MANAGEMENT OF A PETROLEUM HYDROCARBON RELEASE IN A COMMERCIAL SETTING

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INTRODUCTION

The removal or replacement of underground fuel storage tanks provides an opportunity to directly observe the subsurface conditions at these facilities. In some cases it reveals that contamination of the ground has occurred. Once contamination is found additional site investigations are undertaken to more accurately assess the extent of contamination and an assessment made whether there is an associated risk to human health or the environment. If a risk does exist then remedial activities are undertaken to reduce or eliminate the risk.

Pattle Delamore Partners Ltd (PDP) has been involved with a number of environmental assessments following the removal of the underground petroleum storage system (UPSS) from former service station sites. This paper discusses the management and remedial strategy employed by PDP at a site in a commercial setting following the discovery of a zone of separate phase hydrocarbons (SPH) in the soil and groundwater covering an area approximately 25 m wide and 30 m long extending beneath a neigbouring building.

SITE DESCRIPTION

The site is situated in a mixed commercial/residential setting in a suburb of Christchurch. The site is immediately bounded by commercial properties, however, residential properties also exist in the general area. The former service station, decommissioned in August 1995, stored and dispensed petrol and diesel. The former UPSS consisting of underground storage tanks, fuel dispensers and associated pipe work was located on the western side of the property between the on-site retail/service building and neighbouring road. The on-site building has since been used for commercial land use. The nearest down-hydraulic-gradient building also operates under a commercial land use.

The nearest surface waterway is an open ditch located 30 m to the west, up-gradient of the site.

The area is connected to the Christchurch City Council's reticulated water supply, sewer and stormwater services. The reticulated water supply is sourced from a series of groundwater wells drawing groundwater from the deep confined aquifer system beneath Christchurch.

Initial Site Investigations

Following the removal of the UPSS from the former service station site soil sampling results showed the presence of elevated petroleum hydrocarbon residues in the in-situ soils. To provide more detailed information of the underlying hydrogeological conditions and extent of the contamination a series of environmental investigations were carried out. These initial investigations included the drilling and installation of 13 groundwater monitoring wells, the completion of slug tests to determine the hydraulic conductivity of the underlying strata and a series of groundwater monitoring and sampling rounds. Inspection ports were also cut in the concrete floor of the neighbouring building to gain access to the underlying strata and soil-air. The inspection ports were sealed with expandable rubber plugs when not in use to eliminate a direct migration pathway into the building for any petroleum hydrocarbon vapours present beneath the building. A plan showing the layout of the site and locations of the installed groundwater monitoring wells and soil-air inspection ports are shown in Figure 1 below.

The soil conditions encountered beneath the site consisted predominately of silts of low permeability. Within these silts lay irregular layers of fine sand with significantly higher permeability's. Slug test results show that the hydraulic conductivity of the near surface strata varies from 4 x 10^{-7} m/s (in the more silty strata) to 2 x 10^{-5} m/s (in the more sandy strata). This variation in hydraulic conductivities suggest that the more sandy soils will provide preferential pathways for the migration of groundwater and mobile SPH.

The water table was found to occur at approximately 1 m below ground level and was calculated to flow in a general south-easterly direction beneath the site.

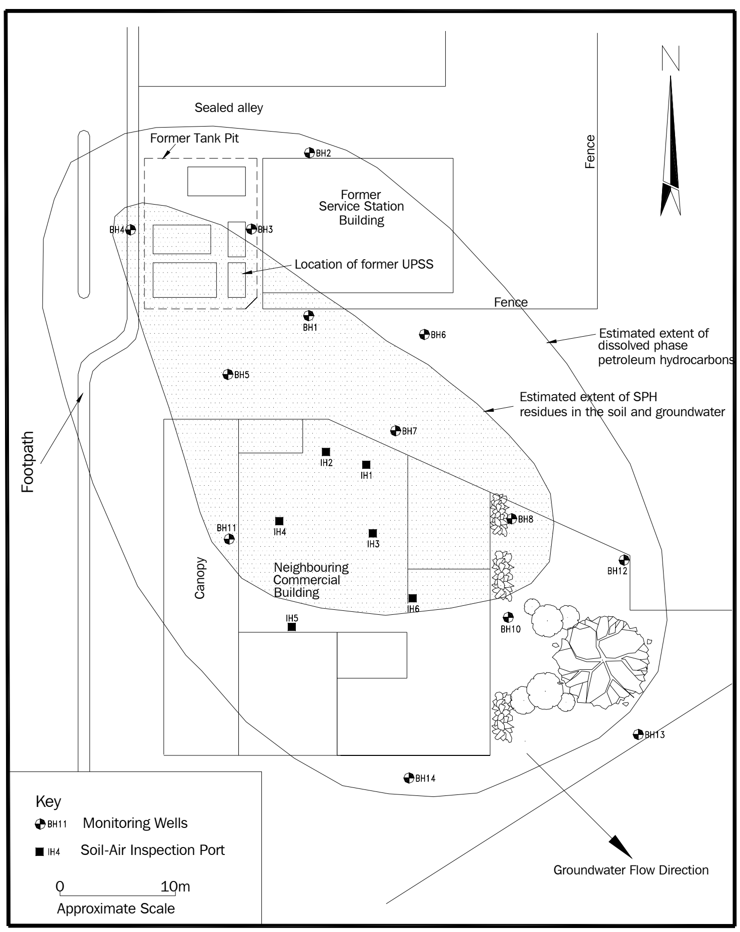

Figure 1: Site Plan and Estimated Extent of SPH Plume (May 1996)

Extent of Contamination

Inspection of the installed groundwater monitoring wells showed the presence of SPH in the soil and groundwater adjacent to the former tank pit extending south-east beyond the property boundary and beneath the neighbouring sealed driveway and commercial building (an area approximately 30 m long and 25 m wide). A gas chromatogram of the SPH shows it to have a carbon banding range similar to that of unleaded petrol. The estimated extent of the SPH and dissolved phase hydrocarbons are shown in Figure 1. Due to the heterogeneous nature of the underlying soils providing preferential pathways the distribution of SPH may in fact be quite irregular in shape opposed to the uniform shape shown in Figure 1.

Apparent product thicknesses observed in monitoring wells showed significant variation between wells (between 0.035 m and 0.861 m, August 1996). This variation in apparent product thickness is likely due to the heterogeneous nature of the ground conditions and spatial separation from the former source (UPSS). However, the thickness of SPH floating in a monitoring well does not represent the actual product thickness on the water table (i.e continuous layer of SPH floating on the water table). Instead it reflects the pressure balance between mobile SPH that can move into the well and the resulting depression of the oil water interface in the monitoring well. The mobile fraction of SPH will only be a part of the total SPH that is smeared out in varying degrees of saturation across the zone of the water table fluctuations (see Figure 2 below).

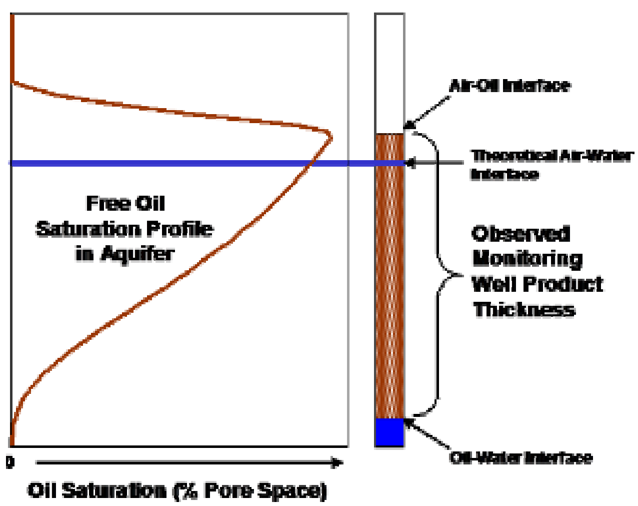

Figure 2 : Conceptualisation of SPH in a Monitoring Well

SPH saturation is the percentage of SPH in the soil pore space of the strata. Whilst petroleum hydrocarbons are hydrophobic in nature, with larger volumes of SPH the SPH will displace the water by pushing into the pore spaces of the upper portion of the profile reducing with depth until at some depth no water is displaced and the pores remain completely filled with water.

Vapour monitoring completed within the inspection ports drilled through the floor of the building showed elevated concentrations of photoionizable compounds (range of chemical compounds including most petroleum hydrocarbons) below the floor of the building. However, vapour monitoring undertaken from the ambient air inside the building showed acceptable levels of photoionizable compounds.

ENVIRONMENTAL AND HEALTH RISKS

The presence of SPH in the soil and groundwater beneath the former service station site and neighbouring property presents potential environmental and human health risks. Risk is defined in the Ministry for the Environment (MfE) Guidelines for Assessing and Managing Petroleum Hydrocarbons Contaminated Sites in New Zealand (1999) as the probability of an adverse outcome in a person, a species, a group, or an ecosystem that is exposed to a hazardous agent. Risk depends on both the level of toxicity of a hazardous agent and the level of exposure.

The MfE guidelines also suggest three levels of risk:

- Negligible risk,
- Tolerable or acceptable risk, and
- Unacceptable risk.

With appropriate management potentially unacceptable risks can be reduced to a tolerable or acceptable risk, and over time through natural attenuation of the petroleum hydrocarbon residues, the risk can be reduced to a negligible risk. A review of the level of risk should be continually updated as monitoring data becomes available or as land use or site conditions change.

For there to be a risk there first must be a source of contamination, secondly there must be an exposure pathway and finally a receptor. If any of these are not present then there is no perceivable risk. In this case study, the SPH release into the ground and resulting plume provides a source of contamination.

The following are potential exposure pathways and receptors for petroleum hydrocarbon contaminated sites.

Potential Exposure Pathways:

- Indoor/outdoor inhalation of vapours from soil/water.
- Soil ingestion/dermal contact (during maintenance and excavation works).
- Produce ingestion.
- Usage of surface water/groundwater.

Potential Receptors:

- People living/working on or in close proximity to the site.
- Maintenance/excavation workers during any development works at the site.
- People drinking groundwater on/adjacent to/ downgradient of the site.
- People involved in leisure activities on or in close proximity to the site.
- Livestock/animals in contact with the site soil.
- Aquatic ecosystems within waterways on/adjacent to/ downgradient of the site.
- Vegetation growing on the site.

Using the list of the potential exposure pathways and receptors a site specific assessment is made so the potential relevant exposure pathways and receptors can be identified. For this case study the possible scenarios where an unacceptable risk could potentially occur included:

1. Soil ingestion/dermal contact by site excavation workers during any future development works.
2. Indoor inhalation of vapours by people working within the neighbouring commercial building.
3. Migration of mobile SPH into nearby underground services lines, which due to the more permeable backfill material would act as preferential pathways.

Once potential risks have been identified site investigations, monitoring and remedial activities assess the level of risk (i.e. unacceptable, acceptable, negligible) and then also contribute in addressing the risks through appropriate management.

REMEDIAL STRATEGY

Maintenance/Excavation Workers

To reduce the risk for workers undertaking future excavation/maintenance works at the site coming into contact with petroleum hydrocarbon affected soils and groundwater a site management plan was prepared for the site. The plan outlines measures to mitigate against the risk associated with SPH beneath the site describing what personal protection equipment (PPE) is required to be worn and how to address issues related to the handling and disposal of any hydrocarbon affected soils and/or groundwater that may be encountered. This site management plan was made available to the owners and occupiers of the land where the petroleum hydrocarbon plume has migrated and also the owners of services in the area so as to protect their maintenance workers.

By the implementation of appropriate site management measures the potentially unacceptable risk to maintenance/excavation workers is reduced to an acceptable risk through providing information as to how to reduce exposure to the source.

Indoor Inhalation

The presence of SPHs beneath the neighbouring commercial building creates a potentially unacceptable risk through the possible migration of vapours up into the building and their effect on people working within the building. Although initial vapour monitoring conducted within the building showed photoionizable compound concentrations at acceptable workplace exposure levels, there was the possibility that further migration of mobile SPH beneath the building may result in higher vapour concentrations in the building or a zone of SPHs of greater area resulting in vapours finding a more accessible point of entry into the building.

To restrict any additional mobile SPH migrating beneath the building a barrier trench was installed on the northern side of the building. Whilst this approach would restrict any further migration of mobile SPH beneath the building, any SPH already beneath the building would remain. These remaining petroleum hydrocarbon residues beneath the building would over time degrade through natural attenuation reducing the associated risk to on-site workers.

The significance of the remaining SPHs beneath the building was assessed by making ongoing vapour measurements within the neighbouring building and beneath the building within the soil-air inspection ports. If there was an unacceptable accumulation of vapour beneath the building a soil vapour extraction system was proposed to be installed.

Underground Service Trenches

Underground services trenches, due to their relatively permeable backfill material, provide preferential pathways for mobile SPHs. The main underground services of concern are the large stormwater and sewer collection pipes as they are typically installed at depths at or around the water table elevation at this site. Underground service plans provided by the local service providers indicated that no main service trenches (stormwater and sewer) are located in the estimated zone of the SPHs. A water main, abandoned phone line and sewer lateral (beneath the building) may be present in the zone of SPH although it is expected that these services will be shallower than the water table and SPH levels.

These further investigations showed that the exposure pathway was incomplete as the services are not expected to be in the area of SPHs or at a depth intercepting the water table beneath the site.

BARRIER TRENCH

The barrier trench consisted of a 30 m long trench excavated to a depth of 2.8 m below ground level and backfilled with approximately 0.1 m of pea gravel before a high density polyethylene (HDPE) liner was installed vertically down the length of the trench. The 0.1 m layer of pea gravel at the base of the trench ensures hydraulic connection on both sides of the liner to avoid any building up of groundwater pressure across the barrier. The HDPE liner will act as a physical barrier to any mobile SPHs while still allowing groundwater to pass underneath (via the permeable layer at the base of the trench). Monitoring wells were placed on either side of the liner to provide access points for apparent SPH and water level measurements before the trench was backfilled with pea gravel. To restrict migration of SPH around the ends of the HPDE liner a plug of lower permeability material removed from the trench was backfilled around the two ends. The position of the trench and monitoring wells installed in the trench (TH1 – TH10) are shown in Figure 3 below.

The trench's primary role was to act as a physical barrier (HDPE Liner) to prevent further migration of mobile SPHs beneath the neighbouring building. Also, due to the very small capillary fringe in the backfill material (pea gravel) in the trench compared to the surrounding natural soils a localised capillary fringe depression was created enabling the trench to act like a sump. This phenomenon occurs as the SPH occurring on the capillary fringe will be higher in the natural soils (due to the larger capillary fringe) compared to the top of the capillary fringe in the gravel trench. SPH would be drawn to the localised depression on both sides of the trench. The influence on the down-gradient side of the trench would be limited, however, any mobile SPHs on the up-gradient side will be prevented from moving past the HDPE barrier.

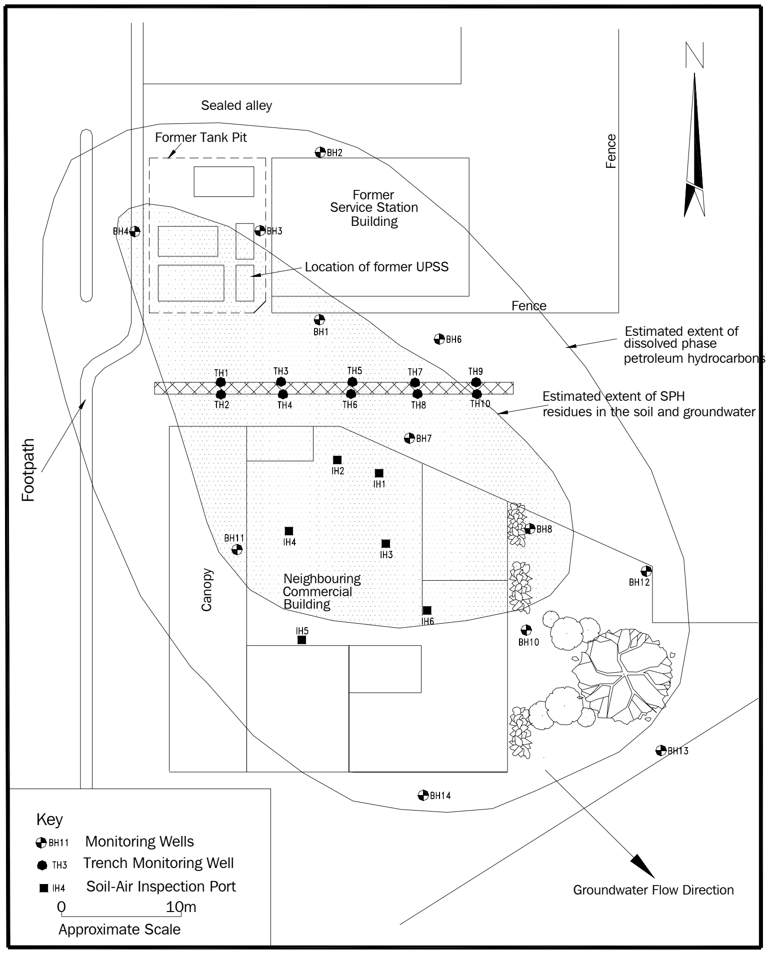

Figure 3: Site Plan showing location of Barrier Trench (Feb 1997)

LONG TERM MONITORING RESULTS

Ongoing groundwater and SPH monitoring was carried out to monitor the effectiveness of the barrier trench and migration of the SPH plume. In addition, ongoing vapour monitoring was conducted within and beneath the building to continually assess the level of risk to the on-site workers with regard to inhalation of vapours associated with the presence of remaining petroleum hydrocarbon residues beneath the neighbouring building.

Comparison of the SPH levels measured in the trench monitoring wells and the immediately surrounding groundwater monitoring wells show that the surface level of the SPH measured in the trench is lower that the surface level of the SPH measured in the nearby surround monitoring wells (see Figure 4 below for measured levels). This confirms that the vertical saturation profile is larger in the natural strata compared to that in the trench and subsequently the barrier trench is acting like a sump.

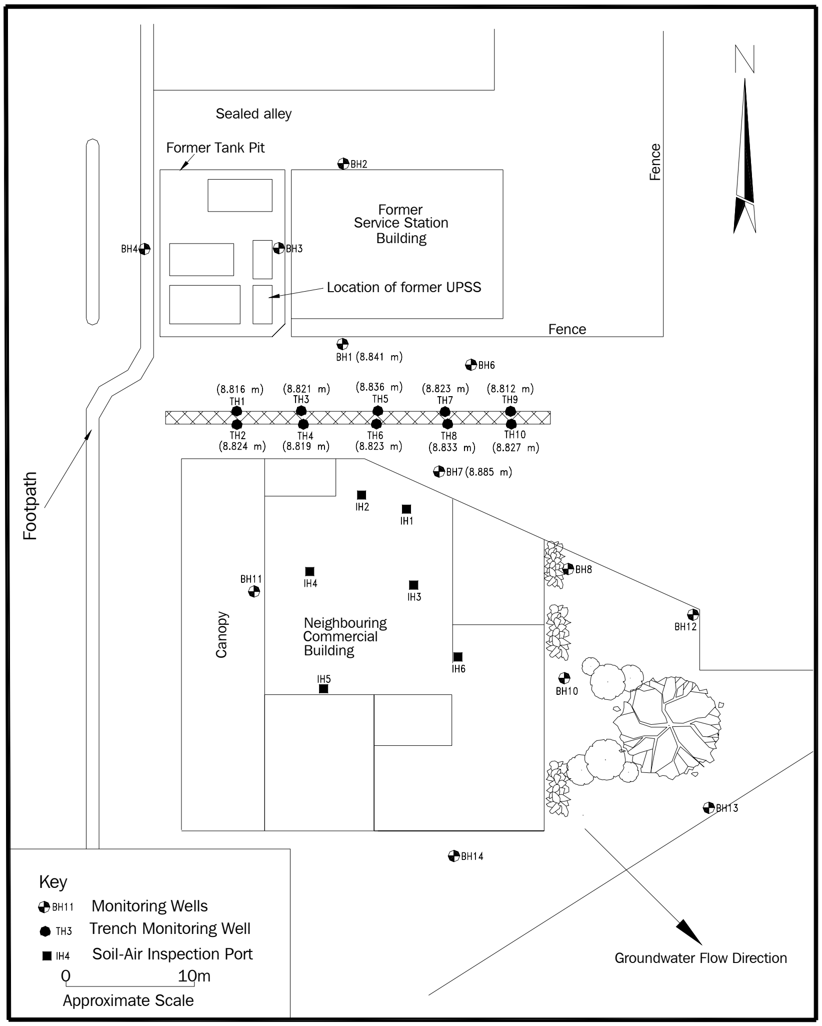

Figure 4: SPH Levels Relative to an Arbitrary Datum (Jan 1998)

The rate of SPH accumulation was not quick as the passive system relies on the natural migration of SPH through the low permeability soils. Using the hydraulic conductivity measurements of the underlying strata (3×10^{-7} m/s for the silty strata and 2×10^{-5} m/s for the sandy strata) together with the water table gradient of around 4×10^{-3} and an assumed porosity of 0.3, suggests a groundwater velocity of around 0.3 to 23 mm/day. Any movement of SPH would be even slower than the estimated groundwater velocity due to its hydrophobic characteristics.

Recent groundwater monitoring and sampling undertaken in February 2004 has shown that the SPH residues are reducing with measured levels of SPH reducing in most wells. This was particularly the case in wells BH1 and BH11, which during the most recent monitoring round showed no sign of SPH being present on the water table. Groundwater samples did show that dissolved phase petroleum hydrocarbons continue to exist in these two wells. Whilst no SPH were noted in some of the monitoring wells which previously showed SPH, there will still be some SPH present within the strata as residual or immobile SPH trapped by capillary forces within pores spaces. These will over time continue to degrade further through natural attenuation.

Figure 5 below shows those wells with SPH present on the water table together with the benzene concentrations for those wells not containing any SPH. Monitoring data was not collected from wells BH3, BH4 and BH6 as they had been sealed over during redevelopment works at the former service station site. The results continue to show the presence of SPH in the trench wells (TH1 – TH10) and within wells BH7, BH8 and BH10. The down-gradient wells (BH14 and BH13) show benzene concentrations at below the laboratory detection limit suggesting that any petroleum hydrocarbon residues remaining beneath the building have not migrated any significant distance.

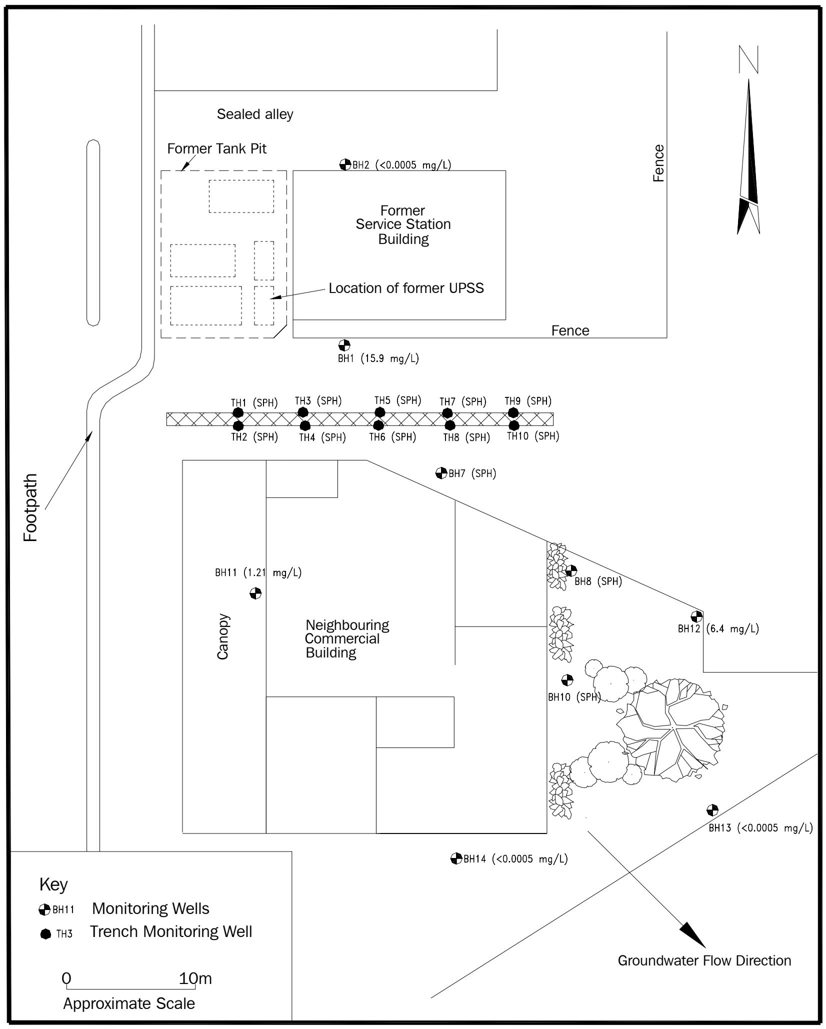

Figure 5: SPH detection and dissolved benzene concentrations (Feb 2004)

Vapour monitoring undertaken within the building and beneath the building via the soil-air inspection ports generally showed a decreasing trend in photoionizable compounds to a point where monitoring in January 2000 showed no detectable photoionizable compounds in the soil-air beneath the building and also within the building.

CONCLUSION

The discovery of petroleum hydrocarbon residues within in-situ soils following the removal of an UPSS from a former service station site required additional investigations to determine the extent of contamination. These investigations discovered a zone of SPHs covering an area 25 m wide and 30 m long extending beneath a neighbouring commercial building.

An assessment of the relevant potential exposure pathways and receptors revealed the following unacceptable risks:

1. Soil ingestion/dermal contact by site excavation workers during any future development works.
2. Indoor inhalation of vapours by people working within the neighbouring commercial building.
3. Migration of SPH into nearby underground services lines, which due to the more permeable backfill material would act as preferential pathways.

The preparation of a site management plan enabled the potentially unacceptable risk to maintenance/excavation workers to become an acceptable risk by providing information as to how to reduce exposure to the source.

The issue of vapours affecting the neighbouring building was addressed by continual on-site monitoring, which showed no immediate risk. To ensure the risk did not worsen a barrier trench was constructed to provide a passive mechanism preventing further migration of SPH beneath the building and allowing natural attenuation to gradually reduce this risk over time with any remaining SPH residues. Ongoing monitoring has confirmed this lessening of risks arising from both SPH and dissolved hydrocarbons.

This paper has shown that human health and environmental risks associated with the presence of petroleum hydrocarbon residues resulting from a historic release from a former service station can be avoided through detailed environmental site investigations and appropriate management. It was shown that lowering the risk can be achieved both through providing information as to how to reduce exposure to the source and by undertaking remedial works that rely on passive controls to reduce the concentration of the source.

REFERENCES

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