PINTER
& ASSOCIATES LTD

PROJECT: **Enhanced Anaerobic Bioremediation Achieves Site Remediation**

PREPARED FOR: CANADIAN CONSULTING ENGINEERING AWARDS 2018

Abstract

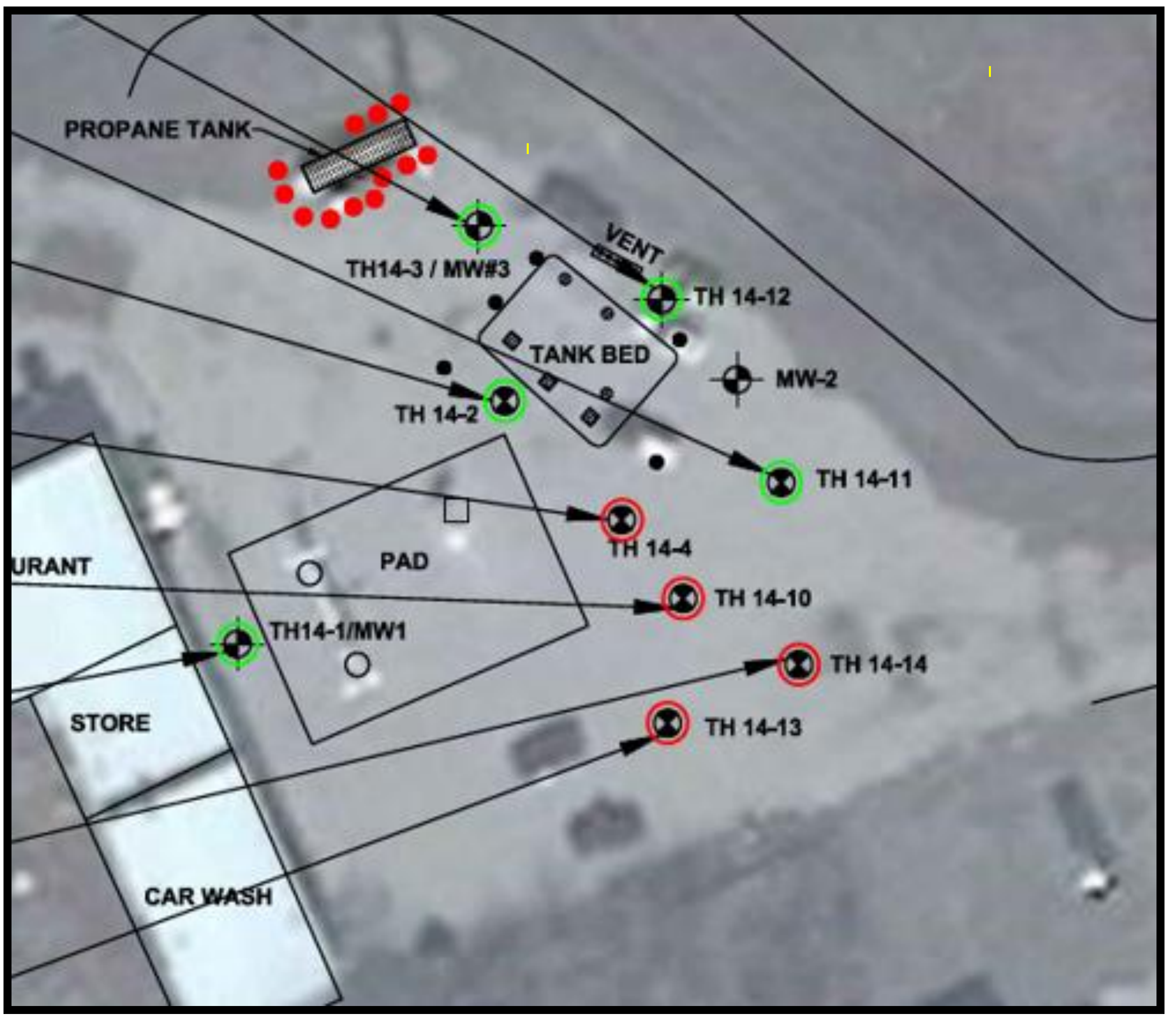
The client needed to remediate approximately 3000 m^3 of gasoline impacted soil and groundwater to facilitate the sale of his property and business. PINTER & Associates Ltd. (PINTER) developed and implemented an innovative, cost effective solution that achieved remediation at a cost approximately 90% less than a conventional excavate and replace approach. Now, the client can sell the property with no environmental liabilities attached and can add the remediation savings of ~$450,000 to his retirement fund.

Enhanced Anaerobic Bioremediation Achieves Site Remediation

1. Introduction

The trigger for the remediation project was the client's desire to sell his property within 3 to 5 years. He retained PINTER & Associates Ltd. in 2015 to undertake a detailed Phase II Environmental Site Assessment (ESA) and design a cost-effective remediation plan for the Site. A cost estimate for a conventional excavate and remove remediation came to about $500,000. Previous investigations on the Site indicated shallow soil and groundwater on the Site were impacted by Petroleum Hydrocarbons (PHCs) which have accumulated over the 30-year operation of the Site as a fuel distribution center. Figure 1 below shows the PHC plume present south of the tank bed prior to the initiation of remediation work. PHC concentrations in the groundwater were as high as 60 times Health Canada's maximum acceptable concentrations (MAC) for PHCs in potable groundwater and were headed off-site to the south towards a freshwater lake which is the town's potable water supply.

Figure 1 – PHCs South of Tank Bed, Pre -Remediation



1.1. Project Objectives

Three primary objectives were set out by the client as follows:

1. Remediate the site in order to facilitate sale of the property within 3-5 years
2. Keep costs to a minimum
3. Minimize disruptions to business activities on the Site

Objectives not set out explicitly, but which were integral to project success included; minimized disturbance to the business, maintaining an aesthetically pleasing and safe worksite, maintaining a positive working relationship with the adjacent landowners, improving the appearance and function of the work area, and protecting the public during the remediation activities.

1.2. Evaluation and Selection of Remediation Option

Upon request from the client, PINTER developed conceptual designs and a comprehensive cost/benefit analysis on six alternatives for remediation of the identified PHC soil and groundwater impacts. Options had to meet each of the project objectives listed above. The four alternatives evaluated were:

i. Excavation and Removal of soils across the impacted area.

ii. Injection of a chemical oxidation amendment throughout the source area.

iii. Enhanced Aerobic Bioremediation to remove PHCs from impacted soil and groundwater through bacterial activity

iv. Enhanced Anaerobic Bioremediation to remove PHCs from impacted soil and groundwater through bacterial activity.

The excavation and removal, injection of chemical oxidation amendment across the site, and enhanced aerobic bioremediation were eliminated due to high costs, uncertainty over whether remedial objectives could be met, and high anticipated disruptions to site operations.

It was decided to pursue an enhanced anaerobic bioremediation approach by adding potassium sulphate within the bottom of an excavation needed to remove existing tanks in the north portion of the Site. In order to ensure full treatment of the plume, a permeable reactive barrier (PRB) was installed near the southern property line which was close to the leading edge of the plume. The treatment would be used to intercept and remove PHCs through sulfate-reducing bacteria(SRB) from the groundwater and soil within the treatment area. Figure 2 on page 5 shows the location of the PRB and north excavation on the Site.

PINTER's final design was based on detailed site information gathered during the course of two ESAs on the property and an extensive literature review encompassing both field applications of enhanced anaerobic bioremediation and laboratory-based work. PINTER relied on in-house expertise and experience in the disciplines of hydrogeology, bioremediation, contaminant transport, groundwater modeling, biochemistry and project management to successfully meet the challenges of the project.

2. Background Theory

2.1. Sulphate-Reducing Bacteria

Sulphate-reduction bacteria (SRB) are capable of breaking down SO_4 under anaerobic conditions in order to "breathe" the oxygen it contains in the presence of an energy (carbon) source. There are several variations of SRB which contribute to the reduction of sulphate to oxygen. SRB tend to be active in concentrated areas where oxidizable organic matter such as PHCs are readily available and anaerobic conditions dominate. PINTER's assessment indicated that sulphate was the limiting factor needed to improve conditions for SRB on the Site. Sulphate on the Site was present below 3 mg/L, after the treatment it was as high as 400 mg/L.

3. Construction and Design

The installation occurred in fall of 2015, concurrent with the removal of underground storage tanks which were at the end of their useful life. The source chosen for the sulphate was potassium sulphate (see photo below). Potassium sulphate was selected due to the availability, cost and also because SRB require potassium as a macronutrient. Furthermore, potassium sulphate has a lower solubility than other sulphate sources, so it should dissolve into the groundwater more slowly, providing an extended treatment period.

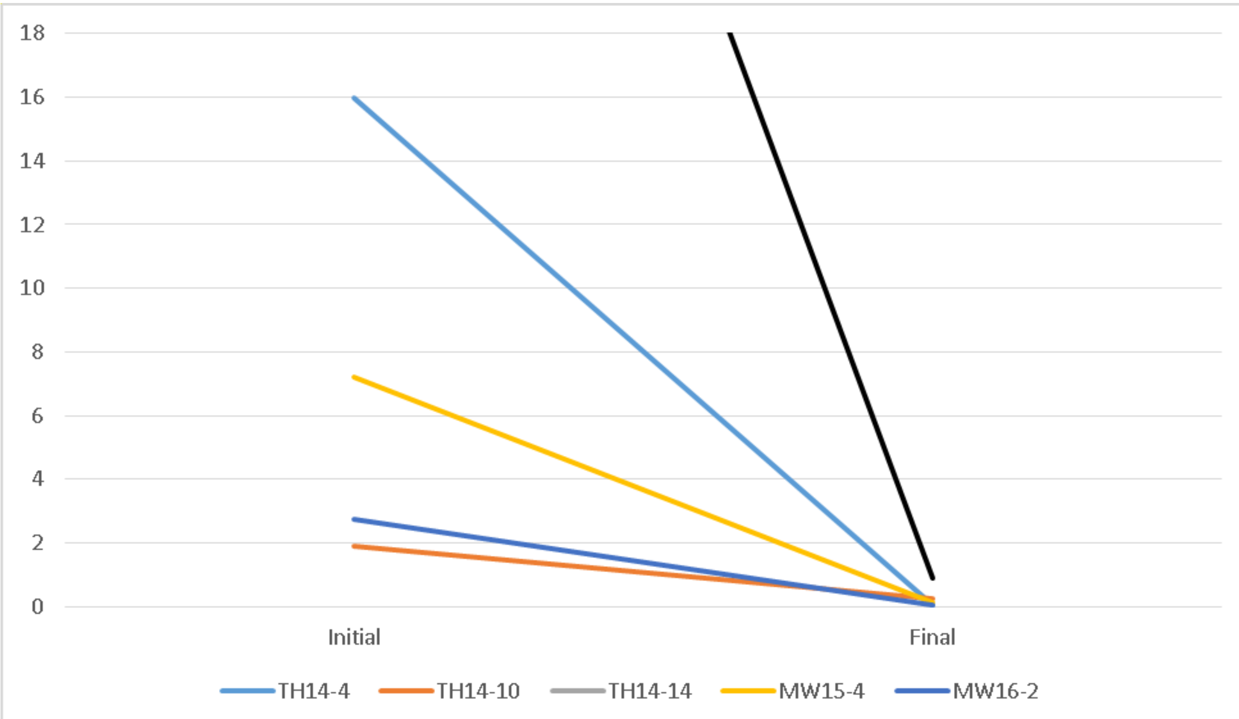
The bioremediation program proceeded concurrently with the planned removal of the aged underground storage tanks in order to minimize costs. Potassium sulphate was added to the bottom of the excavation before backfilling with native soils.

The PRB on the southern portion of the Site was constructed by removing native soils, placing potassium sulphate at approximately 2 m below ground surface and returning the native soils above the potassium sulphate The amount of potassium sulphate used was determined by calculating the expected sulphate mass flux and using a mass balance approach to provide enough sulphate to remove PHCs for a period of at least 5 years. In total, 2400 kg of potassium sulphate was placed. The maximum sulphate levels on the Site were designed to safeguard the lake which is 300 m downstream.

Groundwater monitoring wells were installed upon completion of the installation to monitor the efficacy of the remediation process. A total of 12 wells were used within and around the treatment area.

4. Results

The work was done in order to reduce soil and groundwater concentrations of PHCs to below criteria values on the Site to facilitate the sale of the property. The soil concentration of benzene was the only remaining portion of PHCs remaining above laboratory detection limits after two years. The average benzene removal was approximately 98%, and all concentrations were below the relevant criteria. Five locations were sampled at the beginning of the project, and identical locations and depths were sampled at the conclusion of the project. Results can be seen below for benzene in soil.



Groundwater concentrations were reduced significantly as well over the two-year span of this project. All groundwater PHCs were below applicable criteria at the close of this project. The two Figures on the following page show the groundwater plume at the start and one year into the two-year project. The final results are not shown as everything is below criteria, and the entire figure would show blue. In the Figures, blue is below applicable criteria, red is more than 20 times above.

Figure 2 – Initial Groundwater Concentrations

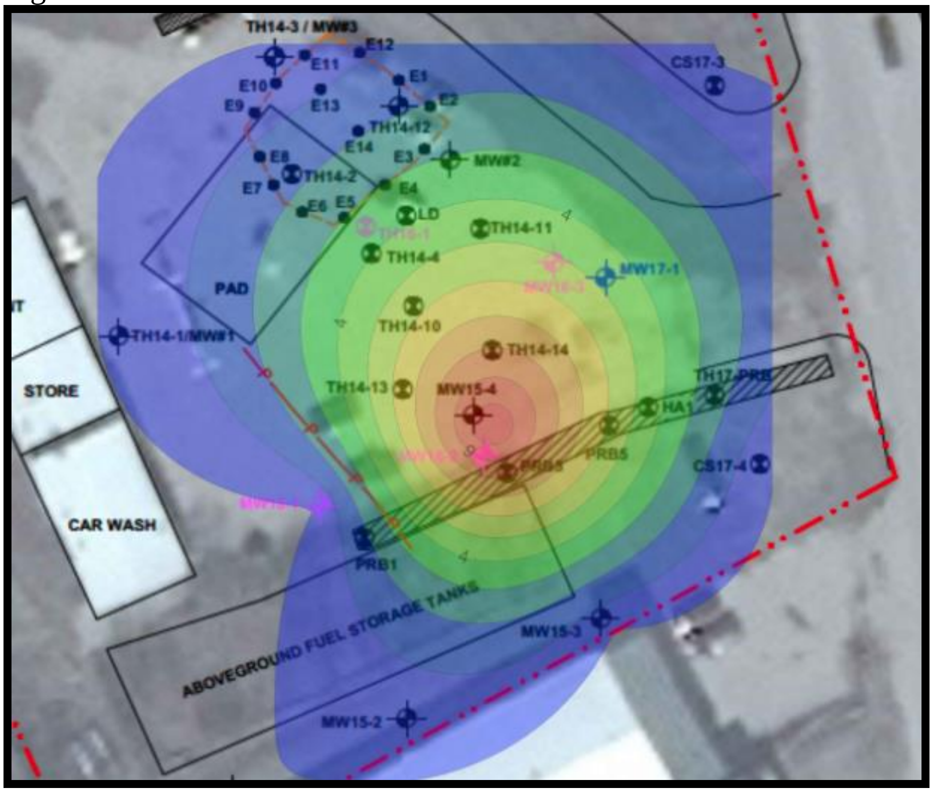
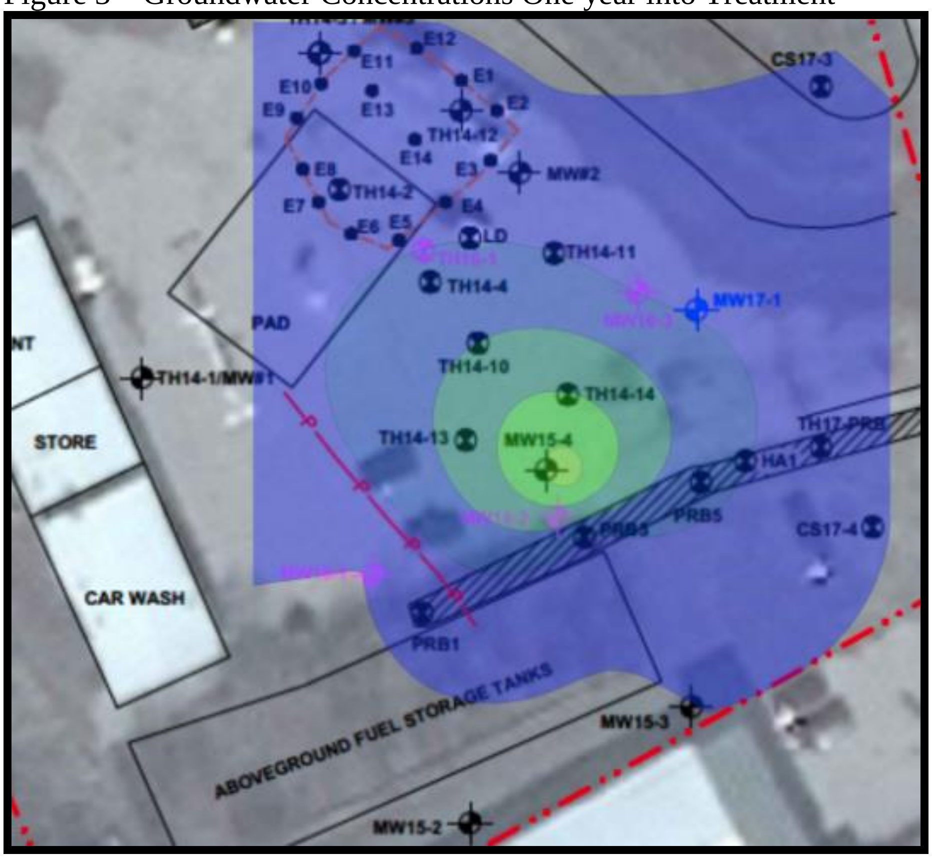


Figure 3 – Groundwater Concentrations One year into Treatment



5. Project Highlights

5.1. The Innovation

The client needed to remediate approximately 3000 m^3 of gasoline impacted soil and groundwater to facilitate the sale of his property. PINTER & Associates Ltd. (PINTER) developed an innovative and cost-effective solution that achieved remediation at a cost approximately 90% less than a conventional excavate and replace approach.

The client received estimates for a conventional excavate and remove approach with costs coming in around $500,000, which was well beyond his desired budget. After site assessment, PINTER proposed an innovative enhanced anaerobic bioremediation program at a cost of $50,000. The program was expected to take 2-5 years, which matched the client's desired timeline.

The key piece of science underlying the bioremediation approach is that sulphate-reducing bacteria (SRB) are able to "breathe" sulphate (SO_4) rather than oxygen (O_2). If a sulphate source is added, the SRB bacteria should be able to utilize it and speed up the rate at which the carbon source is eaten or degraded. In this case, the carbon source for the bacteria was the subsurface gasoline plume.

The bioremediation program proceeded concurrently with the planned removal of the aged underground storage tanks in order to minimize costs. Potassium sulphate was added to the bottom of the excavation before backfilling with native soils. A permeable reactive barrier (PRB) was also constructed near the leading edge of the gasoline plume to the south. The PRB was an engineered control for the plume which allowed for the elimination of the potable and aquatic pathways. Groundwater flow was determined to be south and natural groundwater flow was used to distribute the sulphate throughout the remediation area.

Enhanced Anaerobic Bioremediation is not well understood and is often not even considered as a remediation option for most contaminated sites. It can take significantly longer than other approaches and is not well suited for short duration projects. Anaerobic bioremediation rates are approximately 1/10th of aerobic bioremediation rates. PINTER made use of the longer timeframe available for this project to select a very unconventional remediation approach. The innovative approach was the key to keeping project costs below $50,000.

PINTER's innovative work on this project has been featured at the 2018 Sustaintech Conference and will be featured at Remtech 2018 this fall. Work on an article for Environmental Science & Engineering magazine is underway. PINTER applied for and received tax credits for portions of this work under the federal Scientific Research and Experimental Development (SR&ED) Tax Incentive Program.

5.2. Complexity

The budget for the project was only 10% of what a conventional excavate and remove approach would cost. This required a much more complex, innovative and strategic approach.

More than 90% of the gasoline impacts were absorbed to peat which was present at a depth of about 2 metres below ground surface across the Site. Peat strongly binds with gasoline and is used in many commercially available spill control products. The sulphate added to the Site would need to last for two years or more to ensure full remediation.

A fish bearing lake, which is also the potable water supply for the community, is present only 300 metres south of the Site. Any remediation approach would need to deal with the gasoline, but also ensure that sulphate added to the Site did not reach the lake at concentrations detrimental to aquatic life.

Groundwater modeling was used to determine that maximum sulphate concentrations on the Site should be no more than 1000 mg/L in order to guarantee it would not reach the lake above 100 mg/L. From literature it was determined that 100 – 300 mg/L would be the optimum sulphate concentrations on the Site.

Mass balance and mass transfer calculations were used in the design to attain the optimum concentration between 100 – 300 mg/L throughout the treatment area, while keeping maximum concentrations below 500 mg/L. Results indicated that optimum concentrations were attained, and the maximum was not exceeded.

5.3. Social and/or Economic Benefits

PINTER’s approach provided a substantial cost savings for the client with a cost reduction of more than 90% compared to a conventional excavation and removal of the source area. The client has received a clearance letter from the Ministry of Environment and can now sell his property without environmental liability. This will benefit the broader community as well because the property and business will be transferred and continue to serve the community as a viable gas station for the foreseeable future. Bank financing of properties with environmental liability is very difficult, that hurdle has been removed.

Many similar properties in Canada end up abandoned as the cost of conventional remediation can exceed the business/property value. This problem is particularly acute in rural Canada, where property values are relatively low. Abandoned former gas stations with significant environmental liabilities can be found in nearly every community. These abandoned sites can be an eyesore, pose environmental risks to the community, tie up otherwise useful real estate, and reduce taxes payable to all levels of government. They also provide no employment opportunities.

Without environmental liability attached to the property, future owners have the opportunity to redevelop the site as they see fit. The owner and community benefited from the continued operation of the business through the remediation process. The use of this approach allowed for safe use of the business by the public by limiting the scope of invasive work at the Site.

5.4. Environmental Benefits

This project is of direct benefit to the Site, the nearby lake and surrounding environment, citizens of the town, and to the client. The potential hazards to the environment and the public posed by the groundwater PHC plume reaching sensitive off-site receptors no longer exist. In addition, the carbon footprint of the total onsite remediation and mobilizations to the site was significantly less than if a conventional treatment was used. A conventional dig and dump for the Site would have involved at least 60,000 more km of heavy truck traffic on the roads along with all the extra carbon emissions and safety concerns. The work on the Site was planned to coincide with the necessary removal of Underground Storage tanks, therefore equipment was on Site already and site disturbance was minimized.

A source of sulphate in the form of potassium or magnesium sulphate was the only thing added to the Site. Potassium sulphate is commonly used as a fertilizer, while magnesium sulphate is commonly known as Epsom salt. There are no undesirable emissions from the treatment as the primary byproduct of the process is water and Carbon dioxide gas. The amount of Carbon dioxide released would be a small percentage when compared to a conventional heavy equipment approach and is therefore not of concern. The distribution of sulphate through the remediation area was achieved using natural groundwater flow. The system did not require any ongoing maintenance or power for operations.

5.5. Meeting Client's Needs

The client's three main project goals were:

1. Remediate the site in order to facilitate sale of the property within 3-5 years
2. Spend substantially less than the $500,000 required by a conventional approach
3. Minimize disruptions to business activities on the Site

PINTER was able to meet all three of these goals within a two-year timeline. A clearance letter confirming full remediation was received from the Ministry of Environment which will simplify financing for the Site. Total costs came in at approximately $50,000 which was a savings of about 90% when compared to a conventional approach. Disruptions to business activities on the Site were avoided by completing the remediation activities concurrently with the planned removal of the underground storage tanks. The client's needs were considered at every step of the project and the client is exceptionally pleased with the process and the outcome.