F1 and F2 concentrations at different phases of the groundwater treatment system. Samples to determine the efficacy of the system are typically collected on a monthly basis at the inlet manifold and after the air stripper. Samples are also collected quarterly after carbon treatment as well. As indicted in Figure 6, the air stripper efficiency for removal of BTEX parameters is approximately 99%, whereas, the treatment efficiency for PHC F1 and F2 is approximately 76 %. The effluent from the air stripper stills meets municipal sewer discharge criteria. However, the carbon vessel provides an additional "polishing" step prior to discharge to the sanitary sewer.

Figure 6 Pre and Post Treatment BTEX and PHC F1 and F2 Concentrations



Conclusions

The off-site remedial approach was effective in removing off-site liability in the time frame requested by the client. Analytical results from soil samples collected during excavation activities and groundwater samples collected after off-site remedial activities were completed indicate that the remedial objectives have been met.

Approximately 2,600 L of product have been recovered by the VER system over 4,100 hours of operation time. Essentially all of the recovery volume to date has been recovered in the vapour phase, with only approximately 1 L of product recovered in the dissolved phase. No measurable free-phase product has been observed in the VER or treatment system. The VER system has been effective in containing free-phase and dissolved phase hydrocarbon on the site.

Acknowledgements

Installation details and figures supplied by Golder Associates Innovative Applications in Montreal, Quebec.

References

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