

CLOSURE OF A MALL SITE CONTAMINATED BY OFF-SITE SOURCES USING A PHASED REMEDICATION APPROACH

Presented by:

Lynda Smithard, P.Eng., URS and Sean Todd, P.Geo., URS

INTRODUCTION

URS's involvement with the mall site began in 1993 when a site investigation identified free phase gasoline product in the southeast corner of the site. Subsequent investigations conducted between 1994 and 2006 concluded that the product had migrated from two off-site gasoline retail operations. The presence of tetraethyl lead in the product identified the window of potential release times as being either the period prior to 1981 or prior to 1985. Remediation was initiated at the site in August 2002 with the commissioning of a dual phase extraction (DPE) system at the boundary of the mall site with the adjacent source site. Remediation was undertaken before the detailed site investigation had been completed in order to prevent further degradation of the environmental condition of the site. An Approval in Principle (AiP) was issued by the BC Ministry of Environment (MOE) on May 6, 2002 for a phased Remediation Plan combining active (i.e. engineered) and passive approaches. The objective of the Remediation Plan was to remove free phase petroleum hydrocarbon product identified at the site and to risk manage residual soil and dissolved phase contamination to meet the BC regulatory requirements for a Certificate of Compliance.

URS's paper details the concept and metrics used for the phased remediation approached that led to site closure.

SITE DESCRIPTION

The mall was constructed in 1979 and redeveloped in 1983/84. The mall replaced a smaller shopping plaza constructed in 1967/68. Prior to the mid 1960's the site had been vacant.

The area of the site above the groundwater plume is currently a parking lot for the mall. There are currently no structures on the lot. Based on planning-level future land use scenarios obtained from the mall owner, the site risk assessment included risk characterization for the general public and workers if a retail building was constructed above the groundwater contaminant plume in the future.

Surrounding land uses are mixed residential and commercial/light industrial.

OVERVIEW OF SITE ENVIRONMENTAL CONDITONS

Preliminary site investigations were conducted in 1993, 1994 and 1999. Remedial planning was conducted in 2001 and in the early part of 2002. Between March 2002 and January 2006, URS conducted five drilling programs at the site. The first two supported remedial works initiated at the site while the last three focused on further site assessment. The overall objective of the staged site investigation was to identify, delineate and characterize the petroleum hydrocarbon contamination at the site. The January 2006 drilling program also included the advancement and completion of 16 soil vapour sampling probes (nested in eight locations) required for the risk assessment.

Site Hydrogeology

Groundwater is present beneath the site within a fine to medium grained sand unit noted below a depth of 5.0 metres below ground surface (mbgs). The water table is generally found between 7.0 and 9.0 mbgs and is under unconfined conditions. Groundwater flows towards the north/northwest across the site. The 50 and 100-year groundwater travel distances were calculated for site groundwater. Calculations were based on the following:

- K – The most conservative hydraulic conductivity estimate between bail test data and Modflow draw down analysis was used in the velocity calculation (2.8×10^{-5} m/s).
- i – The hydraulic gradient of 0.018 m/m, calculated using data collected in November 2005 was used in the velocity calculation.
- n – A value of 0.30 was used to represent effective porosity in the fine to medium grained, sand aquifer. This is consistent with literature values of porosity (eg. Freeze and Cherry, 1979).

Stratigraphic Unit	Groundwater Flow Direction	Hydraulic Conductivity (K) (m/s)	Hydraulic Gradient (i) (m/m)	Effective Porosity (n)	Groundwater Velocity (v) (m/yr)	50 year Travel Distance (m)	100 year Travel Distance (m)
Sand	N/NW	2.8×10^{-5}	0.018	0.30	53	2650	5300

The closest down gradient, receiving water body, supporting aquatic life is a lake approximately 500 m to the northwest. Groundwater flowing from the site may reach this lake within a 50 year timeframe.

Soil Contamination

While developing the conceptual contaminant fate and transport model, URS studied the distribution of hydrocarbon (BTEX) concentrations in soils on the mall site. On-site soil petroleum hydrocarbon contamination is present at the watertable and in the saturated smear zone between 6.5 and 8.2 mbgs, and no deeper than 9.3 mbgs, as measured in N6 (1999), EW3 (2002) and VP4 (2006). This soil contaminant zone was attributed to the LNAPL plume formerly present in the same area and provided evidence that the contamination originated off site. Depths to groundwater typically ranged from 7.0 to 9.0 mbgs across the mall site over the investigation period. The maximum product thickness

encountered in any well across the site and two source sites was 1.2 m in August 1999 in on-site monitoring well MW13. As such, soils at the site shallower than 4.5 mbgs would not have been impacted by LNAPL migrating with local groundwater, as was the case.

In 2001, the LNAPL plume covered an approximate 700 m² area at the mall/source site boundary and downgradient area. Based on soil quality in N6, situated just north of the LNAPL plume edge, the soil contaminant zone is estimated to have covered a slightly larger area than the LNAPL plume or about 800 m². Assuming a maximum uniform thickness of 2.8 m, the maximum volume of contaminated soils at the site was estimated at 2,240 m³.

Free Phase Product Distribution

URS's conceptual contaminant fate and transport model considered the nature and distribution of free phase petroleum hydrocarbons at the mall site and the source sites. The model considered groundwater quality data collected in 2004, during comprehensive Monthly Groundwater Monitoring and Sampling Programs conducted by URS and consultants representing the owners and operators of the source sites.

At the mall site, gasoline-range hydrocarbons were initially identified as a LNAPL in monitoring wells MW5 and MW13 along the southern property boundary, and subsequently in a much wider array of groundwater monitoring wells. URS's 2001 Stage II Preliminary Site Investigation (PSI) and Detailed Site Investigation (DSI) and subsequent Remediation Plan indicated LNAPL had been detected in five on-site monitoring wells in 1999: MW5, MW13, MW37, MW38 and MW50. These wells had not been installed by URS. In 1999, maximum product thicknesses in MW5 and MW13 were 0.65 m and 1.2 m, respectively. These maximum thicknesses were increased from the maximum thicknesses measured in the same wells in 1994, suggesting that the LNAPL plume was mobile.

Dissolved Phase Plume Distribution

The contaminant fate and transport model also looked at dissolved phase BTEX and light extractable petroleum hydrocarbons in water (LEPHw (C10-<C19)) concentrations across the mall site.

Prior to the commissioning of the remediation system on the mall site in 2002, URS estimated that the dissolved phase petroleum hydrocarbon plume extended 35 m north of the mall site/source site boundary and was 55 m wide at its widest point. This estimate of plume extent was documented in URS's Remediation Plan at a time when the leading edge of the plume still had not been delineated. Vertical delineation of the dissolved phase contaminant plume was achieved in wells U4 and N6, which are located immediately adjacent to each other but screened at differing depths.

URS's supplemental DSI delineated the leading edge of the dissolved phase plume. Based on the measured naphthalene concentrations in U18 and U21, the leading edge of the dissolved phase petroleum hydrocarbon plume is approximately 70 m from the site/source site boundary.

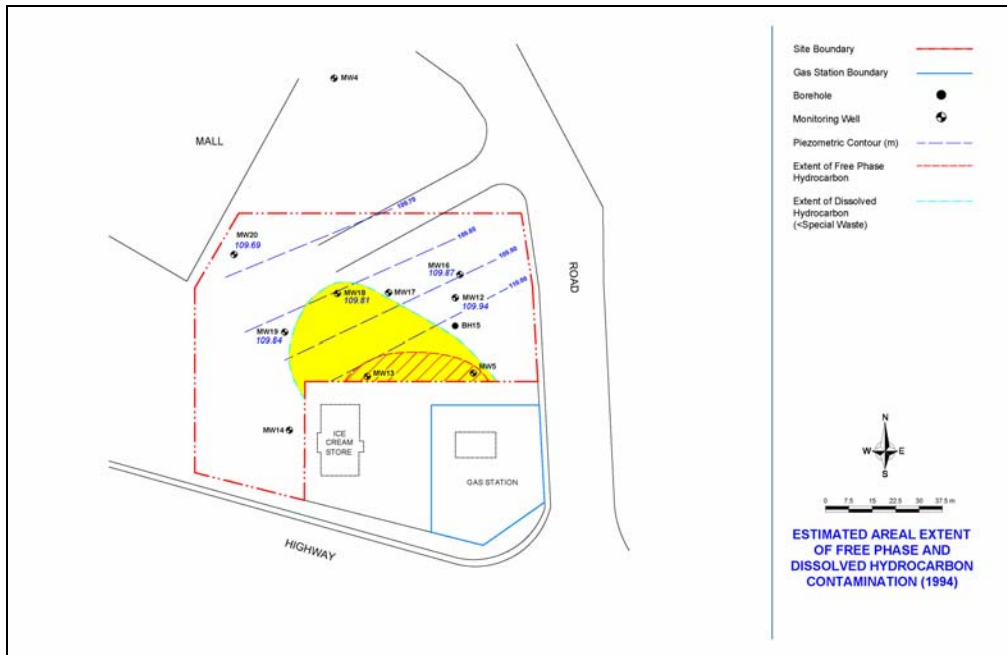


Figure 1: Estimated Areal Extent of Free Phase and Dissolved Hydrocarbon Contamination (1994)

PHASE 1 – ENGINEERED REMEDIATION PROGRAM

URS recommended vacuum enhanced recovery (VER) technology for remediation of mobile and residual free phase hydrocarbons beneath the site based on a desk-top evaluation of remedial alternatives and estimated order of magnitude costs. URS conducted a single well (EW2) pilot trial of VER technology in March and April 2002. The primary objective was to confirm the compatibility of VER with site-specific conditions by monitoring the aquifer response and hydrocarbon mass recovery, and to obtain high quality system performance data for a detailed system design if the technology proved viable.

The pilot trial configuration comprised a single (4 inch diameter) extraction well screened 3ft above the seasonal high watertable and 3ft below the seasonal low watertable. A liquid ring pump (containing oil as a working fluid) was used to apply a vacuum to a phase separator, which was connected to the extraction well both via an internal $\frac{3}{4}$ inch drop tube and directly to the 4 inch wellhead.

Pilot trial operations involved a series of tests with different drop tube elevations and a test combining vacuum application both to the drop tube and directly to the 4 inch piezometer. Following the different trial runs, the system was shutdown and off-gas concentrations were monitored periodically to establish vapour equilibrium recovery times. The pilot trial data obtained enabled scale-up design of a DPE system installation at the site.

The DPE system configuration comprised three (4 inch diameter) extraction wells (EW1 to EW3) connected to liquid and vapour treatment systems. EW1 to EW3 were situated

just north of the mall site/source site boundary and connected via buried 1 inch PVC total fluids header and 4 inch PVC vacuum header lines running parallel to the site boundary in a trench excavated to an approximate 3.5ft (1.1 m) depth and bedded with sand. System wells/wellheads remained accessible via 24-inch gasketed, bolt down steel road boxes secured with concrete and asphalt.

Total fluids (i.e. LNAPL and groundwater) extraction occurred via three in-well QED Environmental Systems 4" AP-4 pneumatic total fluids pumps connected to a treatment system comprising an oil/water separator, air stripper unit, two bag filters connected in series, and a water phase granular activated carbon (GAC) unit. Vapour extraction/treatment occurred via a 500 cubic feet per minute (cfm) vacuum blower connected to a 500 cfm thermal catalytic oxidizer for off-gas treatment. Compressed air was supplied by a 7.5 horsepower (HP) air compressor. All extraction/treatment equipment except the oxidizer was housed in a prefabricated steel enclosure within a fenced compound. The oxidizer was a stand-alone unit and had also been situated in the fenced compound.

Remedial system installation was carried out in July 2002 with full-scale operation of the system starting in August 2002. There were three modes of system operation between 2002 and 2006.

Remediation System Operations August 2002 to July 2005

System monitoring was conducted on a minimum bi-weekly frequency. Site monitoring was also performed in order to track changes in the LNAPL plume thickness and extent. System operation was continually monitored and optimized in response to measured performance and changing site conditions to ensure both high hydrocarbon mass removal efficiency and treatment efficiencies were maintained.

The top loading AP-4 pumps were initially placed and then left on the bottom of each of the three extraction wells to maximize the total fluids recovery rate year round. The air compressor supplied 60 to 90 pounds per square inch (psi) of compressed air to the pump network. Each of the pumps was equipped with a regulator set to control the air supply at 65 to 70 psi. Vacuum equalling 4 inches of mercury ("Hg) was applied to the extraction well network for VER of total fluids.

During the first 12 months of operation when extracted vapour contaminant concentrations exceeded 25% of the lower explosive limit (LEL), the oxidizer unit was operated in thermal mode. Following this initial 12-month period, extracted vapour contaminant concentrations reduced to those consistently less than 25% LEL and accordingly, the oxidizer was switched from thermal to catalytic mode. Catalytic operation cut extraneous fuel consumption rates and associated costs nearly in half.

Operation times between system start-up in August 2002 and July 2005 were largely continuous, with the exception of an estimated 24% down-time associated with periodic shutdowns to facilitate static groundwater monitoring/sampling for quarterly BC MOE and monthly multi-site monitoring programs, and system maintenance/repair works.

System performance monitoring data for the period August 2002 to July 2005 is summarized as follows:

- Vacuum radius of influence at the site was consistently measured at distances >30m radius from operational extraction wells. Vacuums > 20 inches of water were consistently achieved within a 15m radius from operational extraction wells;
- Hydraulic, watertable drawdown, radius of influence > 15m from operational extraction wells were recorded; and
- Average water/product recovery rates from the combined (3) total fluids pumps equalled approximately 10 LPM. Average vapour flowrates equalled 400 CFM.

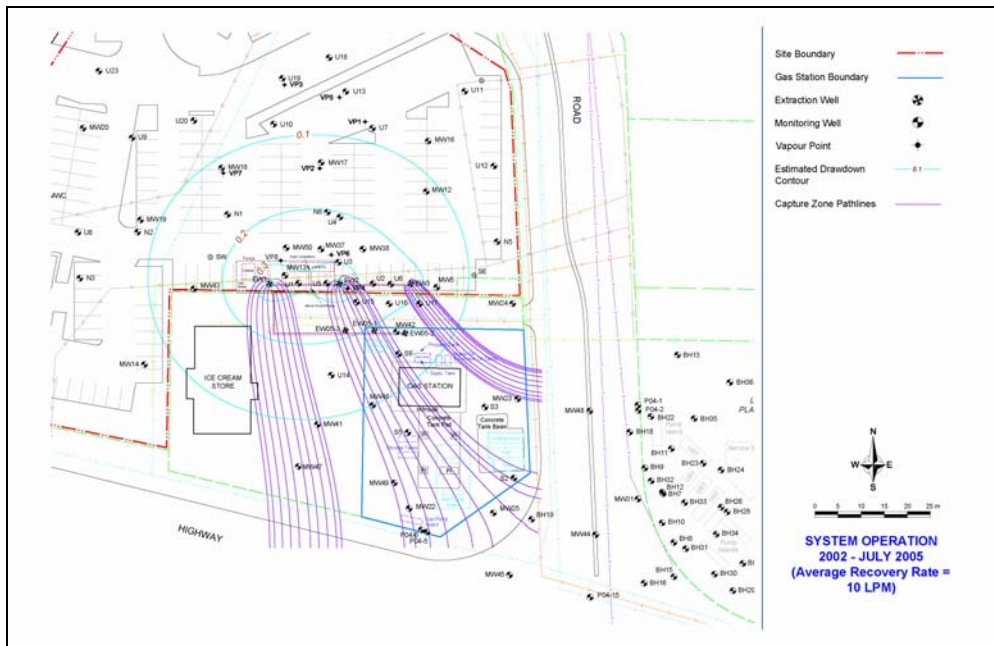


Figure 2: System Operation 2002 – July 2005

Remediation System Extension & Operations July 2005 to November 2005

In September 2004, URS proposed to extend the remediation system onto the adjacent source site to step the system operation off the mall site so that the risk assessment could be initiated. A detailed system design was based on May 2005 performance data for the mall site system and a capture zone analysis completed with MODFLOW.

The detailed design of system extension was as follows:

- Three purpose-built 4" system extraction wells (EW05-1 through EW05-3) for the combined operation of pneumatic total fluids pumps and soil vapour extraction were installed approximately 10m south of the existing system well-network on the northern portion of the adjacent source site.
- The new extraction wells (EW05-1 through EW05-3) were installed to approximately 12 mbgs but otherwise constructed the same as the extraction wells on the mall site

(EW1 through EW3). Deeper installations were made to permit greater flexibility with controlling pumping rates.

- Four additional 2" groundwater monitoring wells (U14 to U17) were installed to monitor the system's performance. These monitoring wells were specifically situated to permit the early detection of any migrating LNAPL before it reached and re-impacted the mall site.
- Associated system trenching and pipework connections were conducted immediately following drilling and well-installation works.

Construction of the system extension was completed on July 20, 2005 and AP-4 pumps were installed in each of the three new extraction wells EW05-01 to EW05-03 and brought online on July 25/26, 2005.

Operation times between July, 26 2005 and November 21, 2005 were again largely continuous, with the exception of an estimated 7% down-time associated with periodic shutdowns to facilitate static groundwater monitoring/sampling for quarterly BC MOE and monthly multi-site monitoring programs, and system maintenance/repair works.

EW2 was operated in conjunction with the source site extraction wells as the capture zone analysis indicated operating EW2 would have a desired effect on overall drawdown and hydraulic capture (Figure 3).

The AP-4 pump in EW2 remained on the bottom of the extraction well. Pumps in EW05-01 to EW05-03 were set so their intakes were at 8.6 mbgs. Total fluids were recovered at an approximate total rate of 20.8 LPM under this configuration. Operating parameters were set the same as for the previous operation period: the air compressor supplied 90 psi of compressed air to the pump network, and each pump was regulated to receive 65 to 70 psi of compressed air. Vacuum equalling 4 inches of mercury ("Hg) was applied to the extraction well network for VER of total fluids.

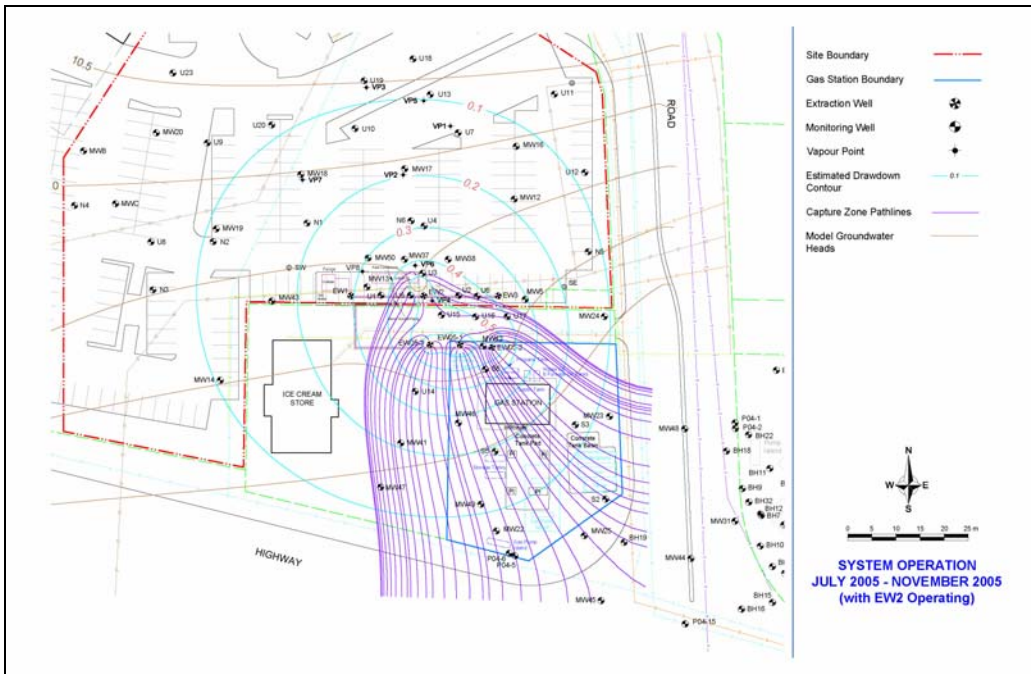


Figure 3: System Operation July 2005 - November 2005

Remediation System Operations November 2005 to August 2006

Remedial system operations on the mall site were ceased on November 21, 2005 and completely transitioned to the adjacent source site to support mall site closure. Between November 21, 2005 and August 1, 2006, when the system was shutdown and decommissioned, total fluids were pumped from EW05-01, EW05-02 and EW05-03; the pump positions had not changed since start-up. This set-up was designed to recover total fluids at an estimated rate of 16.6 LPM. Operating parameters were the same as those of each of the two previous operation periods.

Performance of this system set-up was verified using transducer data collected in December 2005 and a capture zone analysis completed using the pre-existing site MODFLOW model. The estimated drawdown, zone of influence and groundwater capture zone for this mode of operation is illustrated on Figure 4.

In mid February 2006, the air stripper air effluent was re-routed to two air phase GAC drums connected in parallel. Previously, the air stripper air effluent was combined with the SVE unit air discharge and routed to the oxidizer for treatment. Separating the air stripper air effluent from the SVE unit air discharge lowered the air flow rate into the oxidizer, in turn lowering the extraneous fuel consumption rate by the oxidizer and associated natural gas cost.

The entire system was shutdown in August 2006 and post-remediation monitoring initiated, consistent with the Risk Management Plan.

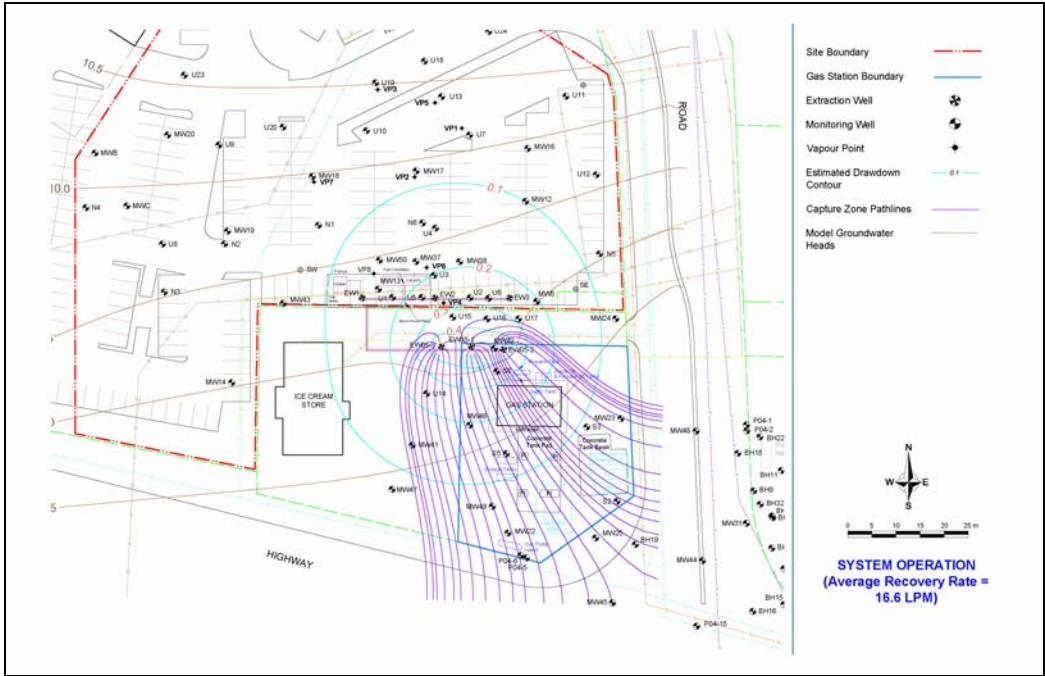


Figure 4: System Operation November 2005 – August 2006

Free Phase Plume Remediation

Prior to the initiation of remedial operations in August 2002, the extent of the LNAPL plume was defined by monitoring wells MW5, MW13, MW37, MW38 and MW50 (Figure 1). All monitoring and system wells located outside this area of plume coverage contained no LNAPL during the period of assessment and remediation. Groundwater monitoring conducted in December 2005 indicated that only a trace amount (~1mm) of LNAPL remained in U1. It was on this basis that engineered remediation of LNAPL at the site was concluded and system operations were entirely transitioned to the adjacent source site (see Phase 2 – Passive Remediation Program).

A total hydrocarbon mass removal of approximately 100,000 L (liquid product equivalent) was achieved with all mobile free phase product now removed from the mall site.

Confirmatory Soil Quality Assessment

URS collected and analyzed confirmatory soil samples in January 2006 to assess residual concentrations of contaminants in site soils subsequent to operation of the remediation system on site.

Analytical results for soil samples collected in the former free product plume area on site identified residual soil contamination within the saturated zone at depths between 8 mbgs and 9.3 mbgs. Residual soil contaminants of concern were xylenes, volatile petroleum hydrocarbons (VPH) and light extractable petroleum hydrocarbons (LEPH).

PHASE 2 - PASSIVE REMEDIATION PROGRAM

On August 30, 2005, URS met with representatives of the MOE to review remedial progress on the mall site, and to discuss and agree on how to implement the final steps in the site remediation plan. It was agreed that when transitioning of remedial system operations to the source site was complete, site risk assessment to support remediation closure reporting could be initiated. Remedial system operations on the mall site ceased on November 21, 2005 and completely transitioned to the source site. As such, URS proceeded with closure reporting and a human health and ecological risk assessment (HHERA) for risk management of residual contaminants in January through March 2006.

Monitored Natural Attenuation Assessment

An assessment of active natural attenuation (NA) processes within the site aquifer was completed in support of the human health or ecological exposure pathways analysis. URS conducted a detailed groundwater assessment in February 2006 subsequent to cessation of the remediation system operations on the site. Note that on January 26, 2006 the remedial system was shut down to allow initial groundwater conditions to be re-established. Approximately two weeks after system shut down, the NA groundwater monitoring was carried out between February 8 and 10, 2006.

The objectives of the groundwater assessment were to:

- Characterize site groundwater quality following source (i.e. free product) removal;
- Assess the stability of the dissolved contaminant plume; and
- Characterize NA processes in groundwater to confirm that intrinsic contaminant degradation was occurring, and would be effective for continuing management of residual contamination.

The scope of the groundwater assessment included monitoring and sampling of groundwater wells in the source area, and in upgradient, cross-gradient, downgradient, and far downgradient locations, contaminant mass flux calculations, plume statistical tests, geochemical sampling, and investigation of plume redox zone distribution.

Groundwater samples were analyzed for BTEX/VPH, VOC, LEPH, PAH, and dissolved metals as well as dissolved oxygen, nitrate, ammonia, sulphate, sulphide, dissolved iron, dissolved manganese, dissolved methane, alkalinity, and dissolved and total organic carbon (DOC/TOC).

Dissolved oxygen concentrations in groundwater ranged between 1.5 and 5.8 mg/L in all of the plume and downstream wells while groundwater in representative background wells MW1 and MW33 contained dissolved oxygen concentrations of 14.7 mg/L and 10.8 mg/L, respectively. These high values indicate a good potential for aerobic degradation of contaminants along the upstream and sidestream fringes of the plume and may explain the sharp drop in contaminant concentrations along the outer limits of the plume.

The measured concentrations of dissolved ferrous iron, sulphate, nitrate and methane indicate that sulphate reduction, methanogenesis and iron/manganese reduction are active at the site.

In summary, the geochemical data provide strong evidence of significant on-going natural attenuation, especially when considering the short lag period of approximately two weeks for the initiation of anaerobic degradation processes after system shut-down.

Redox Zone Distribution: The vertical and lateral distribution of redox zones within the dissolved contaminant plume was investigated by redox indicator tapes. The tape type used at the site consisted of 2 cm wide synthetic textile coated with reactive manganese dioxide minerals. The tapes were submerged into existing monitoring wells for four weeks. Given adequate reaction time, site microbiological communities readily occupy the tape emitting the manganese dioxide minerals. These redox reactions lead to characteristic colour changes of the tape surface, indicative of a distinctive redox process. Thus, the actual redox zonation within the contaminant plume on the centimetre-scale can be detected.

The redox-environment specific colors are as follows:

- drab = manganese(II)-oxidizing redox zone (RZ 1);
- ochre = manganese(IV)-reducing and iron(II)-oxidizing redox zone (RZ 2);
- light ochre to white = iron(III)-reducing and sulphide-oxidizing redox zone (RZ 3); &
- light grey to dark grey = sulphate-reducing redox zone (RZ 4).

On February 28, 2006, redox tapes were installed in five monitoring wells (U18, U19, U20, U21 and U24). Well-specific tape lengths were tailored to allow for a complete logging of the water column. The total tape length installed in all five wells was 13.3 m.

The redox tapes were recovered on March 28, 2006 and photographed for documentation purposes and are attached.

Well-specific results are outlined in the discussion below.

U19: In U19 (21,000 µg/L VHw), located in the plume centre, a complete reduction of the manganese dioxide coating and replacement by ferric hydroxide (ochre) occurred indicative of manganese(IV) reduction and iron(II) oxidation. This finding is supported by elevated dissolved iron (5.06 mg/L) and dissolved manganese (11.3 mg/L) concentrations measured in this well. Note that between 0 cm and 60 cm, no chemical reaction of the manganese dioxide coating occurred, as this section of the tape was not submerged in groundwater.

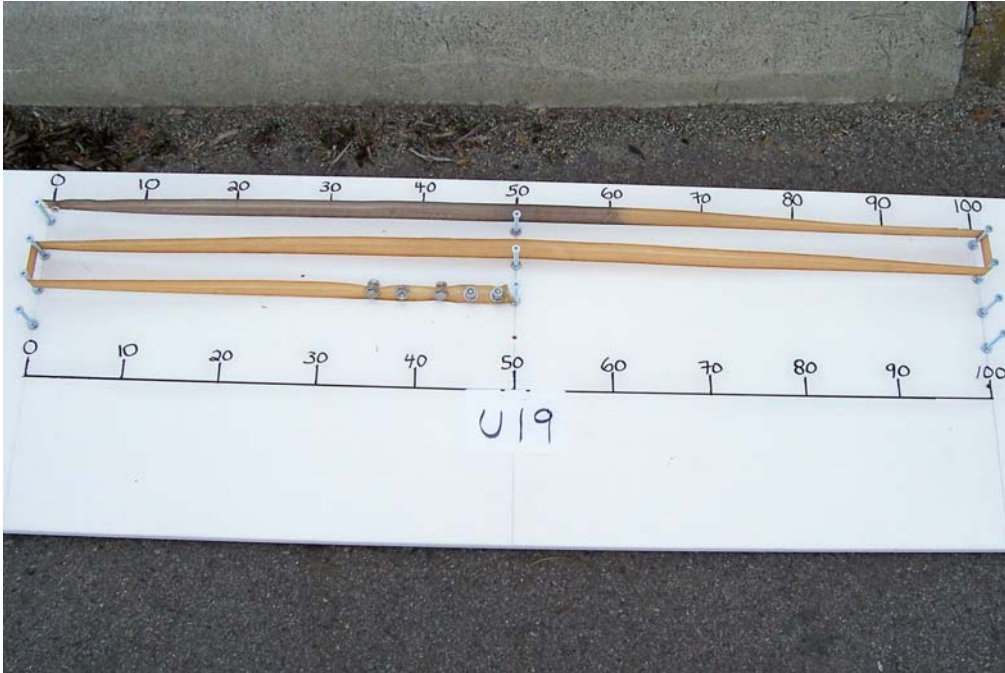


Figure 5: Redox Indicator Tape from U19

U24: In U24 (non-detect Vhw) which is located at the eastern plume fringe, no chemical reaction of the manganese dioxide coating occurred. This result matches well with the detected low concentrations of dissolved iron (0.08 mg/L) and dissolved manganese (0.8 mg/L), respectively.

In summary, there was a good match of redox tape data with hydrochemical data at the wells investigated. In the majority of plume wells, manganese reduction appears to be prevailing.

The conceptual attenuation model developed using the February 2006 data demonstrated significant ongoing NA processes at the site and indicated the dissolved plume was controlled within 70 m of the source area without human intervention.

RISK ASSESSMENT

A HHERA was completed in March 2006. Based on the conceptual contaminant fate and transport model, NA assessment, and depth to contaminated groundwater and soils, URS concluded that the key potential human exposure pathway was the direct inhalation of volatile chemicals moving to outdoor and indoor air from impacted soil and groundwater, and that no exposure pathways existed to ecological receptors. The site risk assessment was conducted on this basis.

The purpose of the risk assessment was to evaluate the potential for adverse effects to human and valued ecological receptors resulting from assumed exposures to residual concentrations of Chemicals of Potential Concern (COPCs) remaining in soil and groundwater and present in soil vapour at the site following remediation of free phase petroleum hydrocarbons.

Human Health Risk Assessment

The human health risk assessment evaluated potential risks of site contaminants in soil, groundwater and soil vapour to human receptors at the site. The HHRA assessed potential exposures to the general public who would visit the site (adults, teens, children, toddlers and infants), commercial and maintenance/general landscapers working at the site, and construction workers involved in subsurface excavations at the site. COPCs assessed in the HHRA were: petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylenes, hexane, and 1,2-dichloroethane (1,2-DCA).

The key potential human exposure route identified was inhalation of volatile COPCs from soil vapour to outdoor and indoor air. The risk assessment evaluated COPCs under two exposure scenarios: (1) current use of the site as a parking lot and (2) future land use of the site if a commercial building was constructed in the parking lot near the site boundary with the adjacent source site.

Estimates of potential chemical exposures to human receptors were compared with BC MOE accepted thresholds. In regulatory terms, possible human health effects have been divided into non-carcinogenic and carcinogenic effects. BC MOE considers a combined COPC hazard index of 1 as an acceptable risk level of for non-carcinogens, while the target health goal for carcinogenic risk used in this HHRA was 1.0×10^{-5} .

Findings of the Human Health Risk Assessment

The potential for human health risks was estimated using conservative exposure scenarios consistent with BC MOE guidance. The HHRA found:

- Currently there are no unacceptable health risks to workers or the general public who work in or visit the existing parking lot based on concentrations in the ambient air samples and the minimum COPC concentrations in shallow soil vapour;
- Health risks from non-carcinogenic chemicals were identified for all populations if undiluted shallow soil vapour is inhaled at the maximum concentration of COPCs in shallow soil vapour. Health risks for the non-carcinogenic chemicals are driven primarily by VPH aliphatic fractions, which comprise up to 90% of the total hazard quotient; and
- Health risks from benzene and 1,2-DCA (carcinogenic chemicals) exceeded the target cancer risk goal of 1×10^{-5} only for adult site visitors if a future retail facility is constructed above the existing parking lot and undiluted benzene and 1,2-DCA concentrations in soil vapour are inhaled.

Using shallow soil vapour and ambient air concentrations measured at the site, a site-specific attenuation factor of approximately 10^{-4} was estimated. A Risk Management Plan was developed on the basis of the confirmation of remediation for free product removal and the results of the risk assessment. Key components of the Risk Management Plan included:

- Subsurface soil in the area with the maximum concentrations of residual petroleum hydrocarbons should not be disturbed unless appropriate health and safety measures are taken to protect workers;
- If a building were to be constructed before vapour phase contaminant concentrations in soil have significantly decreased, vapour mitigation strategies such as a vapour barrier and/or crawl space ventilation underneath the building should be considered to provide an attenuation factor of 10^{-3} between indoor air and shallow soil vapour concentrations; and
- To confirm the dissolved phase plume attenuation model and to demonstrate continued acceptable human health risk at the site, monitoring of COPCs in groundwater and ambient air, respectively, should continue on a semi-annual basis for a period of one year¹.

POST-REMEDATION ACTIVITIES

Quarterly Groundwater Monitoring Program

Quarterly monitoring and sampling of groundwater had been ongoing at the site between August 2002 and August 2006 as a requirement of the AiP for the remediation plan. The quarterly program was voluntarily continued following the decommissioning of the system in August 2006 to comply with the Risk Management Plan. Since August 2006, site groundwater monitoring and sampling programs were conducted in September 2006, December 2006, February 2007, May 2007 and August 2007.

At the conclusion of the one-year voluntary groundwater monitoring and sampling program, URS analyzed groundwater quality data trends in select monitoring wells and completed additional testing of the conceptual dissolved phase plume attenuation model using BIOSCREEN-AT software (Figure 6).

On the basis of these analyses, URS concluded that the spatial extent of the dissolved hydrocarbon plume is stabilized by naturally occurring, active biodegradation processes and that human intervention in the form of further engineered remediation of the site was not required to maintain plume stability or acceptable human health risk levels in the parking lot.

URS further concluded that human intervention (i.e. operation of an engineered remediation system) is not required to prevent recontamination of the site by the free product plume remaining on the adjacent source site for the following reasons:

- Free product has not been detected on site since the fall of 2005, nor has free product been detected to date in monitoring wells situated on the source site upgradient of the site (U15, U16 and U17); and
- No free product was recovered by the remediation system during the final 18 months of its operation.

¹ This 1-year monitoring program concluded in September 2007.

Supplemental Risk Characterization Information

In August 2007, URS completed supplemental human health risk characterization work for the site in conjunction with the final quarterly groundwater monitoring program in support of site closure. The work comprised collection of an ambient air sample from the portion of the site overlying the highest COPC concentrations in groundwater; comparison of worker exposure estimates to risk assessment toxicity criteria rather than WCB worker levels used in the previous risk assessment; and, application of risk assessment approaches documented in new MOE Technical Guidance issued since the completion of the 2006 HHRA, “Director’s Interim Criteria for Contaminated Sites, Air Concentration Criteria” and “Technical Guidance 4 on Contaminated Sites, Soil Vapour Investigations”.

Findings of the Supplemental Risk Characterization Work

The findings of the supplemental work are summarized as follows:

- Ambient air quality at the site continues to meet acceptable health risk levels.
- The conclusions of the 2006 Risk Assessment regarding risks to worker populations (construction and maintenance/landscape) are unchanged by comparison of exposure estimates with risk assessment toxicity criteria rather than WCB worker levels.
- The COPCs identified for assessment of potential risks to human receptors at the site in 2006 are the same as those identified by comparison with new BC MOE air concentration criteria.
- The new Technical Guidance 4, permits outdoor and indoor attenuation factors to be applied to measured site soil vapour contaminant concentrations. Hence, the level of risk to potential human receptors at the site is now characterized as being significantly lower. Based on the risk assessment approach documented in Technical Guidance 4, the updated risk characterization is as follows:
 - COPCs for future indoor air would be limited to benzene if a building were to be erected in the area of the current parking lot and overlying the worst contamination.
 - Risks and hazards identified in the 2006 assessment for receptors exposed to outdoor air would be lowered by a factor of 100,000. No risks or hazards would exceed target health goals for current maintenance/landscape workers, or visitors using the existing parking lot.
 - Risks and hazards identified in the 2006 assessment for receptors exposed to future indoor air would be lowered by a factor of 10,000. Accordingly, no risks or hazards would exceed target health goals for either commercial workers or retail customers.
 - URS noted these attenuation factors would not apply to workers engaged in active subsurface soil disturbance.

CONCLUSIONS AND LESSONS LEARNED

The primary remedial objective of removal of recoverable free product was achieved by November 2005. A total of approximately 100,000 L (liquid product equivalent) was removed during operation of the remediation system. The risk characterization completed in August 2007 using new Technical Guidance 4 showed that a Risk Mitigation Plan is not required to protect current and future outdoor maintenance/landscape workers and visitors, nor future indoor retail workers and customers. If, however, active soil disturbance was to be conducted at the site in the future, a Risk Management Plan would need to be implemented for the protection of workers engaged in subsurface soil disturbance. On the basis of these results, the BC MOE issued a Certificate of Compliance for the mall site in December 2007.

A phased remediation approach combining engineered and passive approaches proved to be a practical and cost effective solution for our client. Risk management of residual groundwater and soil contamination released our client of the environmental liability associated with the site sooner than if engineered remediation had been conducted until groundwater and soil quality at the site met numerical provincial environmental quality standards. Although the MOE had issued an AiP for the phased approach at the project outset, working with the ongoing input and approval of the regulators was critical to the success of the project.

There was little written policy in BC governing risk assessments at the time the work was conducted and URS required technical guidance from the BC MOE respecting the end point of Phase 1 (engineered remediation program) and the risk calculations. In the absence of detailed technical guidance implementation of the phased remediation plan requires a clear scientific process. URS therefore provided several lines of evidence to prove the effectiveness of our passive approach to the regulators. Having substantiated our conclusions regarding the results of the engineered and passive programs with reliable data, the regulators were satisfied with the remediation work undertaken at the site and issued the Certificate of Compliance for the site.

REFERENCES

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*. Prentice Hall, New Jersey.

National Research Council (NRC). 2000. *Natural Attenuation for Groundwater Remediation*.-255 S.; Washington, D.C. (National Academy Press).

ACKNOWLEDGEMENTS

McCue Environmental Contracting: Remediation system installation, operation and maintenance.