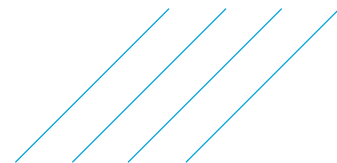


Building what matters

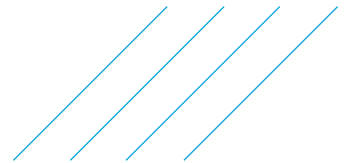


## Our vision

We strive to be the premier engineering solutions partner, committed to delivering complex projects from vision to reality for a sustainable lifespan.



# Remediating F2 Impacts in Soil Via Hydrogen Peroxide Injections



## Site History and Background

- Muncho Lake Maintenance Camp is a 9 ha site located approximately 240 km NW of Fort Nelson, BC, along Highway 97 (the Alaska Highway)
- located in the Terminal Range of the Rocky Mountains in Muncho Lake Provincial Park
- surrounding lands remain expressly natural and undeveloped
- the Trout River, the closest freshwater aquatic receptor, borders the west boundary of the Site
- Muncho Lake is located 1.2 km to the north
- the Site was developed in 1942 during the construction of the Alaska Highway, and has since been used as a maintenance camp for the highway
- the Site was a historic refuelling stop with multiple bulk storage tanks (with a total capacity of 276,000 litres) providing fuel oils, gasoline, and lubricants to military and civilians



# Site Overview





# Site Plan



## Site Conditions

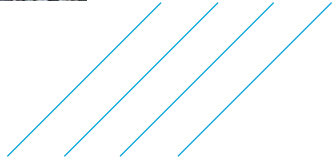
In 2016, SNC-Lavalin reviewed and noted the following site environmental conditions from historic investigations:

- deep petroleum hydrocarbon impacts (PHC) were primarily associated with the groundwater smear zone (approximately 8 metres to 15 metres below ground)
- the source of PHC impacts at the Site is considered to be primarily fuel oil, gasoline, and limited quantities of used oil
- soils in the smear zone are primarily sand and gravel with some silt



# Site Conditions Cont'd

## Contaminated Interval Stratigraphy





## Site Conditions Cont'd

- low to non-detect dissolved hydrocarbon concentrations (BTEX, F1, and F2)
- no light non-aqueous phase liquid (LNAPL) was noted in monitoring wells at the site
- contaminants of concern are primarily F2 in soil (up to 10,000 µg/g)
- F1 and benzene, toluene, ethylbenzene, and xylenes (BTEX) also present in soil
- initial inferred extents of F2 impacts exceeding CCME guidelines (150 µg/g) were 8,200 m<sup>2</sup>
- inferred extents exceeding CSR light extractable petroleum hydrocarbons (LEPH) criteria in soil (2,000 µg/g) were estimated to extend over an area of 6,500 m<sup>2</sup>
- deep PHC impacts were noted in 4 distinct areas
- excavation of deep impacts was not feasible due to depth and groundwater

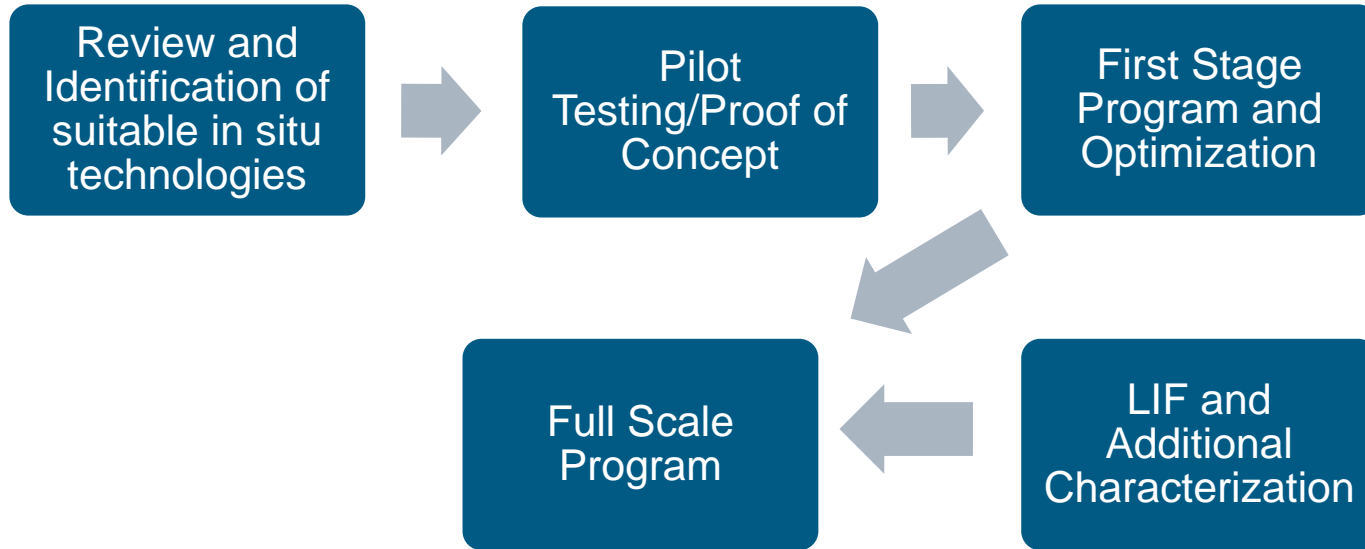


## In Situ Program Objectives

- reduce petroleum hydrocarbon (PHC) impacts at the sites utilizing a suitable full scale remediation technology
- affect a reduction in PHC impacts with a reasonable effort and associated cost
- achieve a reduction in PHC impacts within the Federal Contaminated Sites Action Plan (FCSAP) funding window



# In Situ Program Development



## 2016 Pilot Testing

- confirm approach for injection of hydrogen peroxide injection method (direct push);
- evaluate surfactant performance via push/pull test;
- confirm injection parameters (flow rates, injection pressures, suitable hydrogen peroxide concentrations);
- determine hydraulic parameters;
- provide an initial evaluation of hydrogen peroxide performance; and
- evaluate the potential for completing LIF with direct push.





## 2016 Pilot Testing Cont'd



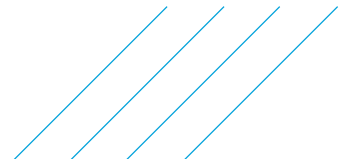
## 2016 Pilot Testing Results

- surfactant enhanced recovery increased dissolved phase concentrations of hydrocarbons by several orders of magnitude. Further evaluation identified full scale application at the site not feasible
- hydrogen peroxide injections could be completed readily via direct push as confirmed through testing and evaluation of hydraulic parameters (hydraulic conductivity was 6 to 10 x 10<sup>-4</sup> m/s)
- advancement of the LIF tool could be completed readily with direct push (with some modifications)



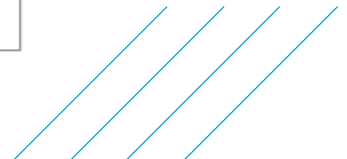
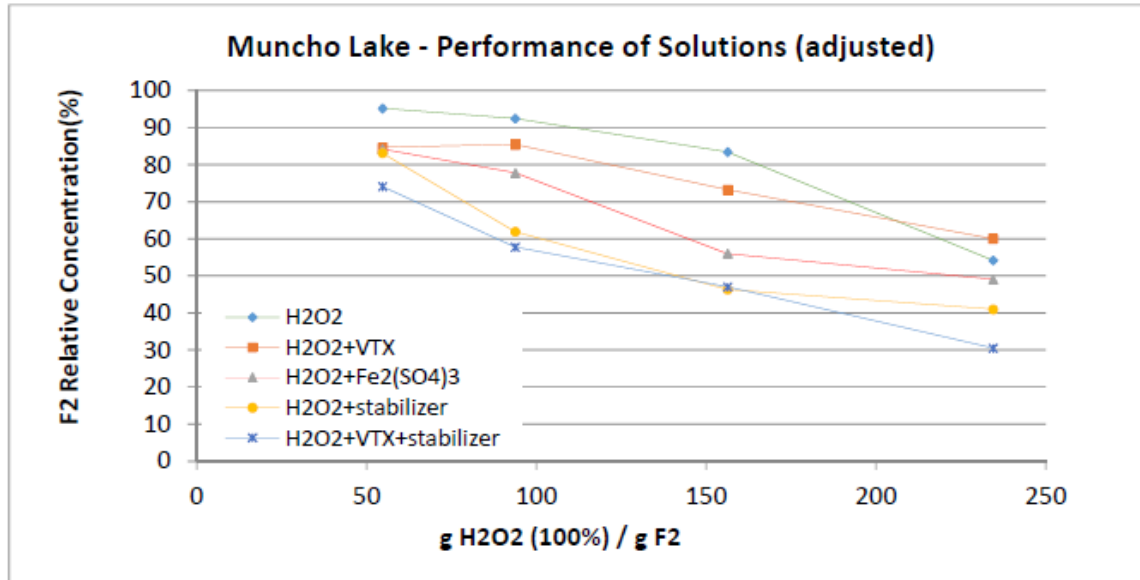
## 2017 First Stage In Situ Remediation Program

- collected baseline soil to improve delineation and characterization of PHC impacts in the target area, collect pre-injection soil quality data, and collect soil samples for a treatability study
- completed a treatability study for injection solution optimization (evaluate performance of stabilizers and catalysts)
- evaluated radius of influence (ROI) during the injections
- evaluated the potential for deflection during the advancement of boreholes and injection points
- evaluated remediation performance via hydrogen peroxide injections through comparison of pre and post injection soil quality data
- confirmed larger scale injections were technically feasible



# 2017 First Stage In Situ Program (Treatability Study Results)

- treatability study determined that using the stabilizers (citrate and citric acid) was the most cost effective formulation for enhancing hydrogen peroxide performance













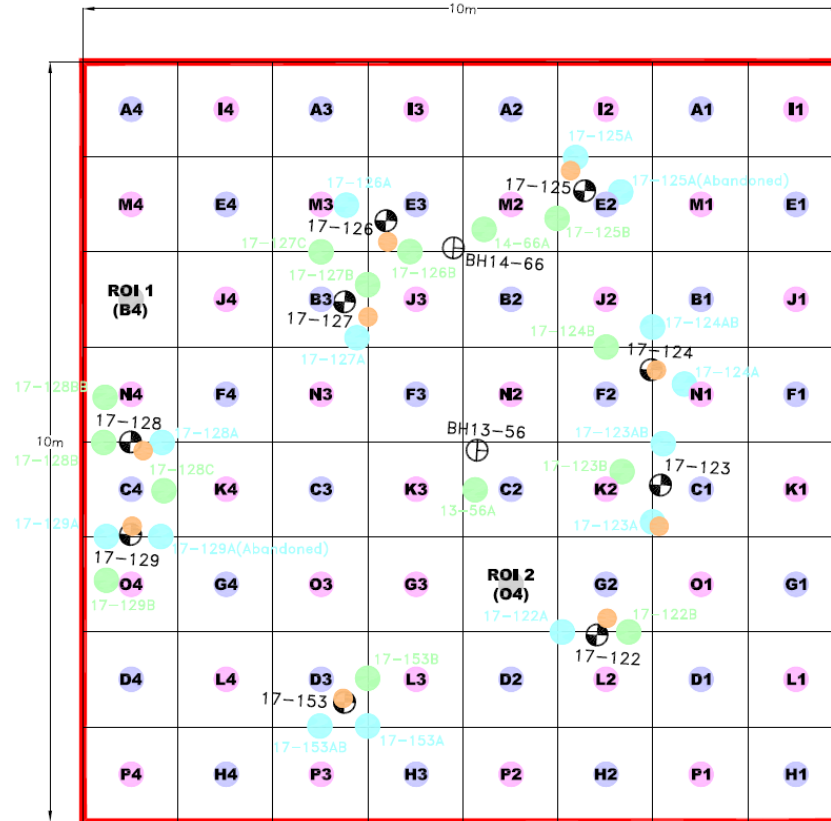
# 2017 First Stage Hydrogen Peroxide Injections

- first stage injections involved the injection of 400,000 L of a solution of 17.5% (m/m) hydrogen peroxide, 0.875% potassium citrate, 0.35% citric acid
- the solution was injected at 64 points within a 10 x 10 m grid
- injections were completed in two passes with soil data collected between the first and second pass as well as post second pass
- comparison of pre, post first pass, and post second pass data was completed with soil samples collected from the eleven points (same depth and location)

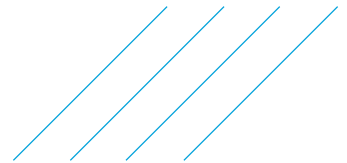
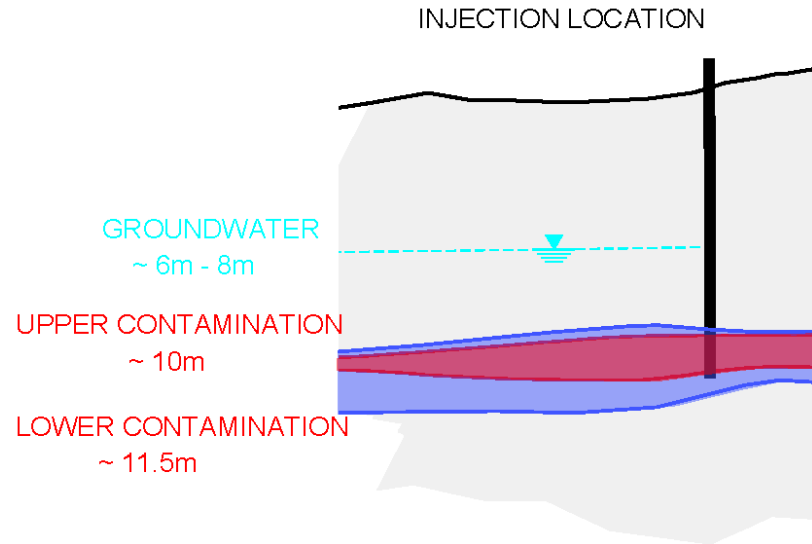


# First Stage Injection Approach

-  MONITORING WELL LOCATION
-  DESTROYED MONITORING WELL
-  POST FIRST PASS SOIL SAMPLING LOCATION
-  POST SECOND PASS SOIL SAMPLING LOCATION
-  FIRST PASS INJECTION LOCATIONS
-  SECOND PASS INJECTION LOCATIONS
-  ROI INJECTION LOCATION
-  MONITORING WELL POSITION AT BOTTOM



# Injection Conceptual X-Section



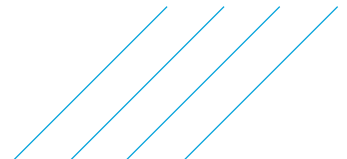
# 2017 First Stage Hydrogen Peroxide Injection Area





## 2017 First Stage In Situ Injection Program Results

- deflection was measured to be minimal for boreholes when advanced (maximum of 0.5 from position at surface)
- ROI was determined to be between 2 and 3 meters
- an average reduction of 13% in F2 concentrations was observed between the post first pass drilling program and the baseline investigation;
- an average reduction of 64% in F2 concentrations was observed between the post second pass drilling program and the baseline investigation; and
- the percentage of soil samples with F2 concentrations greater than 1,600 µg/g decreased from 40% for the baseline to 7% after the post second pass drilling program



## 2018 Full Scale In Situ Program

- the full scale in situ remediation program targeted deep PHC impacts everywhere at the site that was inferred to have F2 concentrations exceeding 1,600 µg/g or LEPH concentrations greater than 2,000 µg/g
- information from historic investigations, the laser induced fluorescence (LIF) characterization program, and baseline soil sampling was used to ensure the hydrogen peroxide injections were properly targeted
- 13 baseline boreholes were advanced and soil samples were collected using the DT45 sampling system for comparison post injection.
- wells were installed, monitored, and sampled in the target areas to assess the effects of the injections on groundwater conditions

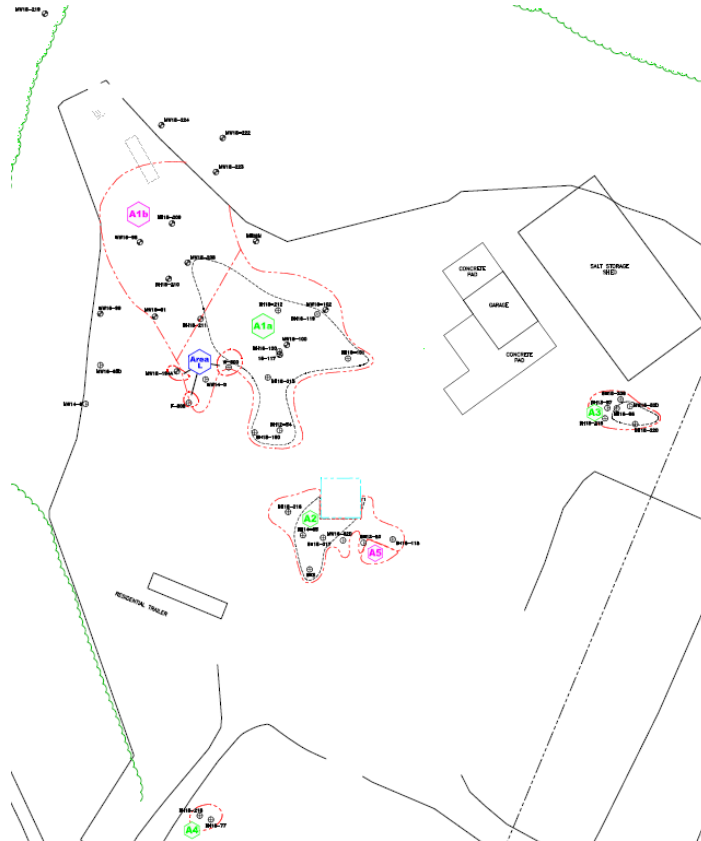


## 2018 Full Scale In Situ Program Cont'd

- 4,700,000 L of a 17.5% hydrogen peroxide solution (with citrate and citric acid) was injected at 568 points targeting 4 areas at the site
- 59 tankers of 59% hydrogen peroxide were delivered to the site and injected (equivalent to 880 tonnes of 100% hydrogen peroxide)
- a mix water source well was installed at the site for the mixing and dilution of hydrogen peroxide
- advancement of 34 boreholes post injection for comparison to baseline and historic soil quality data
- post injection soil samples were collected at points coincident with baseline and historic locations

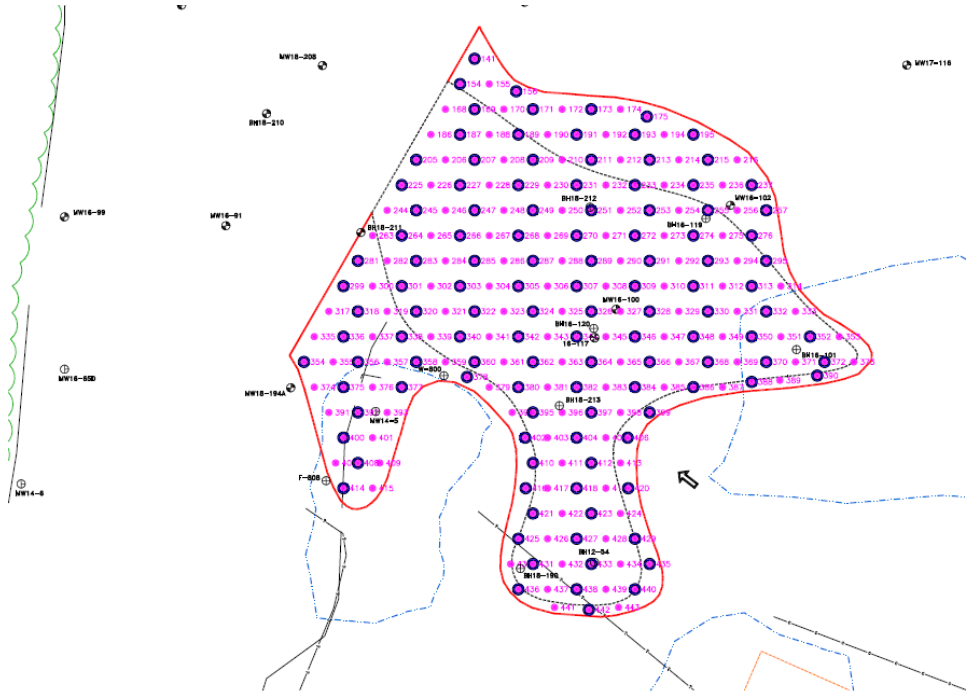


# 2018 Full Scale In Situ Program (Injection Area Plan)

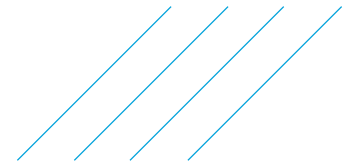




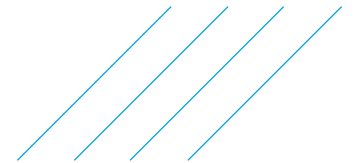
# 2018 Full Scale In Situ Program (Injection Area A1a)



# 2018 Full Scale In Situ Program (Hydrogen Peroxide Storage and Mixing Area)

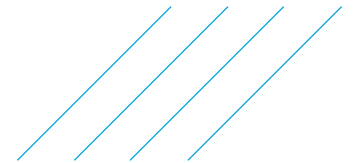


# 2018 Full Scale In Situ Program (Injection Wellhead)



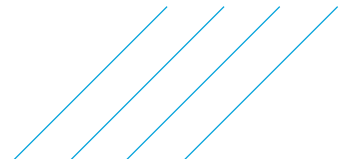


# 2018 Full Scale In Situ Program (Injection Area A1a Overview)

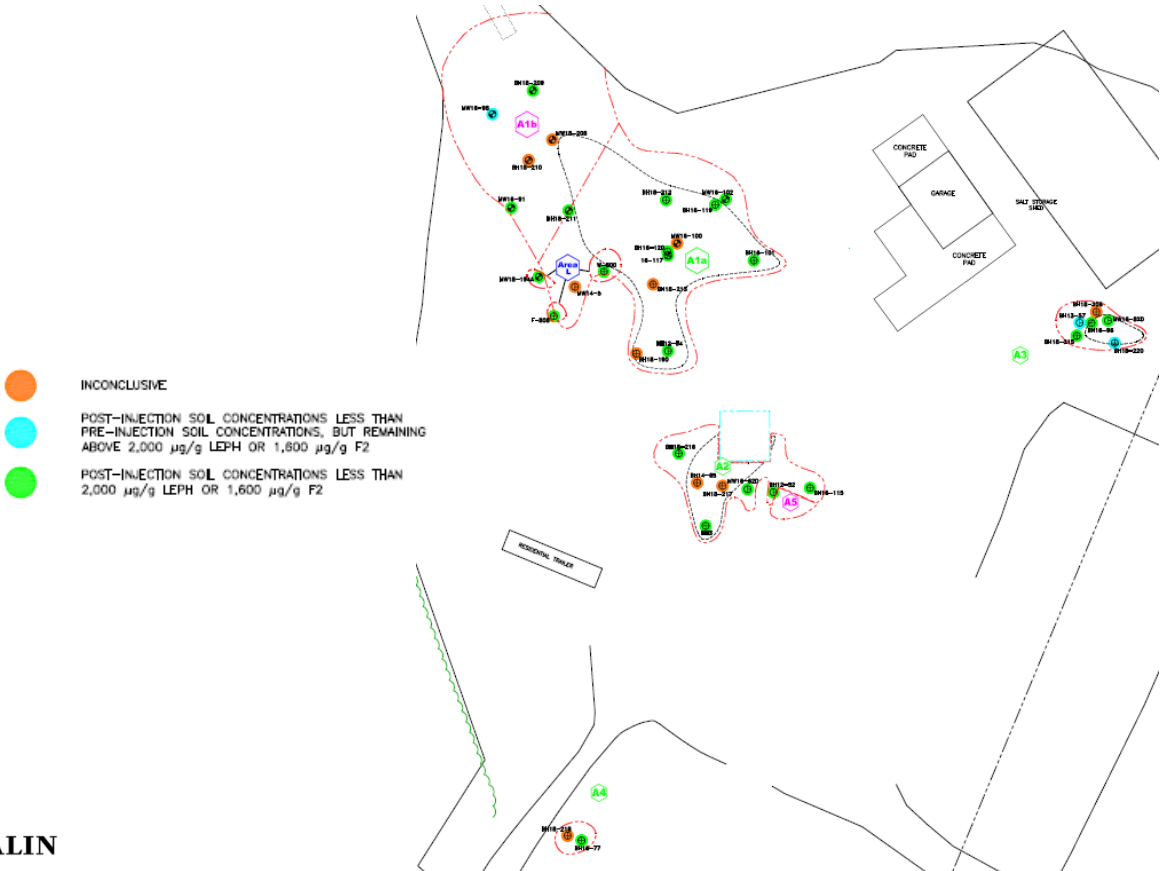


# 2018 Full Scale In Situ Program Results (Comparison of Pre and Post Injection Soil Data)

- an average 47% reduction in LEPH/F2 concentrations in soil was achieved
- initial average F2 concentrations in soil in the target areas was noted to be 2,458 µg/g, where as post-injection the average F2 soil concentration was noted to be 1,292 µg/g
- The number of occurrences of F2 concentrations exceeding 1,600 µg/g or LEPH concentrations exceeding 2,000 µg/g within the targeted areas was reduced by 48% following the completion of the program



# 2018 Full Scale In Situ Program Results Cont'd





## 2018/19 Full Scale In Situ Program Results (Other Observations)

- significant changes in groundwater conditions noted during and post injection
- LNAPL observed at some monitoring well locations within the injection area
- increase in F1 and F2 dissolved phased concentrations noted within injection areas A1a/b with some dissolved phase concentrations suggesting the presence of LNAPL
- increase in dissolved phase concentrations of metals and some geochemical parameters within the injection area and downgradient
- post injection dissolved phase metal concentrations and geochemical parameters were mostly noted to return to pre-injection ranges. Elevated iron and manganese concentrations remain at some monitoring well locations
- Dissolved phase F1 and F2 concentrations were noted to decrease post injection at most monitoring well locations as of July 2019



## In Situ Program Summary

- hydrogen peroxide injection program (First Stage and Full Scale) treated a volume of 3,950 m<sup>3</sup> of F2 impacted soils at the site noted to have concentrations greater than 1,600 µg/g or 2,000 µg/g LEPH
- injections were targeted over an area of 2,900 m<sup>2</sup> over 4 separate areas
- the combined costs for the First Stage and Full Scale In Situ remediation program was approximately \$4M
- estimated cost per volume of impacted soil treated is \$1,000/m<sup>3</sup>
- estimated cost per mass of F2 destroyed is \$500/kg (assuming an approximate 50% reduction in F2 concentrations)



# Questions?



*Our values are the essence of our company's identity.  
They represent how we act, speak and behave together,  
and how we engage with our clients and stakeholders.*

*SAFETY*

*We put safety at the heart of everything we do, to safeguard people, assets and the environment.*

*INTEGRITY*

*We do the right thing, no matter what, and are accountable for our actions.*

*COLLABORATION*

*We work together and embrace each other's unique contribution to deliver amazing results for all.*

*INNOVATION*

*We redefine engineering by thinking boldly, proudly and differently.*

