APPLICATION OF PHYSICAL REMOVAL AND AEROBIC BIOREMEDIATION OF PETROLEUM HYDROCARBONS USING INNOVATIVE WELL DESIGNS

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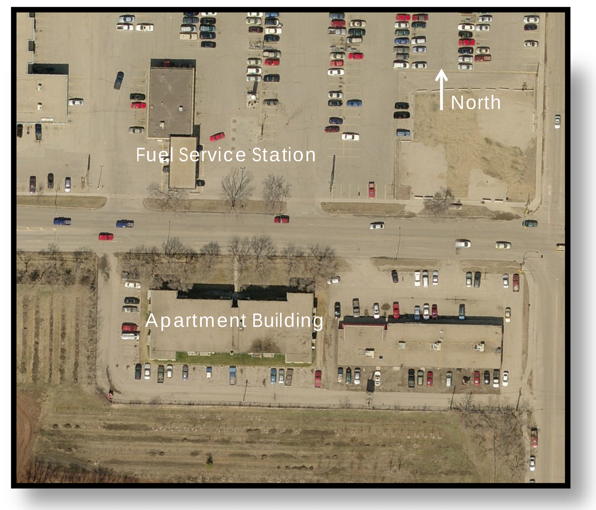
Introduction

The world consumes fossil fuels and as a result accidental releases occur throughout the supply process. A standard industry approach to manage impacted properties includes exsitu removal of the impacted material. This generally requires taking the property out of productive use and possibly demolishing onsite infrastructure if impacts have migrated below buildings during the remedial activities. Not only is exsitu remediation disruptive to land use, it also contributes to an increase in fossil fuel consumption, which is necessary to operate heavy equipment and to landfarm and remediate the soil. This approach is often considered unsustainable. Innovative insitu remediation approaches are needed.

Stantec Consulting Ltd. (the consultant) in collaboration with Federated Co-operatives Limited (FCL) (the proponent) developed an innovative insitu remediation research strategy to remediate PHC impacts at a residential property. This research was completed as part of FCL's commitment to the Sustainable Insitu Remediation Co-operative Alliance (SIRCA).

Background

Petroleum hydrocarbons migrated from an active fuel service station offsite to an adjacent apartment building property (referred to collectively as the Site, see Figure 1). Previous Environmental Site Assessment (ESA) activities were completed, including Phase II ESAs and a Quantitative Human Health Risk Assessment (QHHRA).



(Figure 1: Site location showing the active fuel service station and the apartment building property.)

- PHC impacts were identified in soil and groundwater at the active fuel service station, offsite beneath the adjacent roadway and the adjacent apartment building property.
- A QHHRA including subslab vapour sampling was completed by a third party and concluded that the residents of the apartment are not at risk of experiencing health effects from the inhalation of PHC found in the subsurface.

Environmental Stewardship

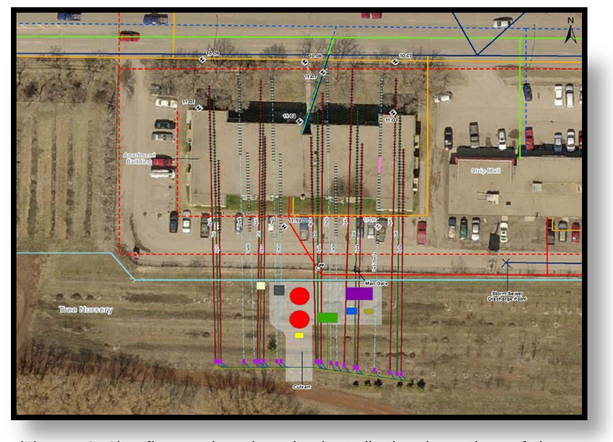
The QHHRA indicated that no remedial efforts and/or risk management measures needed to be implemented; however, FCL (the client) chose to implement a remediation program designed to:

- Reduce PHC mass from beneath the apartment building property.
- Provide an additional level of comfort to the residents of the apartment.
- Reduce the negative stigma and potential property devaluation associated with environmental impacts.

Remediation Concept

The remediation strategy consisted of mechanical PHC removal and insitu biodegradation using a multiphase extraction (MPE) system coupled with horizontal air sparge and extraction lines (also referred to as horizontal wells).

(Photo 1: Facing northwest, view of the remediation system components. Note the apartment building in the background.)



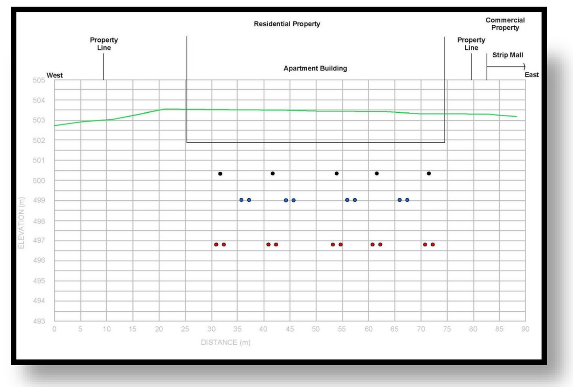
(Figure 2: Site figure showing the installation location of the horizontal wells below the apartment building.)

Remediation System Components

The remediation system consisted of:

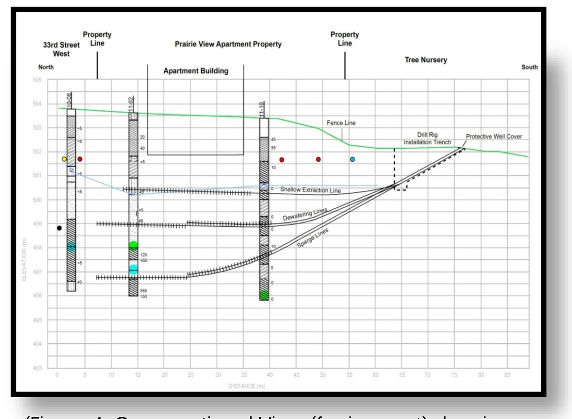
- 100 HP MPE blower motor.
- Silt knock out.
- 25 HP compressor.
- Pulsed air water lift (PAWL) lines.
- Granular activated carbon (GAC) filtration.
- 120,000 L aboveground storage tank (AST) capacity.

Three types of wells were installed as part of this remediation project, which consisted of horizontal air sparge, extraction and dewatering wells. The horizontal air sparge wells were installed within the PHC impacted soil beneath the apartment building. Pressurized air was pumped into the sparge lines, to increase volatilization of sorbed PHC mass, while also facilitating an aerobic environment conducive to PHC biodegradation. The horizontal extraction lines were installed above the sparge lines to provide soil vapour transport control and to reduce the potential for volatized PHCs from entering the apartment building (see Figure 2 through Figure 4 and Photo 1).



(Figure 3: Vertical profile (facing north) showing installation position of the horizontal wells below the apartment building. From surface, extraction wells, underlain by dewatering wells then the sparge wells.)

Dewatering wells were installed between the sparge and extraction lines, both vertically and horizontally, and used to lower the water table to ensure the extraction lines were within the vadose zone providing vapour transport control and to remove PHC impacted groundwater from the Site.



(Figure 4: Cross sectional View (facing east) showing vertical installation profile of the horizontal wells below the apartment building.)

Horizontal Well Construction

The horizontal wells were installed in pairs (long and short) within separate boreholes, using dedicated header lines. Well screens ranged from 20 m to 30 m in length.

- Sparge lines – constructed with 25 mm (1 inch) carbon steel.
- Extraction lines – constructed of 51 mm (2 inch) Schedule 80 PVC.
- Dewatering wells – constructed using four unique well design concepts.

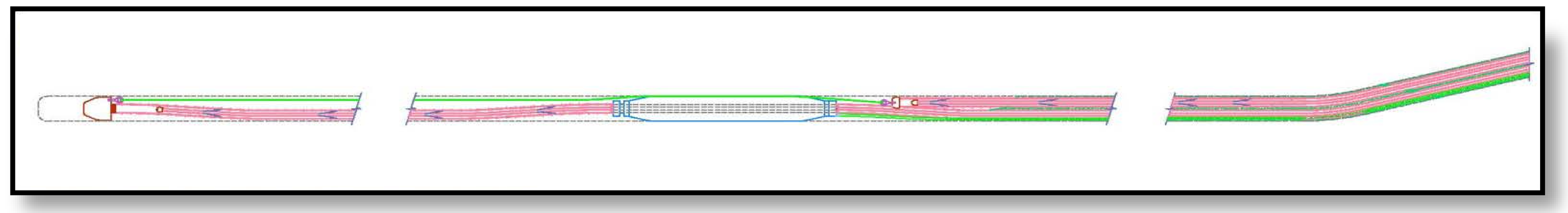
(Photo 2: View of the inflatable packer being assembled to the horizontal well.)

Dewatering Well Concepts

Horizontal wells are known to accumulate silt, which reduces recovery effectiveness and typically requires costly maintenance for silt removal. Four dewatering well concepts (listed below) were installed to evaluate their ability to minimize silting, the labour requirements for installation and the costs of the well materials.

Nested Well with Inflatable Packer

- Two wells installed within a single borehole.
- Wells were separated using an inflatable packer.
- Wells were constructed of 51 mm (2 inch) Schedule 80 PVC.
- Packer was inflated after installation to separate recovery zones.



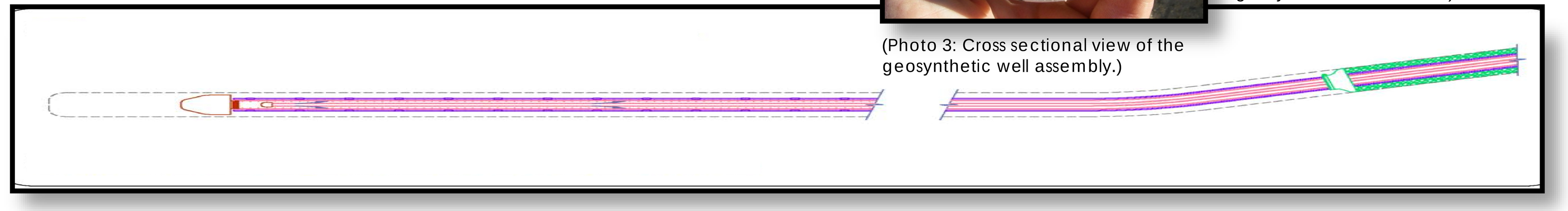
(Figure 5: View of the inflatable packer well concept. Note, the two horizontal wells installed in a single borehole and isolated by the inflatable packer.)

Geosynthetic Well

- Dual layer well specifically designed for horizontal applications for extraction or injection of liquids and vapours.
- Inner well 51 mm (2 inch), outer well 89 mm (3.5 inch) Schedule 40 PVC.
- Uses a non-woven geotextile layer (polypropylene filtration medium) located between the inner and outer PVC wells.

(Photo 3: Cross sectional view of the geosynthetic well assembly.)

(Photo 4: Perforated geosynthetic well screen.)

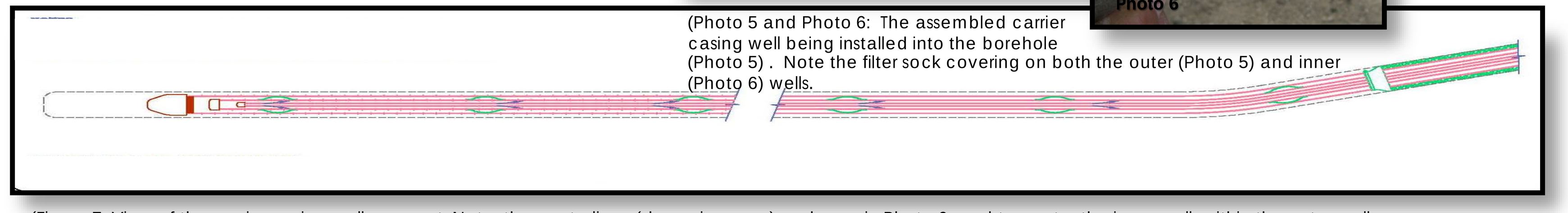


(Figure 6: View of the geosynthetic well concept.)

Carrier Casing Well

- Constructed with a 102 mm (4 inch) outer well and a 51 mm (2 inch) PVC inner well.
- Inner well supported with centralizers.
- Filter sock installed over wells prior to installation.

(Photo 5 and Photo 6: The assembled carrier casing well being installed into the borehole (Photo 5) . Note the filter sock covering on both the outer (Photo 5) and inner (Photo 6) wells.



(Figure 7: View of the carrier casing well concept. Note, the centralizers (shown in green) and seen in Photo 6 used to centre the inner well within the outer well.

Standard PVC Well

- Standard 51 mm (2 inch) Schedule 80 PVC.
- Filter sock installed over well prior to installation.
- Sand pack pumped into the well screen annulus.

(Photo 7 and Photo 8: View showing he standard PVC well concept being installed into the borehole. Note the well is attached to the specialty tooling adaptor using a cable grip.

(Figure 8: View of the standard PVC well concept. Sand (shown in green) was pumped into the borehole annulus adjacent to the well screen.

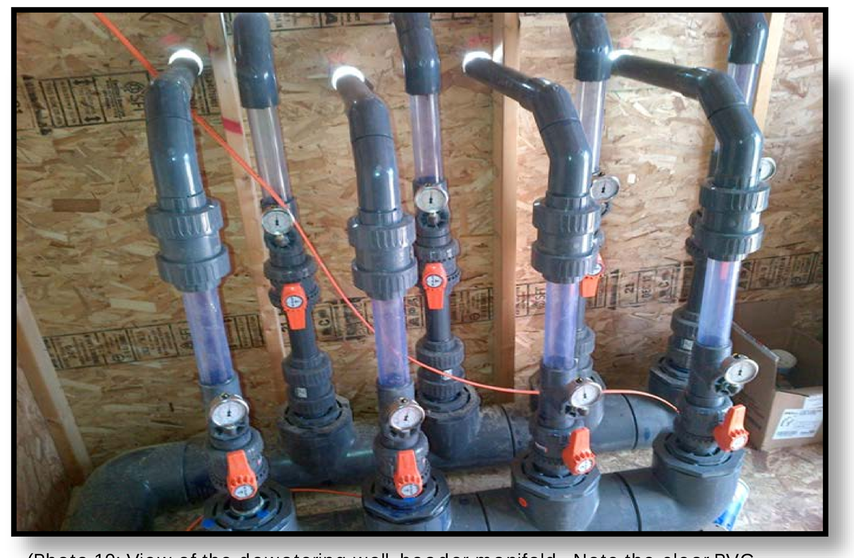
Horizontal Well Installation

The horizontal lines were installed using a Vermeer 2433 directional drill rig and completed as blind installations (i.e. with a single daylighted entry point). The boreholes were then reamed to remove soil and excess drilling mud prior to well installation. Wells were developed using approximately 1,000 L of water to flush out silt and 500 L of a 3% to 5% hydrogen peroxide solution to accelerate the breakdown of drilling mud. Select wells were completed using filter sand around the well screen and completed with a 10 m bentonite/cement grout plug to prevent short circuiting through the annulus.

(Photo 9: Vermeer 2433 horizontal drill rig installing a sparge line.)

Dewatering Well Assessment

Each of the wells were installed and developed using a similar process and volume of water/hydrogen peroxide solution. The dewatering wells were then assessed for their ability to withstand siltation, the labour and installation costs and the cost of the well materials.

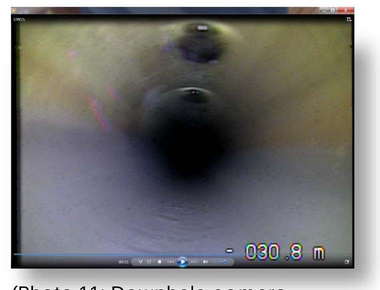


(Photo 10: View of the dewatering well header manifold. Note the clear PVC casing, which was used for visually assessing groundwater recovery and silt load.

Siltation Assessment

Included daily visual inspections (Figure 10) and a downhole camera evaluation:

- Recovered groundwater in each well had a similar silt load during an initial 4 week operating period.
- Silt load decreased after approximately 4 weeks.
- A downhole camera was inserted into the geosynthetic and the standard PVC dewatering wells. Less silt was observed within the geosynthetic well compared with the standard PVC well (see Photo 11 and Photo 12).
- The PAWL lines within the nested well with inflatable packer and the carrier casing wells could not be removed; therefore, were inaccessible for the downhole camera assessment.



(Photo 11: Downhole camera assessment of the silt accumulation within the geosynthetic well. Note the air bubbles near the top of the well. The greyish colour along the bottom is likely water discolouration.)

(Photo 12: Downhole camera assessment of the silt accumulation within a standard PVC well. Note the irregular silt accumulation at the bottom of the well and the suspended silt in the top left corner.)

Labor and Installation Assessment

- The nested well with inflatable packer and carrier casing wells required additional time to assemble.
- Larger well diameters require more drilling mud, multiple reaming using larger reamers and a greater volume of drill cuttings are produced.
- An increase in drilling mud/cutting volume requires additional costs for disposal.

Cost Assessment

- The nested well with inflatable packer was the most costly considering the cost of the packer. However, less drill time was required, since two wells were installed within a single borehole.
- The geosynthetic well was the most costly of the materials on a per meter of well screen comparison.
- The carrier casing well, is a well within a well and was the second most costly well based on a per meter of well screen comparison.
- The standard PVC well was the most economical option.

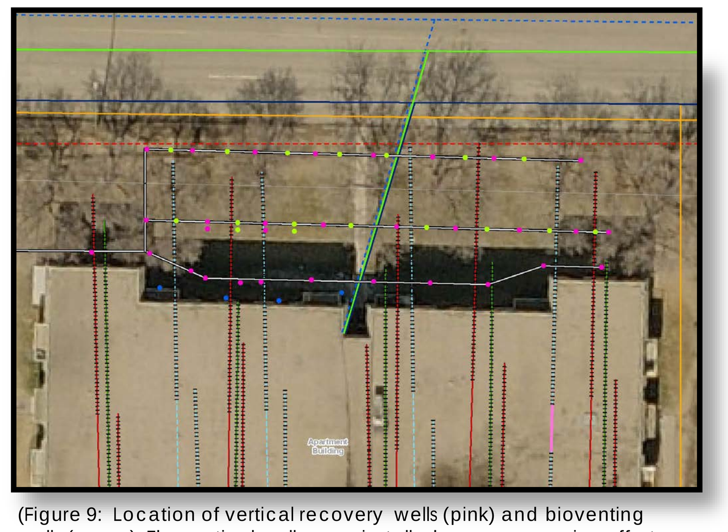
Table 1: Installation and Well Cost Comparison

Well Type	Relative Well Cost (per m of well screen)	Labour and Installation Requirements
Nested Well with Inflatable Packer	1x + Packer*	-drilling time reduced by half -well assembly time required
Geosynthetic Well	3.5x	-easy to assemble -simple installation
Carrier Casing Well	3x	-well assembly time required -additional drill time to advance larger diameter borehole
Standard PVC Well	1x	-easy to assemble

(Well costs compared to Standard PVC Well concept of $37/m of well screen. *Packer cost was an additional $3900.)

Remediation System Enhancements

Borehole assessment activities were completed to evaluate the remediation success of the MPE system. PHC impacts were identified in an area not previously assessed, which was outside the extent of the MPE system footprint. Therefore, an aggressively spaced grid of alternating recovery wells and bioventing wells (49 in total) were installed in an effort to reduce remediation timelines (see Figure 9). The recovery wells were connected to the MPE system and the bioventing wells were opened to atmosphere to facilitate air flow through to the subsurface.



(Figure 9: Location of vertical recovery wells (pink) and bioventing wells (green). The vertical wells were installed as an aggressive effort to reduce remediation timelines.)

(Photo 13 and Photo 14: View of unique vertical recovery well design. Note the well screen is attached directly to the header line without elbows or connectors, thus reducing vacuum friction loss. Centralizers were also attached for proper positioning.)

Remediation Results

The MPE system operated between October 2013 and October 2014 and will be commissioned for further operation during the 2015 field season.

- The MPE has operated for approximately 7,600 hrs.
- Over 1.5 Million Litres of groundwater has been recovered.
- A total PHC mass of approximately 12,200 Kg has been removed from the Site.

Future activities planned at the Site will include carbon isotope analysis of the recovered soil vapour to evaluate PHC mass removal in the biodegradation phase and potential surfactant and nutrient injections to enhance the remediation success.

(Photo 15: View facing east of the north side of the apartment building. Approximately 2,500 m of dedicated header line was used during the installation.)

Acknowledgements

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SIRCA
Sustainable In-Situ Remediation Co-operative Alliance

This research was conducted as part of Federated Co-operatives Limited's commitment to the **Sustainable In-Situ Remediation Co-operative Alliance (SIRCA).**