In-Situ Pilot Testing and Laser-induced Fluorescence Evaluation

Muncho Lake and Fireside Maintenance Camps, Alaska Highway, BC
(PWGSC-Project # R. 016701.004/005)

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Executive Summary

On behalf of Public Works and Government Services Canada (PWGSC), SNC-Lavalin Inc. (SNC-Lavalin), has prepared this report for the pilot testing of in-situ chemical oxidant injection and surfactant application, as well as an evaluation into the feasibility of using a laser induced fluorescence (LIF) tool to further characterize and delineate petroleum hydrocarbon (PHC) concentrations at the Muncho Lake Maintenance Camp, kilometre 698, Alaska Highway, BC and Fireside Maintenance Camp, kilometre 839, Alaska Highway, BC (the Sites).

Pilot testing was completed in early Q4 2016 and identified that technical challenges associated with the in-situ application of oxidants and surfactants were easily overcome. Similarly it was identified that advancement of the LIF device was possible and could be considered for characterization of the deep petroleum hydrocarbon impacts at each yard.

Results from the initial in-situ chemical oxidation application suggest favourable conditions for larger scale remediation using this approach. Probe rods for the direct injection of hydrogen peroxide were advanced quickly and easily to target deep contaminated soil zones associated with the smear zone. Hydrogen peroxide was injected at flow rates, pressures, and concentrations that is expected to allow for remediation.

The application of surfactants was also successful in solubilising petroleum hydrocarbon impacts for subsequent recovery and remediation. However the increase in the concentration of dissolved phase PHCs is not sufficient to affect remediation without the recovery of a significant groundwater volume, and is not considered to be practical.

For the LIF evaluation probe rods with a solid point were advanced to simulate the advancement of the LIF tool at the Sites. It was observed that soil conditions were very tight for this type of advancement to the target depths required. However a “pre-probing” strategy in which a larger bore probe rod is advanced prior to deploying the LIF device was identified as a suitable approach for characterizing the plume at depth while minimizing the potential for any tooling damage.

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1 Introduction

On behalf of Public Works and Government Services Canada (PWGSC), SNC-Lavalin Inc. (SNC-Lavalin), has prepared this report for the pilot testing of in-situ chemical oxidant injection and surfactant application, as well as an evaluation into the feasibility of using a laser induced fluorescence (LIF) tool to further characterize and delineate petroleum hydrocarbon (PHC) concentrations at the Muncho Lake Maintenance Camp, kilometre 698, Alaska Highway, BC and Fireside Maintenance Camp, kilometre 839, Alaska Highway, BC (the Sites). All proposed work was completed under the Human Health and Ecological R.A.C.S. Contract with task Authorizations (CTA) No. EZ897-161534/003/VAN and PWGSC Project No. R.016701.004/005 and specific Task Authorization (TA) number 700362482.

The field work for in-situ chemical oxidant injection, surfactant application, and the LIF evaluation was completed from October 3, 2016 to October 14, 2016. The pilot test and LIF evaluation was completed in accordance with the Azimuth/SNC-Lavalin workplan, *FY 2016/2017 Work Plan for Limited In-Situ Pilot Testing Muncho Lake and Fireside Maintenance Camps, Alaska Highway, BC (PWGSC Project # R. 016701.004/005)*, provided to PWGSC on August 31, 2016.

SNC-Lavalin understands that PWGSC's remediation objectives for the Sites are to reduce PHC impacts utilizing a suitable remediation technology with a reasonable effort and cost, within the Federal Contaminated Sites Action Plan (FCSAP) funding window. The objectives of the pilot test and LIF evaluation were to:

- Evaluate the potential to complete in-situ remediation of deep PHC impacts through in-situ chemical oxidation or surfactant application;
- Collect data and information for designing and planning a larger scale in-situ chemical oxidation program or surfactant application;
- Evaluate the option for site wide characterization of PHC impacts through advancement of the LIF device with direct push technology; and
- Develop recommendations for the in-situ remediation of deep PHC impacts at both Muncho Lake and Fireside maintenance camps.

The report format is as follows:

- Section 1 -- introduction and background;
- Section 2 -- scope of work, results and interpretations for the Muncho Lake Maintenance Camp;
- Section 3 -- scope of work, results and interpretations for the Fireside Maintenance Camp;
- Section 4 -- closure section; and
- Section 5 -- notice to reader.

1.1 Background

1.1.1 Muncho Lake Maintenance Camp

The Muncho Lake Maintenance Camp is located approximately 240 km west of Fort Nelson, BC, on the west side of the Alaska Highway. As outlined in previous environmental investigation reports residual PHC contamination greater than the applicable Canadian Council of Ministers of the Environment (CCME) and *Contaminated Sites Regulation*[1] (CSR) standards/guidelines for soil, groundwater, and soil vapour remains on the Site. Salt and metals impacts were also identified, however for the purposes of this letter report only PHC contamination is considered.

Shallow PHC impacts (from ground surface to the water table) at Muncho Lake were excavated in seven areas and moved to an off site PWGSC managed soil treatment facility in Q4 2016.

Deep PHC impacts targeted for in-situ remediation pilot testing are primarily within the groundwater smear zone (approximately 8 metres to 15 metres below ground [mbg]). The source of PHC impacts at the Site is considered to be fuel oil and possibly limited quantities of used oil. Soils in the smear zone are primarily sand and gravel with some silt.

Generally low dissolved hydrocarbon concentrations have been detected and no light non-aqueous phase liquid (LNAPL) has been encountered in monitoring wells at the site. The contaminants of concern are primarily F2 and light extractable petroleum hydrocarbon (LEPH) for soil. F1 and benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations have also been identified as contaminants of concern.

There are three areas currently identified that have deep PHC impacts at the Muncho Lake Maintenance Camp. The following areas of environmental concern (AEC) with deep PHC impacts were previously identified:

› AEC 1 – **SW Portion of Maintenance Yard**: Residual soil contamination was identified to be present within and adjacent to a previous remedial excavation in the southwest portion of the operational area on the Site;

› AEC 2 – **Northwest of Maintenance Garage**: The deep PHC plume in soil within the groundwater smear zone extends to the northwest from the maintenance garage. PHC contamination in soil within this area exceeds the applicable guidelines. A second PHC plume to the north and west of this area appears to be separate, however deep impacts appear to be similar in nature and vertical extent (i.e., elevated F2 concentrations in soil at the smear zone). The full extent of the deep PHC impacts in soil and groundwater in these areas has not been delineated; and

[1] *Contaminated Sites Regulation* (CSR), B.C. Reg. 375/96, includes amendments up to B.C. Reg. 184/2016, July 19, 2016.

- AEC 7 – **South of Salt Shed**: PHC contamination in soil was identified in the groundwater smear zone (i.e., 8 m to 15 mbg) adjacent to the salt storage shed area. A contaminant plume in the smear zone extends to the northwest from the apparent source area.

Additional investigation activities were undertaken by SNC-Lavalin in 2016 to further delineate the PHC plume within the smear zone to the northwest of the maintenance garage. The full extent of deep PHC impacts associated with the smear zone, and primarily associated with the AEC 2 – Northwest of Maintenance Garage remains undelineated. Refer to the attached Drawing 635031-501 for a site plan outlining Site features and historic investigation locations.

1.1.2 Fireside Maintenance Camp

The Fireside Maintenance Camp is located approximately 378 km northwest of Fort Nelson, BC, and 150 km southeast of Watson Lake, YT, on the northeast side of the Alaska Highway. Residual PHC exists below the active maintenance yard, likely related to aboveground releases from aboveground fuel storage tanks (ASTs) and site maintenance activities. The following AECs were previously identified:

- AEC 1 – **Northwest Portion of Yard**: PHC contamination in soil was identified in this area over 2,400 m^2;
- AEC 2 – **North Portion of Yard**: PHC contamination in soil was identified in this area over 150 m^2; and
- AEC 3 – **Central Portion of Yard**: PHC contamination in soil was identified in this area over 5,150 m^2.

Shallow PHC impacts (from ground surface to the water table) at Fireside were excavated in four areas and moved to an off site PWGSC managed soil treatment facility in Q4 2016.

In addition to shallow PHC impacts identified at these AECs, deeper PHC impacts are coincident with two perched water tables and the regional aquifer. The upper perched water table is at a depth of 10 m to 14 mbg. PHC impacts associated with this water table are considered to extend over an area of 500 m^2 and are primarily coincident with AEC 3. The lower perched water table is at a depth of 19 m to 23 mbg and PHC impacts associated with this water table are considered to extend over an area of 5,600 m^2. The regional aquifer is at a depth of 26 m to 32.5 mbg and PHC impacts associated with this water table are considered to extend over an area of 2,300 m^2.

The source of PHC impacts at the Site is considered to be fuel oil and possibly limited quantities of used oil. Deep PHC impacts targeted for in-situ remediation pilot testing are associated with perched water tables and the regional aquifer. Soils associated with these PHC impacts are primarily sand and gravel with some silty layers. The contaminants of concern are primarily F2 and LEPH for soil. F1 and BTEX concentrations have also been identified as contaminants of concern. Generally low dissolved hydrocarbon concentrations have been detected and no LNAPL has been encountered in monitoring wells at the site.

The full extent of deep PHC soil impacts associated with the perched water tables and regional aquifer remain undelineated in portions of these plumes. Refer to the attached Drawing 636200-501 for a site plan outlining Site features and historic investigation locations.

1.2 Remediation Options Overview

1.2.1 In-situ Remediation Technologies

SNC-Lavalin reviewed in-situ remediation technologies in consideration of site applicability, contaminant type, total costs, time frame to affect remediation, regulatory compliance, stakeholder considerations, and impacts to future operations at the site. Preferred technologies were required to achieve meaningful reduction in hydrocarbons within the 4 year FCSAP funding window with reasonable costs.

The two technologies that were selected for testing and further evaluation were chemical oxidation and surfactant flushing. Air sparging and nutrient addition were rejected since these technologies are expected to require a significant time frame (15+ years) to achieve a meaningful reduction in hydrocarbons. Pump and treat, multiphase extraction, and vapour extraction were discounted given that the PHC impacts have low solubility and volatility.

With respect to chemical oxidation, the oxidizer persulfate was not considered for further evaluation due to the potential for significant sulfate addition to groundwater at the site, and as sulfate is a regulated parameter in British Columbia. Given this consideration, the oxidizer hydrogen peroxide was selected for further evaluation.

In conjunction with hydrogen peroxide, SNC-Lavalin also considered the injection of a catalyst to enhance the performance of the hydrogen peroxide through the formation of hydroxyl and other free radicals. Additional hydroxyl and free radical production can significantly improve both the rate and overall efficiency of the oxidation treatment. VTX Catalyst 4.4 (VTX), an organo-metallic catalyst was selected, as it is designed to enhance the performance of hydrogen peroxide.

For surfactant application, two surfactants were considered for further evaluation. Iveysol 106 was selected as it has been used successfully at another maintenance yard site along the Alaska Highway. It is a proprietary, non-ionic surfactant formulated for solubilising and mobilizing fuel oil based contaminants, manufactured by Ivey International Inc. SNC-Lavalin also selected the ionic surfactant Task, manufactured by Tersus Environmental LLC (Tersus). It is a proprietary surfactant that is mixed with an electrolyte, which in turn provides a cation to optimize the effectiveness of the surfactant. Task was selected as a surfactant to allow for comparing the performance of non-ionic (Iveysol 106) versus ionic surfactants. The ratio of Task to electrolyte can also be varied when applied to optimize the degree of solubilisation or mobilization of PHC contaminants.

In addition to evaluating in-situ chemical oxidation and surfactant application, an evaluation of hydraulic conductivity in the regional aquifers at these Sites through pumping and slug testing was also completed. This was done to provide supporting information for the larger scale application of surfactants, should this approach to in-situ remediation be selected.

1.2.2 Characterization of PHC Impacts

As part of the evaluation of options for in-situ remediation, SNC-Lavalin identified that further characterization of the extent and degree of deeper PHC impacts will improve the targeting of the selected remedial technology and provide more certainty on the lateral and vertical extent of impacted areas. Further delineation of the deep PHC impacts is also required to close data gaps identified in the conceptual site models (CSMs) for these Sites.

SNC-Lavalin identified LIF as a tool that may allow for more rapid and cost-effective delineation of the deep PHC impacts, as compared to conventional drilling and soil sampling, provided it could be advanced via direct push technology. Therefore, an evaluation of the advancement of direct push tooling at forces compatible with the device was completed. Soil samples were also collected for off-site testing with the tool to confirm that it would respond to the type of hydrocarbons encountered. This evaluation is intended to assist with the development of a suitable program for further delineation and characterization of deep PHC impacts at the Sites.

2 Muncho Lake Maintenance Camp Testing

In advance of ground disturbance activities BC One Call was contacted and members were requested to locate and mark utilities subject to encroachment. Additionally a utility survey was completed in the areas where ground disturbance was planned. Utilities or buried lines were marked by the utility survey contractor. Following the completion of the utility survey, SNC-Lavalin's ground disturbance checklist was reviewed and completed.

To allow for the collection and temporary storage of recovered liquids during the pilot test, an open top steel tank was supplied and delivered to the Site.

Work at the Muncho Lake Maintenance Camp included:

- Borehole advancement and well installation;
- Hydrogen peroxide injection into dedicated wells and injection points;
- Monitoring well response evaluation;
- Pump testing;
- Surfactant application (push/pull) test; and
- LIF evaluation.

Refer to the attached Drawings 635031-801 and 635031-802 showing the locations of the test areas, boreholes, and monitoring wells.

2.1 Borehole Advancement and Well Installation

2.1.1 Methodology and Observations

To allow for surfactant and chemical oxidizer application (injection) as well as to provide pre and post in-situ treatment soil characterization, five boreholes (i.e., 16-116 to 16-120) were advanced with three of the boreholes (i.e., 16-116 to 16-118) completed as monitoring wells. Boreholes and soil samples were collected using the DT45 soil sampling system which was advanced with the Geoprobe 8040DT direct push and rotary rig.

Monitoring wells 16-116 and 16-117 were constructed as injection wells to allow for targeting the injection of surfactants and hydrogen peroxide into PHC impacted soils. As such these wells were screened across PHC impacts at depth. The injection wells were also completed with a cement/bentonite grout to minimize the potential for bypass. Monitoring well 16-118 was constructed to allow for monitoring across the water table to evaluate the potential for mobilizing PHC impacts (i.e., light non-aqueous phase liquid) to the water table adjacent the surfactant injection well. Borehole 16-119 was advanced to evaluate soil quality post surfactant application at monitoring well 16-116. Borehole 16-120 was advanced to evaluate soil quality post hydrogen peroxide treatment.

Borehole logs are provided in Appendix I.

2.1.2 Results and Discussion

It took approximately 1.5 hours to advance the DT45 soil sampling system to a depth of 13.0 m. Following the advancement of boreholes 16-116 and 16-117 it took approximately 2.5 hours to complete the well as an injection well with a cement/bentonite grout from above the screen to near ground surface. Sample collection beyond a depth of 12.2 m was challenging due to the loss of sample. This is likely the result of the loss of loose saturated soils from the end of the sampling tube at depth. It is likely that injection well installation time can be reduced through refinements to the cement/bentonite grout mixing and placement process, such as the use of a cement mixer and a tremie pipe.

Soil samples were collected from boreholes 16-116, 16-117, 16-119, and 16-120. Analytical results indicated that soil exceeded Canadian Council of Ministers of the Environment (CCME) Canadian Wide Standards for Petroleum Hydrocarbons (PHC CWS) for F1 (C6-C10) and F2 (>C10-C16) petroleum hydrocarbons at depths between 10.2 m and 12.3 m. PHC concentrations within this interval consisted of F2 (>C10-C16) in the range of 220 µg/g to 4,300 µg/g and F1-BTEX in the range of 22 µg/g to 130 µg/g. Dark grey and black staining and a slight hydrocarbon odour were observed in soil samples collected at these depths. PHC impacts were noted to be below the water table. Analytical results from the soil sampling are presented in Table 1. Analytical reports are provided in Appendix III.

Soils at these boreholes were generally comprised of fine and coarse grained sands with gravel. Some siltier layers were observed at varying depths as were larger cobbles or rocks. Soil stratigraphy was similar to previous boreholes advanced in this area. These results were in general accordance with soil sample observations from nearby monitoring wells 16-100 and 16-102.

2.2 Hydrogen Peroxide Injection

2.2.1 Methodology and Observations

In-situ chemical injections were completed at five locations using hydrogen peroxide. 50% (m/m) hydrogen peroxide was mixed with water to concentrations between 11.5% and 20% (m/m). Hydrogen peroxide was directly injected through 2.25" (57 mm) probe rods advanced to a target depth of 12.2 m. Probe rods for direct injection were advanced with the Geoprobe 8040DT direct push and rotary rig. The injection probe rods were advanced with a standard expendable 2.45 inch (62 mm) outer diameter drive point. Following advancement of the probe rods to the target depth, compatible fittings were connected to the top of the probe rod to allow for injection through the inner diameter of the probe rod. A flow meter and pressure gauge were connected so that total volume, flow rate, and injection pressure could be monitored during injection. Following advancement to 12.2 m the probe rods were raised approximately

0.2 m to cause the expendable drive point to come off of the bottom of the probe rods and to ease the injection of hydrogen peroxide.

Hydrogen peroxide was injected at four direct injection locations (IP1, IP2, IP3, and IP4) and at the one dedicated hydrogen peroxide injection well (16-117). Drawing 635031-801 shows the injection locations. VTX was injected into IP2 to enhance the action of hydrogen peroxide. VTX was mixed with water at a ratio 1 L VTX : 3 L H2O prior to injecting. A total VTX mixed volume of 160 L was injected into IP2.

The injection of hydrogen peroxide was completed as indicated in Table A.

Table A: Summary of Hydrogen Peroxide Injections – Muncho Lake

Injection Locations	Flow (L/min)	Pressure (psi)	Hydrogen Peroxide Injection Concentration (% m/m)	Volume (L)	Duration (hrs)	Comments
IP1	7-22	0-30	11.5	3440	5	-
IP2	3-6	35-50	11.5	177	0.75	160 L of VTX mixture added. IP2 had soil blockage at tip of probe rod
IP3	21	10	11.5	900	0.7	-
IP4	22	10	11.5	2070	2	-
16-117	8-21	4-20	11.5 and 20	304 and 1833	0.3 and 2	-

In conjunction with the hydrogen peroxide injections, groundwater was monitored at monitoring well 16-100 before, during, and after the hydrogen peroxide injections at the direct injection points and dedicated injection well. Groundwater was monitored for temperature, pH, dissolved oxygen (DO), oxidation/reduction potential (ORP), salinity, and electrical conductivity (EC).

<u>IP1 Injection Observations and Monitoring</u>:

› Limited bypass of hydrogen peroxide at ground surface was observed.

› It was observed that the injection rate increased and injection pressure dropped following the raising of the injection rod. An increase in the injection flowrate was also observed when the injection hose was changed from 0.75” (19 mm) to 1” (25 mm).

Groundwater was monitored at monitoring well 16-100 approximately 3.0 m away from IP1. The following observations at monitoring well 16-100 during injection at IP1 were made:

› Conductivity, pH, and temperature remained steady throughout the injection with pre-injection measured values.

- Dissolved oxygen concentrations increased from less than 5 mg/L to greater than 15 mg/L after the injection of approximately 1,000 L of hydrogen peroxide. Dissolved oxygen concentrations increased up to 65 mg/L during the injection.
- A doubling in the ORP value from approximately 40 mV to 80 mV after the injection of approximately 1,000 L of hydrogen peroxide.

Results from the monitoring at 16-100 are presented in Table 2.

IP2, IP3 and IP4 Injection Observations and Monitoring:

Similar to the advancement of IP1, the probe rods for IP2 were raised to cause the expendable drive point to come off of the bottom. When injecting VTX into IP2 the back pressure was notably higher than at IP1 and the flow rate correspondingly lower. Also, VTX would not flow freely when poured into the probe rod. Injection at IP2 was stopped after 45 minutes to inspect the probe tip. Following the removal of the probe rods at IP2 residual liquid remained in the rods during removal. Soil was also found in the bottom portion of the rod causing the backpressure and reduced flow.

IP3 was advanced 1.0 m away from IP2. Pressure and flow rate during the injections at IP3 followed a similar pattern to IP1 and remained relatively steady during the injection. In general, a higher injection flowrate corresponded with a higher pressure.

IP4 was advanced 0.15 m away from IP2 to allow for injection adjacent the VTX application point. Pressure and flow rate during the injections at IP4 did not change substantially over the course of injections. Gurgling was heard at 16-117 during injection at IP4.

Groundwater was monitored at monitoring well 16-100 and 16-117 approximately 4 m away and 4.7 m away from IP2, respectively. The following was noted at monitoring well 16-100 during injection at IP2, IP3, and IP4:

- Similar to observations made during injection at IP1, conductivity, pH, temperature remained at pre-injection levels throughout the injection;
- Dissolved oxygen concentrations remained greater than 25 mg/L; and
- ORP remained above 125 mV.
- 16-117 Injection Observations and Monitoring:

Monitoring well 16-117 was developed prior to the start of injection at IP2, IP3, and IP4 and after injection at IP1. The following was noted at monitoring well 16-117 during injection at IP2, IP3, and IP4:

- Dissolved oxygen concentrations were approximately 10 mg/L after development, and rose to approximately 30 mg/L after the completion of injections; and
- Post development and post injection ORP ranged between 110 mV and 131 mV.

No bypass of hydrogen peroxide at ground surface was observed during the subsequent injection at 16-117. Pressure did not change substantially over the course of injections and in general a higher injection flowrate corresponded with a higher injection pressure.

Groundwater was monitored at monitoring well 16-100 during injection at 16-117 approximately 2.5 m away. The following was noted at monitoring well 16-100 during injection at 16-117:

› Similar to observations made during injection at the direct injection points, conductivity, pH, temperature remained at pre-injection levels;
› Dissolved oxygen concentrations at 16-100 ranged from 9 mg/L to 44 mg/L; and
› ORP at 16-100 ranged from 126 mV to 190 mV.

Post-Injection Monitoring:

Groundwater was monitored at 16-100 and 16-117 following the completion of injections. 2 hours after the completion of injection at 16-117 the groundwater temperature in 16-117 was measured to be 15 °C. The temperature at 16-117 remained above pre-injection levels 40 hours after the completion of injections, but decreased to pre-injection levels after 7 days. The temperature at 16-100 increased above pre-injection levels approximately 40 hours after injection. Temperature at 16-100 remained above pre-injection levels 8 days after the completion of injections. There was evidence of stratification in temperature at 16-100 with a decrease in groundwater temperature at a greater depth in the monitoring well. Post injection measurements were continued at monitoring wells 16-100 and 16-117 and the results are summarized as following:

› Dissolved oxygen concentrations ranged from 20 mg/L to 50 mg/L at 16-100, and remained above pre-injection levels for at least 8 days;
› ORP remained above pre-injection levels at 16-100 for at least 8 days and ranged from 115 mV to 177 mV;
› Similarly, following the injections dissolved oxygen concentrations ranged from 23 mg/L to 43 mg/L at 16-117, and remained above pre-injection levels for at least 8 days; and
› ORP remained above pre-injection levels at 16-117 for at least 8 days and ranged from 106 to 129 mV.

Figures 1 and 2 present temperature, dissolved oxygen concentrations and ORP response over the course of hydrogen peroxide injections at Muncho Lake.

F1 and F2 (>C_{10}-C_{16}) concentrations at target zone soils collected at 16-117 (pre-injection) and from the adjacent borehole location 16-120 (post injection) did not identify a notable change in F1 or F2 concentrations post injection 0.8 m away. Analytical results from the soil sampling are presented in Table 1.

2.2.2 Results and Discussion

Hydrogen peroxide injections were completed at Muncho Lake Maintenance Camp with relative ease. Hydrogen peroxide was injected at direct injection points (through probe rods) and at a dedicated injection well at concentrations of 11.5% - 20% (m/m), flow rates up to 25 L/min, and pressures less than 30 psi. This suggests the larger scale application of this in-situ remediation option could be completed with few technical limitations.

Installation

Advancement of the 2.25" diameter direct injection probe rods to the target depth of 12 m was fast (less than 15 minutes) indicating injection via this method is feasible. In comparison, the installation of a dedicated injection well took 4 hours. It was possible to raise the probe rods over the course of injections with the Geoprobe 8040DT direct push and rotary rig. This can allow for injection over varying depths if required.

Bypass of hydrogen peroxide at ground surface was observed when completing direct injection through the probe rods. This is presumed to occur from the flow of pressurized hydrogen peroxide preferentially along the outside of the probe rod due to poor sealing between the probe rod and subsurface soils. While bypass was observed at some of the direct injection points, it was estimated to be less than 10 L where evident. The volume of hydrogen peroxide that may have seeped into the formation is unknown.

Leaking from the threaded connections on the probe rods may also further add to this issue. Limited leaking was observed from above ground threaded connections in some instances during the injections. Tightening of the threaded connections was observed to stop this. It was also observed that the threaded connections between probe rods loosened slightly as they were advanced. Given these observations, using o-rings to seal the threaded connections on the probe rods could be considered to minimize leaking and the potential for bypass from these points.

With the observation of materials from the subsurface entering the bottom of the probe rod at IP2 as it was raised, future injections should maintain pressure (through the injection of liquids) in the probe rod as it is raised to reduce the potential for material ingress.

Dissolved Oxygen

The injection of hydrogen peroxide increased the dissolved oxygen concentration notably in groundwater at least 3 m away. Continued elevated dissolved oxygen concentrations were recorded at least a week after the completion of injections. An increase in the concentration of dissolved oxygen likely results from the decomposition of hydrogen peroxide; it does not necessarily indicate the presence of hydrogen peroxide or associated radicals which are necessary for oxidation of petroleum hydrocarbons in soil. In addition to the oxidation of petroleum hydrocarbons, the increase in dissolved oxygen in groundwater from the decomposition of hydrogen peroxide will enhance biodegradation of petroleum hydrocarbons.

Temperature

The injection of hydrogen peroxide resulted in increased groundwater temperature at least 2.5 m away. An increase in temperature was sustained for at least 8 days after injections. The increase in temperature indicates that exothermic reactions are occurring or have occurred. Exothermic reactions are likely a combination of the oxidation of petroleum hydrocarbon, decomposition of hydrogen peroxide, and oxidation of naturally occurring materials. The temperature of groundwater remained well below 70 °C and consequently elevated groundwater temperatures are not expected to prevent the generation of radicals that can further oxidize petroleum hydrocarbons.

Groundwater temperature remained elevated longer at 16-100 than at 16-117. The reason for this is not certain, however it may be the result of the enhancement of hydrogen peroxide upgradient of 16-100 through the application of VTX at IP2. Additionally, injection of 20% hydrogen peroxide at 16-117 may have generated a more vigorous reaction that resulted in the faster decomposition of hydrogen peroxide and associated radicals.

ORP

ORP in groundwater increased at 16-100 and 16-117 following the injection of hydrogen peroxide at IP1 to IP4, indicating the development of oxidizing conditions at these monitoring well locations and further confirming the presence of oxidizing conditions.

pH

Measured pH ranged between 7 and 9 at monitoring wells 16-100 and 16-117 suggesting neutral to alkaline conditions in groundwater at these locations. An acidic pH can sustain oxidation reactions by mobilizing iron ions and increasing the potential for a modified Fenton's system and the generation of oxidizing radicals. With neutral or alkaline conditions this potential is reduced. The addition of a chelated iron compound, such as VTX, has the potential to make available iron ions in a form that can increase the potential of generating a modified Fenton's system.

Soil Quality

F1 and F2 (>C10-C16) concentrations at target zone soils collected at 16-117 (pre-injection) and from the adjacent borehole location 16-120 (post injection) did not identify a reduction in F1 and F2 concentrations post injection 0.8 m away. It is acknowledged that a measurable reduction in F1 or F2 concentrations in soil would most likely require multiple rounds of injections. It was not expected that one injection event would reduce F1 or F2 concentrations in soil.

Summary

Overall, the pilot test indicates that hydrogen peroxide can be readily injected using the direct push technology at a reasonable flow rate. There are also indications of hydrogen peroxide effects in monitoring wells adjacent to the injection locations through increases in DO concentration, temperature, and ORP. Changes in these parameters suggest that oxidation reactions have occurred as a result of the injection of hydrogen peroxide, but do not directly confirm that hydrogen peroxide is present in adjacent monitoring wells. Further testing would be necessary with greater oxidant volumes to evaluate radius of influence of the hydrogen peroxide itself. In order to effectively remediate the soil within a treatment zone, hydrogen peroxide will need to come into direct contact with PHC impacts throughout the intended treatment zone.

2.3 Monitoring Well Response Evaluation

2.3.1 Methodology

Slug tests to evaluate hydraulic conductivity were completed at monitoring well locations 12-55, 13-56, 13-57, 16-62D, 16-100, 16-102, in accordance with SNC-Lavalin's Preferred Operating Procedure "Monitoring Well Response Testing – Field Procedure." Multiple rising and falling head tests were completed at each well, whereby water level displacement was initiated with a slug and water levels were monitored using dataloggers set to record measurements at 0.5 second intervals. The test locations are shown on Drawing 635031-801.

2.3.2 Results and Discussion

Slug tests were interpreted using AQTESOLV for Windows Version 4.5, by HydroSOLVE Inc. (2007). The Bouwer & Rice[2] (1976) analytical solution for unconfined aquifers was used to analyze the majority of tests. The Springer-Gelhar (1991) solution was used in instances where the response was oscillatory. A summary of the hydraulic conductivity results are presented in Table C below.

Table B: Hydraulic Conductivity of Select Wells – Muncho Lake

Monitoring Well Locations	Hydraulic Conductivity (m/s)	Geomean Hydraulic Conductivity (m/s)
12-55	1.7×10^{-4} to 1.6×10^{-3}	4.3×10^{-4}
13-56	5.1×10^{-4} to 7.5×10^{-4}	6.3×10^{-4}
13-57	2.1×10^{-4} to 3.8×10^{-4}	2.7×10^{-4}
16-62D	8.2×10^{-4} to 1.3×10^{-3}	1.1×10^{-3}
16-100	7.7×10^{-5} to 1.1×10^{-4}	9.4×10^{-5}
16-102	4.4×10^{-4} to 9.9×10^{-4}	6.9×10^{-4}
Overall Geomean (m/s)		4.2×10^{-4}

The hydraulic conductivity results indicate that the sands and gravels are highly permeable with a geomean hydraulic conductivity estimate of 4.2×10^{-4} m/s, which is consistent with the ranges reported by Freeze and Cherry (1979) for gravel (10^{-3} m/s to 1 m/s) and clean sand (10^{-5} m/s to 10^{-2} m/s). These results

[2] Bouwer, H., & R.C. Rice, 1976. *A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells.* Water Resources Research, pp. 12:423-28.

indicate that soils at Muncho Lake are highly permeable and conductive for the injection and/or pumping of liquids. The analyses are provided in Appendix IV.

2.4 Pump Test

2.4.1 Methodology

A pump test was completed at monitoring well 16-116 to evaluate hydraulic conductivity and radius of influence. The pump test was completed in accordance with SNC-Lavalin's Preferred Operating Procedure "Water Well Pump Test." Drawing 635031-802 shows the test location.

Using a Grundfos Redi-flo 2 installed near the well bottom a steady state flow rate of 23 L/min was achieved. Pumped liquids were discharged directly to the above ground open top storage tank. Water levels in the pump well and adjacent monitoring wells 16-102 and 16-118 were manually monitored with an electronic water level probe prior to, during, and after the pump test. Dataloggers set to record measurements at 2 second intervals were also deployed in adjacent monitoring wells 16-102 and 16-118.

Pumped liquid was also sampled for analysis of BTEX/volatile petroleum hydrocarbons (VPH)/F1 and F2-F4 parameters during the test. The sample, MW16-116-161006INITIAL, was collected to evaluate pre-surfactant application water quality.

2.4.2 Results and Discussion

Pump testing at monitoring well 16-116 identified that the well was able to yield a continuous 23.5 L/min, which was the maximum rate able to be sustained by the Grundfos pump. The well likely could have sustained a higher yield if a higher capacity pump was used. Steady state drawdown in monitoring well 16-116 was measured to be 0.044 m. Steady state drawdown at monitoring well 16-102 which was 1.7 m away was measured to be 0.015 m. Results from the pump test are presented in Table 3.

The pump test data were analyzed using a modified version of the Thiem (1906) solution for steady state pumping, as described by Kruseman and De Ridder (1990). Using this solution, the transmissivity of an unconfined aquifer can be estimated by

$$T = \frac{Q}{2\pi(S_w - S_1)} \ln\left(\frac{r_1}{r_w}\right)$$

Where Q is the pump rate, S_w is the steady state drawdown in the pump well, S_1 is the steady state drawdown in the observation well (16-102), r_w is the radius of the pump well, and r_1 is the distance to the observation well (16-102).

A transient analysis of the data was also completed using AQTESOLV. The analytical solution used was the Theis curve matching method (1935) adapted for unconfined aquifers.

The transmissivity was estimated to be 9.0 x 10^{-3} m^2/s by the Thiem equation and 1.4 x 10^{-2} m^2/s by the Theis solution, which translates to hydraulic conductivities of 6.0 x 10^{-4} m/s and 9.5 x 10^{-4} m/s (geomean of 7.6 x 10-4 m/s) assuming an aquifer thickness of 15 m (which is not presently known as the bottom of the aquifer has not been encountered during drilling). These results are consistent with the hydraulic conductivity estimate derived from the slug test results from MW 16-102 (6.9 x 10^{-4} m/s) and further confirms that soils associated with the regional aquifer are highly permeable and conducive to the injection and/or pumping of liquids.

Analysis for the pump test at Muncho Lake is provided in Appendix V.

2.5 Surfactant Application (Push/Pull) Test

2.5.1 Methodology and Observations

Tersus was engaged to provide onsite support with optimizing the Task mixture for the surfactant application. SNC-Lavalin provided Tersus with a soil sample collected from the PHC impacted profile at 16-116 for the completion of bench scale testing. Tersus also completed an optimization step using a diesel surrogate to further inform the optimization of the Task surfactant for application. Tersus's procedure for the optimization of Task is presented in Appendix II. Following the identification of an appropriate mix ratio for Task, potassium hydroxide (KOH), Acetic acid, and water by Tersus two batches were mixed for injection. The surfactant was injected as indicated in Table B. A higher injection flowrate for the second batch was observed due to the use of a higher capacity pump. No bypass to surface was observed during the injection.

Table C: Summary of Surfactant Application – Muncho Lake

Injection Location	Flow (L/min)	Pressure (psi)	Surfactant Mixture	Comments
16-116	11-24	0-4	~1,350,700 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic acid	1st Batch injected over ~60 minutes
16-116	11-24	16	~1,350,700 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic acid	2nd Batch injected over ~45 minutes

After approximately 18 hours, monitoring wells 16-102, 16-116, and 16-118 were monitored for the presence of LNAPL. Following monitoring in these wells a Grundfos Redi-flo 2 pump was installed just off the bottom of monitoring well 16-102. Tersus initially recommended pumping from 16-102 to evaluate the potential for circulating the injected surfactant towards this monitoring well location.

While pumping was completed from monitoring well 16-102 pumped liquids were monitored for EC and pH. The sample, MW16-102-161007-1, was also collected for analysis of BTEX/VPH/F1 and F2-F4 parameters during pumping to evaluate post-surfactant application water quality. Following pumping at 16-102 the Grundfos Redi-flo 2 pump was installed just off the bottom of monitoring well 16-116 for further groundwater extraction.

Table D: Summary of Surfactant Extraction – Muncho Lake

Extraction Location	Flow (L/min)	Duration (min)	Volume (L)	Comments
16-102	23	50	432	-
16-116	23	240	5200	Pumped groundwater was foamy with no evidence of free phase PHC

While pumping was completed from monitoring well 16-116 pumped liquids were monitored for TDS and pH. Water quality was also evaluated qualitatively throughout the test. Pumped liquids were also sampled for analysis of BTEX/VPH/F1 and F2-F4 parameters throughout the test. The samples MW16-116-161007-1, MW16-116-161007-2, MW16-116-161007-3, MW16-116-161007-4, and MW16-116-161007-5 were collected during pumping to evaluate post-surfactant application water quality.

Refer to the attached Drawing 635031-802 which shows the test location. Results from the surfactant push/pull test are presented in Table 4.

Groundwater Monitoring

Monitoring of 16-118, approximately 1.2 m away from injection well 16-116, identified that total dissolved solids (TDS) in groundwater was 120 parts per million (ppm) at the start of surfactant injection. During injection at 16-116, TDS at 16-118 increased to 160 ppm and the pH was 9.

During the injection of the Task surfactant at 16-116, TDS in groundwater at monitoring well 16-102, approximately 1.7 m away from 16-116, ranged from 1,150 ppm to 2,250 ppm and pH ranged from 12 to 13. Purged liquid from this well was bubbly and had a strong surfactant odor.

Approximately 18 hours following surfactant injection at 16-116, wells 16-102, 16-116, and 16-118 were monitored for the presence of LNAPL and none was detected.

Measured pH at 16-102 was 8.8 and TDS was 141 ppm prior to commencement of pumping at 16-102. Measured pH at 16-116 was 10 and TDS was 250 ppm prior to commencement of pumping at 16-102 Pumped liquids from 16-102 had a pH of 10 for the duration of extraction from this location. Measured TDS increased slightly from 180 to 220 ppm during pumping from 16-102. Bubbles were present in recovered liquids when pumping from 16-102 suggesting the presence of surfactant in the pumped groundwater.

During subsequent pumping from injection well 16-116, the pumped groundwater pH decreased from 11 to 9 and TDS decreased from 350 ppm to 160 ppm. Bubbles were present in the pumped groundwater from this location during the extraction test. While pumping from 16-116 the pH at 16-102 was noted to drop to 9 and TDS was noted to drop to 140 ppm

Groundwater Analytical

Groundwater samples were collected from well 16-116 prior to surfactant application and while pumping from 16-102 and 16-116. Analytical results indicated the following:`

- Dissolved PHC impacts were not detected at 16-116 prior to surfactant application and therefore did not exceed *Canadian Drinking Water Quality Guidelines*[3] (CDWQG) for BTEX, or the *Federal Interim Groundwater Quality Guidelines*[4] (FIGWQG) for Tier 2 Residential Land Use (RL) for BTEX, F1-BTEX, and F2 ($>C_{10}$-C_{16});
- Following injection of the Task surfactant, the concentration of F2 ($>C_{10}$-C_{16}) in pumped groundwater from 16-116 was 8,700 µg/L, exceeding the FIGWQG RL guideline for this parameter. Trace concentrations of xylenes and F1-BTEX were also present at concentrations less than both of the previously referenced guidelines;
- The F2 ($>C_{10}$-C_{16}) concentration in pumped groundwater from 16-116 decreased to 2,100 µg/L as pumping continued from this location; and
- The concentration of F2 ($>C_{10}$-C_{16}) in pumped groundwater from 16-102 subsequent to surfactant injection at 16-116 was 2,000 µg/L. F2 ($>C_{10}$-C_{16}) was not detected in a previous groundwater sample collected from well 16-102 in July 2016.

Groundwater sampling results for the surfactant application (push/pull) tests are presented in Table 5.

2.5.2 Results and Discussion

Surfactant injections and recovery were completed at Muncho Lake Maintenance Camp with relative ease. Surfactant was injected at a monitoring well at a flow rate of 23 L/min. This suggests the larger scale application of this in-situ remediation option would likely not be affected by physical limitations.

Groundwater Monitoring

Observations from monitoring conducted during injection and recovery suggested that recovered groundwater was dilute (i.e., lower pH and TDS values) relative to what would have been expected. Therefore, limited recovery of the surfactant may have occurred with preferential migration of the surfactant a potential cause.

Groundwater Analytical

Groundwater analytical results indicated a substantial increase in PHC concentrations in the surfactant injection well, from less than 150 µg/L to an initial concentration upon pumping of 8,700 µg/L. The

[3] *Canadian Drinking Water Quality Guidelines (CDWQG),* Health Canada, August 2012.
[4] *Guidance Document on Federal Interim Groundwater Quality Guidelines for Federal Contaminated Sites* (FIGWQG), prepared for the Federal Contaminated Sites Action Plan (FSCAP) Secretariat of Environment Canada, November 2015.

F2 (>C_{10}-C_{16}) concentration in pumped groundwater from 16-116 decreased as pumping continued from this location to 2,100 µg/L.

Summary

Overall, the pilot test indicates that surfactant can be readily injected and recovered at a reasonable flow rate. Groundwater analytical results also indicate that the Task surfactant was effective in increasing the dissolved PHC mass for recovery. However, based on the maximum recovered F2 (>C_{10}-C_{16}) concentration of 8,700 µg/L, it would likely require in excess of 1,000 pore volumes to reduce soil hydrocarbon concentrations substantially which is likely not practical. Given the magnitude of soil PHC concentrations and the absence of measurable LNAPL in monitoring wells at the Site, the potential for mass removal for surfactant application may be limited. However as indicated previously, measured pH and TDS values in recovered groundwater were lower than would have been expected indicating limited surfactant recovery, with preferential migration of the surfactant a potential cause. Therefore, it is possible that higher recovered dissolved hydrocarbon concentrations may be achieved with more comprehensive pilot testing.

2.6 LIF Evaluation

2.6.1 Methodology and Observations

was engaged to provide onsite observation of the advancing of direct push tooling, and gauge, in their experience, the potential for advancing the LIF device at the Muncho Lake Maintenance Camp. and SNC-Lavalin observed advance 1.5 inch (38 mm) diameter probe rods to the potential target depth of 14.6 m at two locations. and SNC-Lavalin also observed the advancement of a 2.25 inch (57 mm) diameter probe rod to a depth of 9.1 m. The 2.25 inch probe was removed and the depth of the open hole was evaluated. The hole was then filled with 10/20 sand. 1.5 inch probe rods were then advanced in the 2.25 inch bore to the potential target depth of 14.6 m.

Following the advancement of the direct probe rods, the holes were backfilled with sand and bentonite chips. Soil samples collected were also shipped to for off-site testing with the LIF device to confirm that it would respond to the type of hydrocarbons encountered.

The 1.5” (38 mm) diameter probe rods were advanced to 14.6 m at two locations in approximately 12 minutes. The probe rods were advanced with the hammer on the Geoprobe 8040DT direct push and rotary rig set at approximately 25% of maximum capacity. Limited wobbling of the probe rods was observed during advancement. At the second direct push location, rod advancement was more difficult from a depth of 6.7 m to 9.1 m as noted by more wobbling and more forceful hammering.

Advancement of a 2.25” (57 mm) diameter probe rod to a depth of 9.1 m was completed in 7 minutes. Following removal of the 2.25” diameter probe rod the hole remained open to a depth of 2.7 m. One bag of filter sand was used to fill the hole to ground surface. A 1.5” (38 mm) diameter probe rod was then advanced to a depth of 14.6 m with hammering from a depth of 9.1 m to 14.6 m and required light to moderate hammering (approximately 25% of maximum hammering capacity). Advancing the bore using the 2.25” and 1.5” tooling took a total of 23 minutes.

Advancement of a second 2.25” diameter probe rod to a depth of 9.1 m was completed in 5 minutes. Following removal of the 2.25” diameter probe rod at the second location the hole remained open to a depth of 5.8 m. 2 bags of filter sand were used to fill the hole to ground surface. A 1.5” (38 mm) diameter probe rod was then advanced to a depth of 14.6 m. Advancing the bore using the 2.25” and 1.5” tooling took a total of 20 minutes at the second location.

Target depths were reached and refusal did not occur. Soil samples shipped to for off-site testing with the LIF tool exhibited a fluorescence response confirming that it would respond to the type of hydrocarbons encountered. Observations made by during the LIF evaluation are provided in their memorandum in Appendix VI.

2.6.2 Results and Discussion

Advancement of the 1.5” rods with a solid point without refusal indicates that the LIF tool can be advanced at the Site. It was observed by that soil conditions were very “tight” for this type of advancement to the target depths required. Based on this, to minimize damage to tooling recommends a “pre-probing” strategy in which 2.25” tooling is advanced to approximately 9 meters below ground surface (mbgs) prior to deploying the LIF device, and this would be sufficient to achieve full scale characterization. It is noted that as advancement of the LIF requires a downward velocity of less than 2 cm / s for data collection, a “pre-probing” approach through shallower soils will result in faster drilling in the upper 9 m, leading to a similar overall length of time to reach the target depth at each location. Soil samples shipped to for off-site testing with the LIF tool exhibited a fluorescence response confirming that it would respond to the type of hydrocarbons encountered.

3 Fireside Maintenance Camp

In advance of ground disturbance activities BC One Call was contacted and members were requested to locate and mark utilities subject to encroachment. Additionally a utility survey was completed in the areas where ground disturbance was planned. Utilities or buried lines were marked by the utility survey contractor. Following the completion of the utility survey, SNC-Lavalin's ground disturbance checklist was reviewed and completed.

To allow for the collection and temporary storage of recovered liquids during the pilot test, an open top steel tank was supplied and delivered to the Site.

Work at the Fireside Maintenance Camp included:

› Borehole advancement;
› Hydrogen peroxide injection into injection points;
› Pump testing;
› Surfactant application (push/pull) test; and
› LIF evaluation.

Refer to the attached Drawings 636200-501 and 636200-502 showing the locations of the test areas, boreholes, and monitoring wells.

3.1 Borehole Advancement

3.1.1 Methodology and Observations

To allow for chemical oxidizer application (injection) with a dedicated injection well one borehole was advanced (i.e., 16-39). The borehole was initially advanced with the DT45 soil sampling system using the Geoprobe 8040DT direct push and rotary rig. The DT45 sampling system was advanced until refusal at a depth of 12.2 m. Air rotary drilling was then used to advance a 4.5 inch diameter casing to a depth 26.8 m. It was not possible to reach the target depth of 30 m as there were issues with the supplied air rotary tooling. The air rotary tooling was removed from the borehole and an attempt was made to advance the DT45 tooling again. Refusal was encountered at a depth of 12.5 m which was approximately 0.3 m beyond the depth to slough. As borehole advancement was not possible to the target depth for injection, the hole was abandoned and backfilled with bentonite to ground surface.

The borehole log is provided in Appendix I. Refer to Drawing 636200-502 for a site plan showing the location of the borehole.

3.1.2 Results and Discussion

Borehole advancement and monitoring well installation with DT45 tooling and the Geoprobe 8040DT direct push and rotary rig was not possible to the target depth of 29 m due to refusal at a depth 12.2 m. The cause of refusal was not identified, but was likely the result of encountering a cobble, boulder, or layer of high density. Borehole advancement and monitoring well installation to depths of 13 m to 32 m with DT45 tooling is not considered a suitable approach at the Fireside Maintenance camp.

Where boreholes and monitoring wells (including injection wells) are required at a depth greater than 13 m air rotary or sonic drilling has been effective historically.

3.2 Hydrogen Peroxide Injection

3.2.1 Methodology and Observations

In-situ chemical injections were completed at three locations using hydrogen peroxide. 50% (m/m) hydrogen peroxide was mixed with water to concentrations between 11.5% (m/m) and 20% (m/m). Hydrogen peroxide was directly injected through 2.25" probe rods advanced to a target depth of 29.3 m, coincident with the depth where PHC impacts in soil were found in the adjacent monitoring well 13-03. Probe rods for direct injection were advanced with the Geoprobe 8040DT direct push and rotary rig. The injection probe rods were advanced with a standard expendable 2.45 inch outer diameter drive point. Following advancement of the probe rods to the target depth, compatible tooling was connected to the top of the probe rod to allow for injection through the inner diameter of the probe rod. A flow meter and pressure gauge were connected so that total volume, flow rate, and injection pressure could be monitored during injection. Following advancement the probe rods were raised approximately 0.3 m to cause the expendable drive point to come off of the bottom of the probe rods and to ease the injection of hydrogen peroxide.

Hydrogen peroxide was injected at three direct injection locations (IP1, IP2, and IP3). Refer to Drawing 636200-502 which shows the location of the injection points. VTX Catalyst 4.4 (VTX) was injected into IP2 to enhance the action of hydrogen peroxide. VTX was mixed with water at a ratio 1 L VTX: 4 L H_2O prior to injecting. A total VTX mixed volume of 200 L was injected into IP2.

The injection of hydrogen peroxide was completed as indicated in the following table.

Table E: Summary of Hydrogen Peroxide Injections - Fireside

Injection Locations	Flow (L/min)	Pressure (psi)	Hydrogen Peroxide Injection Concentration (% m/m)	Volume (L)	Duration (Hrs)	Comments
IP1	13-23	18-38	11.5	3,333	4.3	-
IP2	26	8	11.5	3,485	4	200 L of VTX

						mixture added.
IP3	18-19	18-24	20%	1,798	2	-

In conjunction with the hydrogen peroxide injections, groundwater was monitored at monitoring well BH13-03 before, during, and after the hydrogen peroxide injections at the direct injection points. Groundwater was monitored for temperature, pH, DO, ORP, salinity, and EC.

IP1 Injection Observations and Monitoring

- Probe rods advanced to target depth of 29.3 m in under 25 minutes.
- Injection fittings were connected to the probe rods and pressurized hydrogen peroxide was delivered to minimize the potential for granular material entering the end of the probe rod as it was raised.
- Bypass of hydrogen peroxide at ground surface was observed throughout the injection. Attempts to minimize the occurrence of bypass by tightening the probe rods did not reduce the bypass.
- Flowrate decreased and backpressure increased as injection progressed.

Groundwater was monitored at monitoring well 13-03 approximately 3.1 m away from IP1. The following was noted at monitoring well 13-03 during injection at IP1:

- Conductivity, pH, temperature, and salinity remained steady at pre-injection levels;
- Dissolved oxygen concentrations remained at less than 1 mg/L over the course of injections at IP1, however it was later noted that the DO probe was not functioning properly and required reconditioning; and
- ORP increased from -22 mV to 82 mV.

Results from the hydrogen peroxide injection and monitoring at 13-03 are presented in Table 6.

IP2 Injection Observations and Monitoring

IP2 was installed approximately 6.5 m from IP1. Pressure and flow rate during the injection at IP2 remained steady during the injection.

Groundwater was monitored at monitoring well 13-03 approximately 3.4 m away from IP2. The following observations and data measurements were made at monitoring well 13-03 during injection at IP2:

- Conductivity, pH, temperature, and salinity remained at pre-injection levels;
- Dissolved oxygen concentrations was steady at less than 1 mg/L. As the dissolved oxygen concentrations were lower than expected the probe was inspected and an air bubble was identified in the probe tip. The probe was subsequently reconditioned and recalibrated and confirmed to work normally. Following probe reconditioning and after the completion of injection at IP2, dissolved oxygen concentrations were measured at 20 mg/L and 21 mg/L; and
- ORP was between 100 mV and 115 mV and increased to 142 mV to 144 mV afterwards.

IP3 Injection Observations and Monitoring

IP3 was installed approximately 9 m from IP1 and 4.1 m from IP2.

- Pressure and flow rate remained steady during the injection.
- Bypass of hydrogen peroxide to ground surface was observed towards the end of injection.

Groundwater was monitored at monitoring well 13-03 approximately 3.5 m away from IP3. The following was noted at monitoring well 13-03 during injection at IP3:

- Conductivity, pH, temperature, and salinity remained steady;
- Dissolved oxygen concentrations increased from 12 mg/L to 19 mg/L; and
- ORP increased from 104 mV to 118 mV.

Post-Injection Groundwater Monitoring

Continued groundwater monitoring was completed at 13-03 post injections. 3 hours after the completion of injections the groundwater temperature in 13-03 increased from 3.5 °C to 7.9 °C. Groundwater temperature continued to rise to 12.6 °C 3.5 hours after the completion of injections after which the temperature decreased. Temperature remained above pre-injection levels 5 hours after injection. 24 hours after injections, the groundwater temperature at 13-03 was at pre-injection levels.

Groundwater monitoring at 13-03 after the completion of injections identified the following:

- Dissolved oxygen concentrations ranged from 16 mg/L to 25 mg/L;
- Monitoring of ORP for 5 hours after injections showed an increase from 118 mV to 148 mV; and
- 24 hours after the completion of injections dissolved oxygen was measured to be 11 mg/L to 15 mg/L and ORP was measured to be 98 mV to 104 mV.

Figures 3 and 4 present temperature, dissolved oxygen concentrations and ORP response over the course of hydrogen peroxide injections at Fireside.

3.2.2 Results and Discussion

Hydrogen peroxide injections were completed at Fireside Maintenance Camp with relative ease. Hydrogen peroxide was injected at direct injection points (through probe rods) at concentrations of 11.5% (m/m) – 20% (m/m), flow rates up to 26 L/min, and pressures less than 40 psi. This suggests the larger scale application of this in-situ remediation option could be completed with few technical limitations.

Installation

Advancement of the 2.25” diameter direct injection probe rods to the target depth of 29 m was relatively fast (less than 25 minutes) indicating injection via this method is feasible. In comparison, the installation of the dedicated injection well, BH16-38 by vibrasonic drilling in June 2016 took approximately 14 hours. As was the case at Muncho Lake Maintenance Camp, the probe rods were raised (a maximum of 0.3 m) over the course of injections with the Geoprobe 8040DT direct push and rotary rig. This allowed for injection over varying depths.

Bypass of hydrogen peroxide at ground surface was observed when completing direct injection through the probe rods. This is presumed to occur from the flow of pressurized hydrogen peroxide preferentially along the outside of the probe rod due to poor sealing between the probe rod and subsurface soils. Bypass at IP1 was continuous through the injection and attempts to minimize bypass or leaking through tightening of the probe rods had a limited effect. It is estimated that there was 50 L of hydrogen peroxide bypass to ground surface at IP1. Hydrogen peroxide would also have migrated into the formation along the vertical length of the rod.

Limited leaking was observed from above ground threaded connections in some instances during the injections. The threaded connections between probe rods loosened slightly as they were advanced. indicated that the upper 15 m of probe rods were loose when removed post injection, while the lower 15 m of probe rods remained tight. The use of o-rings to seal the threaded connections on the probe rods could be considered to minimize leaking from these joints.

Dissolved Oxygen

Similar to Muncho Lake Maintenance Camp the injection of hydrogen peroxide increased the dissolved oxygen concentration in groundwater at least 3 m from the injection point. Continued elevated dissolved oxygen concentrations were measured at least 2 days after the completion of injections. The increase in the concentration of dissolved oxygen likely results from the decomposition of hydrogen peroxide. It does not necessarily indicate the presence of hydrogen peroxide or associated radicals which is what is required for affecting oxidation of petroleum hydrocarbons in soil. In addition to the oxidation of petroleum hydrocarbons, the increase in dissolved oxygen in groundwater from the decomposition of hydrogen peroxide enhances the biodegradation of petroleum hydrocarbons.

Temperature

The injection of hydrogen peroxide increased the temperature of groundwater at least 3 m away. An increase in temperature was sustained for 1 day after injections. The increase in temperature indicates that exothermic reactions are occurring. Exothermic reactions are likely a combination of the oxidation of petroleum hydrocarbon, decomposition of hydrogen peroxide, and oxidation of naturally occurring materials. The temperature of groundwater remained well below 70 °C and consequently elevated groundwater temperatures are not expected to prevent the generation of radicals that can further oxidize petroleum hydrocarbons.

An increase in groundwater temperature was measured at 13-03 after the injection of 20% (m/m) hydrogen peroxide at IP3. It is not clear whether or not the injection of 20% (m/m) hydrogen peroxide at IP3 (3.5 m away from monitoring well 13-03) caused the increase in temperature in groundwater at monitoring well 13-03 or if the increase was caused by the injection of VTX and 11.5% (m/m) hydrogen peroxide at IP2 3.4 m away. In any case, the increased temperature was short lived and approached background conditions within a day.

ORP

ORP increased at 13-03 following the injection of hydrogen peroxide at IP1, IP2, and IP3, suggesting the development of oxidizing conditions at this monitoring well location and further indicating effects from hydrogen peroxide injection.

pH

Measured pH ranged between 7 and 8 at monitoring well 13-03 throughout the injections suggesting neutral to alkaline conditions in groundwater at this location. Similar to Muncho Lake Maintenance Camp, the neutral pH is expected to limit the potential for the creation of a modified Fenton's system and the associated generation of oxidizing radicals. The addition of a chelated iron compound, such as VTX, has the potential to make available iron ions in a form that can generate a modified Fenton's system.

Summary

Overall, the pilot test indicates that hydrogen peroxide can be readily injected at a reasonable flow rate using direct push technology. There are also indications of hydrogen peroxide effects adjacent the injection locations through increases in DO concentration, temperature, and ORP. Changes in these parameters suggest that oxidation reactions have occurred as a result of the injection of hydrogen peroxide, but do not directly confirm that hydrogen peroxide is present in adjacent monitoring wells. Further testing would be necessary with greater oxidant volumes to evaluate radius of influence of the hydrogen peroxide itself. In order to effectively remediate the soil within a treatment zone, hydrogen peroxide will need to come into direct contact with PHC impacts throughout the intended treatment zone.

3.3 Pump Test

3.3.1 Methodology and Observations

A pump test was initially completed at monitoring well 16-38 to evaluate hydraulic conductivity and radius of influence. The pump test was completed in accordance with SNC-Lavalin's Preferred Operating Procedure "Water Well Pump Test". A Grundfos Redi-flo 2 pump was installed near the bottom of the monitoring well. Following the installation of the pump, SNC-Lavalin was unable to develop a steady state flow rate from the well due to limited saturated thickness.

After it was determined that continuous pumping at monitoring well 16-38 was not possible, a decision was made to move the pump test to monitoring well location BH13-06. A steady state flow rate of 17 L/min was developed from the well. Pumped liquids were discharged directly to the above ground open top storage tank. Water levels in the pump well and adjacent monitoring wells 14-10 and 16-38 were manually monitored with an electronic water level probe prior to, during, and after the pump test.

Dataloggers set to record measurements at 2 second intervals were also deployed in adjacent monitoring wells 14-10 and 16-38.

Pumped liquid was also sampled for analysis of BTEX/VPH/F1 and F2-F4 parameters during the test. The sample, MW13-06-161009, was collected to evaluate pre-surfactant application water quality at 13-06.

3.3.2 Results and Discussion

Pump testing was initially completed at 16-38. It was indentified that the well was unable to sustain a continuous yield with the Grundfos RediFlo 2 submersible pump. The pump test was then completed at 13-06 which identified that this well was able to yield a continuous 16.7 L/min. Steady state drawdown in monitoring well 13-06 was measured to be 1.45 m. Steady state drawdown at monitoring well 16-38 which was 2.9 m away was measured to be 0.12 m. Steady state drawdown at monitoring well 14-10 which was 9 m away was measured to be 0.019 m. Results from the pump test are presented in Table 7.

The pump test data were analyzed using a modified version of the Thiem (1906) solution for steady state pumping, as described by Kruseman and De Ridder (1990). Using this solution, the transmissivity of an unconfined aquifer can be estimated by

$$T = \frac{Q}{2\pi(S_w - S_1)} \ln\left(\frac{r_1}{r_w}\right)$$

Where Q is the pump rate, S_w is the steady state drawdown in the pump well, S_1 is the steady state drawdown in the observation well (16-38), r_w is the radius of the pump well, and r_1 is the distance to the observation well (16-38).

A transient analysis of the data was also completed using AQTESOLV. The analytical solution used was the Moench curve matching method (1997) adapted for unconfined aquifers in which there is a delayed yield response.

The transmissivity was estimated to be 1.6 x 10^{-4} m^2/s by the Thiem equation and 1.5 x 10^{-4} m^2/s by the Moench solution, which translates to hydraulic conductivities of 1.0 x 10^{-5} m/s and 9.8 x 10^{-6} m/s assuming an aquifer thickness of 15 m (which is not presently known as the bottom of the aquifer has not been encountered during drilling). These results are consistent with the hydraulic conductivity estimate derived from a previous slug test at MW 13-06 (1.7 x 10^{-5} m/s) reported by Arcadis (2016[5]).

The hydraulic conductivity estimated of 1.0 x 10^{-5} m/s through analysis of the pump test data is within the range reported by Freeze and Cherry (1979) for clean sand (10^{-5} m/s to 10^{-2} m/s), but below the range reported for gravel (10^{-3} m/s to 1 m/s). The results of the pump test indicate that the soils associated with the regional aquifer are fairly permeable and conducive to the injection and/or pumping of liquids.

[5] Arcadis, 2016. Data Synthesis, Fireside Maintenance Camp, Kilometer 839, Alaska Highway, BC. Dated March 2016.

Analysis for the pump test at Fireside is provided in Appendix VII.

3.4 Surfactant Application (Push/Pull) Test

3.4.1 Methodology and Observations

When it was identified that monitoring well 16-38 did not yield groundwater at a rate sufficient for completing a pump test it was decided to modify the push/pull test such that surfactant injection would be completed into monitoring well 16-38 and the pump (pull) portion of the test would be completed from BH13-06 which was 2.9 m away and considered to be approximately downgradient.

At Fireside, SNC-Lavalin used the surfactant Iveysol 106 which is a proprietary, non-ionic surfactant formulated for solubilising and mobilizing fuel oil based contaminants. The surfactant was mixed and injected as indicated in Table E.

Table F: Summary of Surfactant Application - Fireside

Injection Location	Flow (L/min)	Pressure (psi)	Surfactant Mixture
16-38	6-8	30	1,000 L H_2O: 20 L Iveysol 106

Approximately 15.5 hours following injection a Grundfos Redi-flo 2 pump was installed near the bottom of monitoring well BH13-06 for the extraction portion of the test. While pumping was completed from monitoring well BH13-06 pumped liquids were monitored for EC, pH, and meniscus development. Pumped liquids were also sampled for analysis of BTEX/VPH/F1 and F2-F4 parameters throughout the test. The samples MW13-06-161011-1, MW13-06-161011-2, MW13-06-161011-3, MW13-06-161011-4, and MW13-06-161011-5 were collected during pumping to evaluate post-surfactant application water quality.

Water quality at monitoring well 16-38 was also monitored for EC, pH, and meniscus development. This well was also sampled for analysis of BTEX/VPH/F1 and F2-F4 parameters towards the end of the pull test (Sample MW16-38-161011). Monitoring wells 16-38 (Sample MW16-38-161027/28) and 13-06 (Sample MW13-06-161121) were also sampled after the completion of the pilot test for analysis of BTEX/VPH/F1 and F2-F4 parameters.

Table G: Summary of Surfactant Extraction - Fireside

Extraction Location	Flow (L/min)	Duration (Hrs)	Volume (L)	Comments
13-06	16	5	4,800	Suds observed in pumped groundwater

Results from the surfactant push/pull test are presented in Table 8.

<u>Groundwater Monitoring</u>

As recommended by the surfactant supplier, Ivey International Inc., meniscus development was evaluated throughout extraction at 13-06 to evaluate qualitatively for the presence of surfactant. There was no observable change in the height of the meniscus throughout the test. Meniscus development was also evaluated in groundwater from well 16-38 where the surfactant was injected and the observed height of the meniscus was similar to the meniscus in water pumped from 13-06. During collection of samples from pumped groundwater from 13-06 the meniscus development in the vials was initially limited, but became more pronounced towards the end of pumping.

Suds and a slight surfactant odour were observed in water pumped from 13-06 at the start of pumping. Suds were observed throughout pumping, however they appeared to diminish towards the end of the test after five hours of pumping. Electrical conductivity in pumped groundwater was 1.3 mS/cm, temperature ranged from 3.9 degrees to 4.6 degrees Celsius, and pH ranged from 7.26 to 7.46.

Groundwater Analytical

Groundwater samples were collected from groundwater monitoring well 13-06 prior to surfactant application, and during pumping and after the completion of the pilot test from 13-06 and 16-38. Analytical results identified the following:

- BTEX concentrations did not exceed the CDWQG and BTEX, F1-BTEX and F2 (>C_{10}-C_{16}) did not exceed FIGWQG RL guidelines at 13-06 prior to and following surfactant injection at 16-38. Only F2 (>C_{10}-C_{16}) and trace xylenes concentrations were detected. F2 (>C_{10}-C_{16}) concentrations were marginally higher following surfactant injection (i.e., 630 µg/L vs 670-860 µg/L); and
- Following surfactant application, concentrations of F1-BTEX and F2 (>C_{10}-C_{16}) in groundwater at 16-38 exceeded the FIGWQG RL guidelines for F1-BTEX and F2 (>C_{10}-C_{16}) and the CDWQG for ethylbenzene and xylenes and ethylbenzene. The concentrations of F2 (>C_{10}-C_{16}) were 2,300 µg/L and 3,200 µg/L.

Groundwater sampling results for the surfactant push/pull test is presented in Table 9. Analytical reports are provided in Appendix III.

3.4.2 Results and Discussion

Although aquifer soils were not as permeable at Fireside than Muncho Lake, permeability was sufficient to complete surfactant injections and recovery. Surfactant was injected at a monitoring well at a flow rate of 6-8 L/min and recovered at an adjacent well at 16 L/min. This suggests the larger scale application of this in-situ remediation option would likely not be affected by physical limitations.

Groundwater Monitoring

Observations from monitoring conducted during injection and recovery suggested that limited recovery of the surfactant occurred. Preferential migration of the surfactant may have occurred in a different direction to well 13-06 where extraction occurred. The volume of surfactant injected in well 16-38 may also not have been sufficient to lead to a more concentrated detection in adjacent monitoring well 13-06 (i.e., 2.9 m away), however it was noted that suds and slight surfactant odour were observed in water pumped at the start of pumping at 13-06 and meniscus development became more pronounced towards the end of pumping.

Groundwater Analytical

Groundwater analytical results in extraction well 13-06 indicated only a marginal increase in F2 (>C_{10}-C_{16}) concentrations following surfactant injection at 16-38 (i.e., 630 µg/L vs 670-860 µg/L). Similar to interpretations made from groundwater monitoring data, preferential migration of the surfactant may have occurred in a different direction to well 13-06 where extraction occurred. The volume of surfactant injected in well 16-38 may also not have been sufficient to lead to higher PHC solubilisation levels in adjacent monitoring well 13-06 (i.e., 2.9 m away). Therefore, it is not known how effective the Iveysol 106 surfactant is in mobilizing and solubilising PHC.

Summary

Overall, the pilot test indicates that surfactant can be readily injected and recovered at a reasonable flow rate. However, groundwater analytical results indicated only a marginal increase in surfactant concentrations in the adjacent recovery well (i.e., 630 µg/L vs 670-860 µg/L) which would not be practical for full scale implementation. Given the magnitude of soil PHC concentrations and the absence of measurable LNAPL in monitoring wells at the Site, the potential for mass removal for surfactant application may be limited. However as indicated previously, observations from monitoring conducted during injection and recovery suggested that limited recovery of the surfactant occurred, with preferential migration of the surfactant and/or insufficient injection volume being potential causes. Therefore, it is likely that higher recovered dissolved hydrocarbon concentrations could be achieved with surfactants with more comprehensive testing.

3.5 LIF Evaluation

3.5.1 Methodology and Observations

was engaged to provide onsite observation of the advancing of direct push tooling, and gauge, in their experience, the potential for advancing the LIF device at the Fireside Maintenance Camp. and SNC-Lavalin observed advance 1.5 inch diameter probe rods to a depth of 25.5 to 26 m at two locations. and SNC-Lavalin also observed the advancement of a 2.25 inch diameter probe rod to a depth of 21 m. The 2.25 inch probe was removed and the depth of the open whole was evaluated. 1.5 inch probe rods were then advanced in the 2.25 inch bore to a depth of 26 m. The 1.5 inch probe rods were then removed, and the 2.25 inch probe rod was then advanced to 33 m, the potential target depth, to observe the advancement of probe rods through soils from 26 m to 33 m. Following the advancement of the direct probe rods, the holes were backfilled with sand and bentonite chips.

The 1.5” diameter probe rods were advanced to between 25.5 m and 26 m at two locations in approximately 35 minutes to 40 minutes. The advancement at the first location was more difficult between a depth of 17.7 m to 19.2 m. An inspection of the drive cap at the end of the probe rods after removal from the first location identified that there was noticeable wear on the cap. Following advancement of the 1.5” probe rods it was noted that 3 rods had a slight bend, however it is uncertain whether this occurred during advancement.

A 2.25” diameter probe rod was advanced at a third location to a depth of 21.3 m. Following removal of the 2.25” probe rod the hole remained open to a depth of 1.8 m. A 1.5” diameter probe rod was then advanced through the same bore and the sluff was fairly continuous to a depth of 21.3. From 21.3 m to 26 m (beyond the depth to which the 2.25” bore was advanced) more significant wobble was observed in the probe rods than at the previous 2 locations. It took approximately 55 minutes to advance a pilot bore with the 2.25” probe rods to 21.3 m and then follow with the 1.5” probe rods to 26 m.

Following advancement of the 1.5” probe rod to 26 m, 2.25” probe rods were advanced in the same bore to a depth of 32.9 m. Advancement of the 2.25” probe rod from 26 m to 32.9 m was challenging except at a depth of 31.4 m to 32 m.

Target depths were reached and refusal did not occur. Observations made by during the LIF evaluation are provided in memorandum in Appendix VI.

3.5.2 Results and Discussion

Advancement of the 1.5” rods with a solid point without refusal indicates that the LIF tool can be advanced at the Site. It was observed by that soil conditions were very “tight” for this type of advancement to the target depths required. Based on this, to minimize damage to tooling recommends a “pre-probing” strategy in which 2.25” tooling is advanced to approximately 20 mbgs prior to deploying the LIF device. As advancement of the LIF tool requires a downward velocity of less than 2 cm/s for data collection, a “pre-probing” approach through shallower soils will result in faster drilling in the upper 20 m, leading to a similar length of time to reach the target depth at each location.

4 Closure

This pilot test was largely an effort to establish proof of concept for in-situ remediation and characterization methods (i.e., chemical oxidation, surfactant injection, and LIF) with the intent of establishing which technologies were feasible options to apply toward meeting the remedial goals for the Sites. Interpretation of the testing, observations, and data collected suggests that the larger scale application of all three of these technologies at the Sites have potential to be applied in the effort to reduce hydrocarbon impacts. Similar conditions exist on the two Sites which include relatively permeable soils, contaminant type, ability to install probe rods to the desired depth, ground surface access in a maintenance yard, weather conditions and available electrical power. The primary difference is the depth of contamination as Muncho Lake contamination is present between approximately 8 m to 14 m below grade, and Fireside impacts are present within three discrete zones at approximately 10 m to 13 m, 20 m to 24 m and 26 m to greater than 30 m below grade.

Further assessment of the two in-situ technologies could be carried out to better understand the probability of successful remediation and the associated costs. There are notable differences in the application of the two technologies and associated requirements to achieve the desired remediation goal. These differences should be considered along with the costs when planning and decisions are made related to the next steps of site remediation. The table below summarizes some of the benefits and uncertainties/challenges as currently understood based on the site investigations and pilot testing.

Table H: Summary of InSitu Technology Benefits and Uncertainties

In-Situ Technology	Benefits	Uncertainties/Challenges
Chemical Oxidation	› Can be targeted/injected directly into areas with PHC impacts; › Application can be completed easily/quickly with direct push technology; › Does not generate a waste stream; › Treatment is rapid (hours to days); and › No permanent infrastructure is required to complete the injections.	› Wide range in estimated mass of oxidant and number of applications to achieve potential target remedial levels; › Remediation of impacts more difficult at lower PHC concentrations or if remediation endpoint concentrations are low; and › Health and safety risks associated with the handling and injection of hydrogen peroxide require attention to safety protocols.
Surfactants	› Can be delivered through targeted well installations screened across specific determined zones of PHC impacts; and › Remediation progress can be monitored through analysis of recovered water samples rather than repeated drilling events.	› Will require significant volumes of groundwater to be pumped, treated, and reinjected on-site; › Potential of treatment equipment and piping freezing during winter months; › Requires separate dedicated power supply generator; › Frequent manpower necessary during treatment equipment operation to ensure uptime; › Requires piping to well heads from treatment system to be buried and frost protected; and › Is challenging to apply where groundwater

		cannot be recovered at a reasonable rate, or where the water table is discontinuous.

Chemical Oxidation

The objectives of the pilot test were met in establishing the proof of concept for peroxide injection using direct push technology. The test results indicate that the effects of hydrogen peroxide oxidation were measurable in adjacent monitoring wells following the injection of the mixture batch. These field measured parameters (DO, ORP, temperature) indicate an oxidation reaction occurred between the hydrogen peroxide and the aquifer soils in the vicinity of the target injection zone.

Estimating the costs for remediation requires understanding the mass of oxidant necessary to remediate the PHC and the well spacing for effective delivery of the oxidant material to the subsurface. The interpretation of the test results provided a better understanding of a suitable injection spacing necessary to deliver the required mass of oxidant to the subsurface. Injection spacing has a significant impact on the potential costs as tightly spaced points increase the remediation costs. Conversely, fewer injection points increases the duration of injection at each location as a greater volume is necessary to affect the target reaction zone. Based on the observations and measurements from the testing at both sites, theoretical calculations of injection volumes, and discussion with remediation contractors interpretation of the testing results suggests that a radius of influence of 2.5 m to 3.5 m may be suitable spacing for injection points at both maintenance camps. Soil hydrocarbon concentrations and vertical thickness would also influence the well spacing.

Determination of the mass of hydrogen peroxide necessary to reduce the PHC impacts by a specified amount requires the test to reach the target end point. This type of test consists of injecting several batches of hydrogen peroxide until no further reaction is measured. There are many variables that determine the mass of hydrogen peroxide required to affect remediation of a target mass of petroleum hydrocarbons (for example: contaminant type, naturally occurring oxygen demand in soil, iron and manganese in soil and groundwater, pH of groundwater, plume geometry, and soil permeability). Moreover, reduction in soil PHC impacts are not necessarily linearly proportional with the mass of hydrogen peroxide injected, with a decrease in oxidant efficiency expected as remediation progresses.

A high level estimate of the hydrogen peroxide mass required to achieve the target remediation can be made. For in situ hydrogen peroxide injection/treatment, vendors and injection contractors generally use an estimated mass ratio of 5 to 50 hydrogen peroxide (100% w/w):1 petroleum hydrocarbons. A greater ratio is used when conditions for oxidation are less favourable. An earlier bench scale test of soil samples from each maintenance camp indicated that the natural oxygen demand was neither exceptionally high nor low in any of the samples at either of the camp sites. Given that petroleum hydrocarbons at Muncho Lake and Fireside are longer chain hydrocarbons, sorbed to soil, have a high concentration, and are at a neutral pH it is roughly estimated that the required mass ratio for hydrogen peroxide to petroleum hydrocarbon is on the order of 50:1. The actual ratio may be higher or lower than this.

Assuming that average F2 ($>C_{10}$-C_{16}) concentrations of 3,800 µg/g are present in soil it is estimated (given a 50 hydrogen peroxide: 1 petroleum hydrocarbon ratio) that 380 kg of hydrogen peroxide is required for each cubic metre of petroleum hydrocarbon impacted soil to reduce the F2 ($>C_{10}$-C_{16}) concentration in soil to levels in accordance with CCME PHC CWS. Calculations and additional discussion with respect to these considerations are presented in Appendix VIII along with assumptions and sensitivities.

Assuming a remediation volume and the above considerations, the estimated cost for remediation would be on the order of for each site. This estimate assumes a cost of hydrogen peroxide of 50% m/m hydrogen peroxide and that application would be completed by a using direct push. Actual costs to complete remediation with hydrogen peroxide will depend on: the volume of impacts targeted for remediation; the ratio of hydrogen peroxide required to oxidize PHC impacts; the starting concentration of PHC impacts in soil; the endpoint concentration of PHCs required to achieve remediation; and the supply and delivery cost of hydrogen peroxide to the sites.

Surfactants

The objectives of the pilot test were largely met in establishing the proof of concept for surfactant application through injection wells. The analytical results from recovered groundwater at Muncho Lake indicate that the Task surfactant was effective in increasing the dissolved PHC mass for recovery. At Fireside however, only marginal increases in PHC concentrations were noted in recovered groundwater using the Iveysol 106 surfactant. Given the magnitude of soil PHC concentrations and the absence of measurable LNAPL in monitoring wells at the Site, the potential for mass removal with surfactant application may be limited. Field measurements and observations made suggested that limited recovery of the surfactant may have occurred which would bias dissolved PHC concentrations low in recovered groundwater, with preferential migration of the surfactant a potential cause leading to it not being readily recoverable during the extraction portion of the test. Therefore, it is possible that higher recovered dissolved PHC may be achieved through further evaluation.

Estimating the costs for remediation through surfactants is dependent on the recovered hydrocarbon mass per pore volumes of injected surfactant, which is calculated from the dissolved PHC concentration in recovered groundwater. Assuming that average F2 ($>C_{10}$-C_{16}) concentrations of 3,500 µg/g are present in soil and that dissolved phase concentrations from surfactant application at Muncho Lake are maintained at 8,700 µg/L for the duration, it would require in excess of 1,000 pore volumes to reduce soil hydrocarbon concentrations substantially, which is not considered to be practical. For Muncho Lake a surfactant enhanced pump and treat system would need to recover, treat, and re-inject recovered liquids at flowrates on the order of 1,000 to 2,000 L/min to achieve this. Installing, operating, and maintaining a surfactant enhanced pump and treat system capable of this is estimated to cost more than for . Assuming that surfactant will need to be applied for every pore volumes recovered it is estimated that surfactants will cost on the order of . Calculations and additional discussion related to the surfactant flushing are presented in Appendix IX.

5 Notice to Reader

This report has been prepared by SNC-Lavalin Inc. (SNC-Lavalin) for Canada, who has been party to the development of the scope of work for this project and understands its limitations. Copyright of this report vests with Her Majesty the Queen in Right of Canada. This report was prepared in accordance with a services contract between SNC-Lavalin and Canada, including General Conditions 2035 of the Standard Acquisition Clauses and Conditions (SACC) Manual.

This report is intended to provide information to Canada to assist it in making business decisions. SNC-Lavalin is not a party to the various considerations underlying the business decisions, and does not make recommendations regarding such business decisions.

The findings, conclusions and recommendations in this report have been developed in a manner consistent with the level of skill normally exercised by environmental professionals currently practising under similar conditions in the area. The findings contained in this report are based, in part, upon information provided by others. If any of the information is inaccurate, modifications to the findings, conclusions and recommendations may be necessary.

The findings, conclusions and recommendations presented by SNC-Lavalin in this report reflect SNC-Lavalin's best judgement based on the site conditions at the time of the site inspection on the date(s) set out in this report and on information available at the time of preparation of this report. They have been prepared for specific application to these sites and are based, in part, upon visual observation of the site, subsurface investigation at discrete locations and depths, and specific analysis of specific materials as described in this report during a specific time interval. Substances other than those described may exist within the site, reported substance parameters may exist in areas of the site not investigated, and concentrations of substances greater or less than those reported may exist between sample locations.

The findings and conclusions of this report are valid only as of the date of this report. If site conditions change, new information is discovered, or unexpected site conditions are encountered in future work, including excavations, borings, or other studies, the findings, conclusions and/or recommendations of this report should be re-evaluated. It is recommended that users of this report should engage a suitably qualified professional to assist in interpreting the significance, if any, of the findings.

Figures

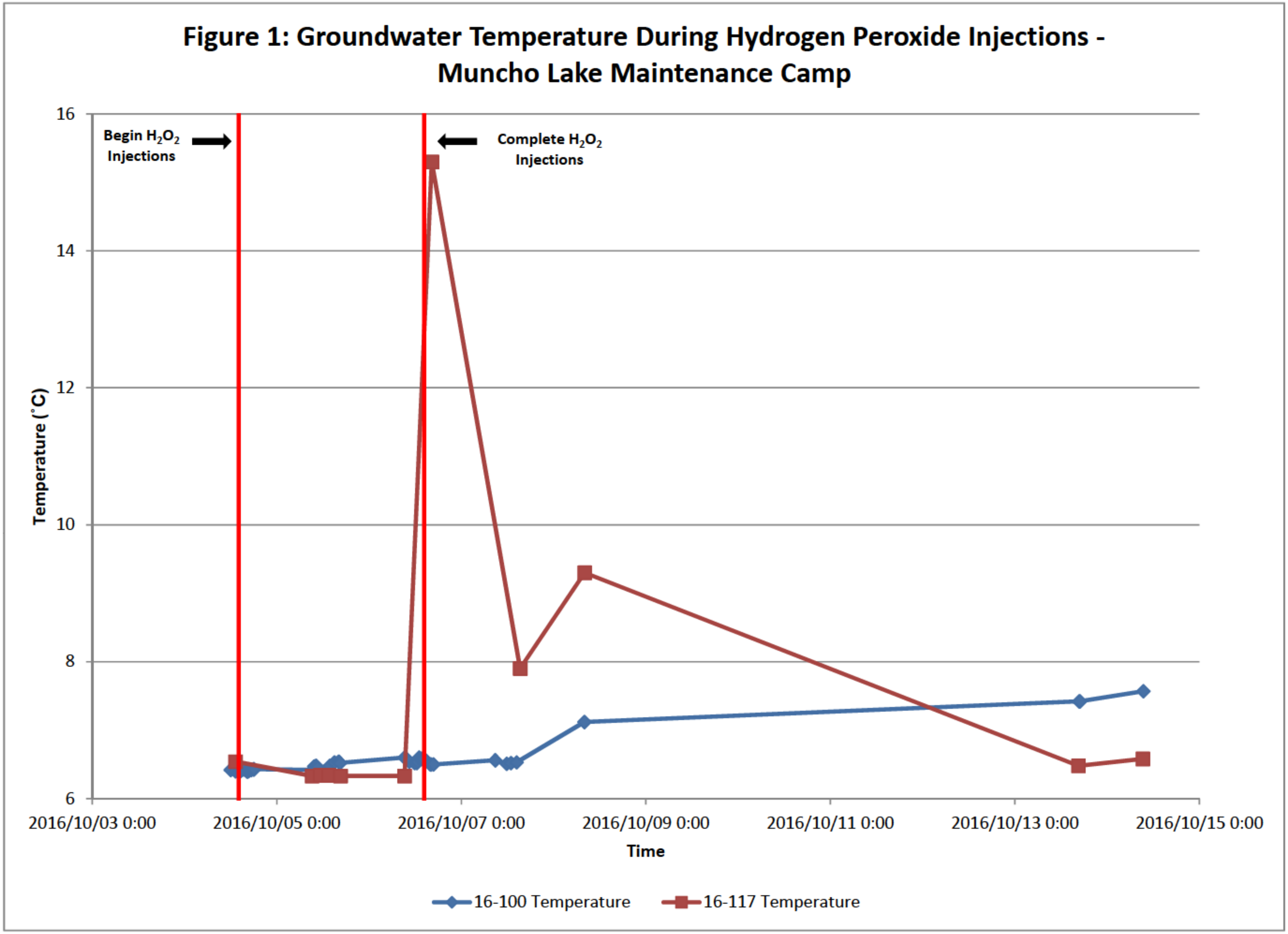


Figure 1: Groundwater Temperature During Hydrogen Peroxide Injections - Muncho Lake Maintenance Camp
Begin H_2O_2 Injections
Complete H_2O_2 Injections
Temperature (˚C)
16
14
12
10
8
6
2016/10/03 0:00
2016/10/05 0:00
2016/10/07 0:00
2016/10/09 0:00
2016/10/11 0:00
2016/10/13 0:00
2016/10/15 0:00
Time
16-100 Temperature
16-117 Temperature

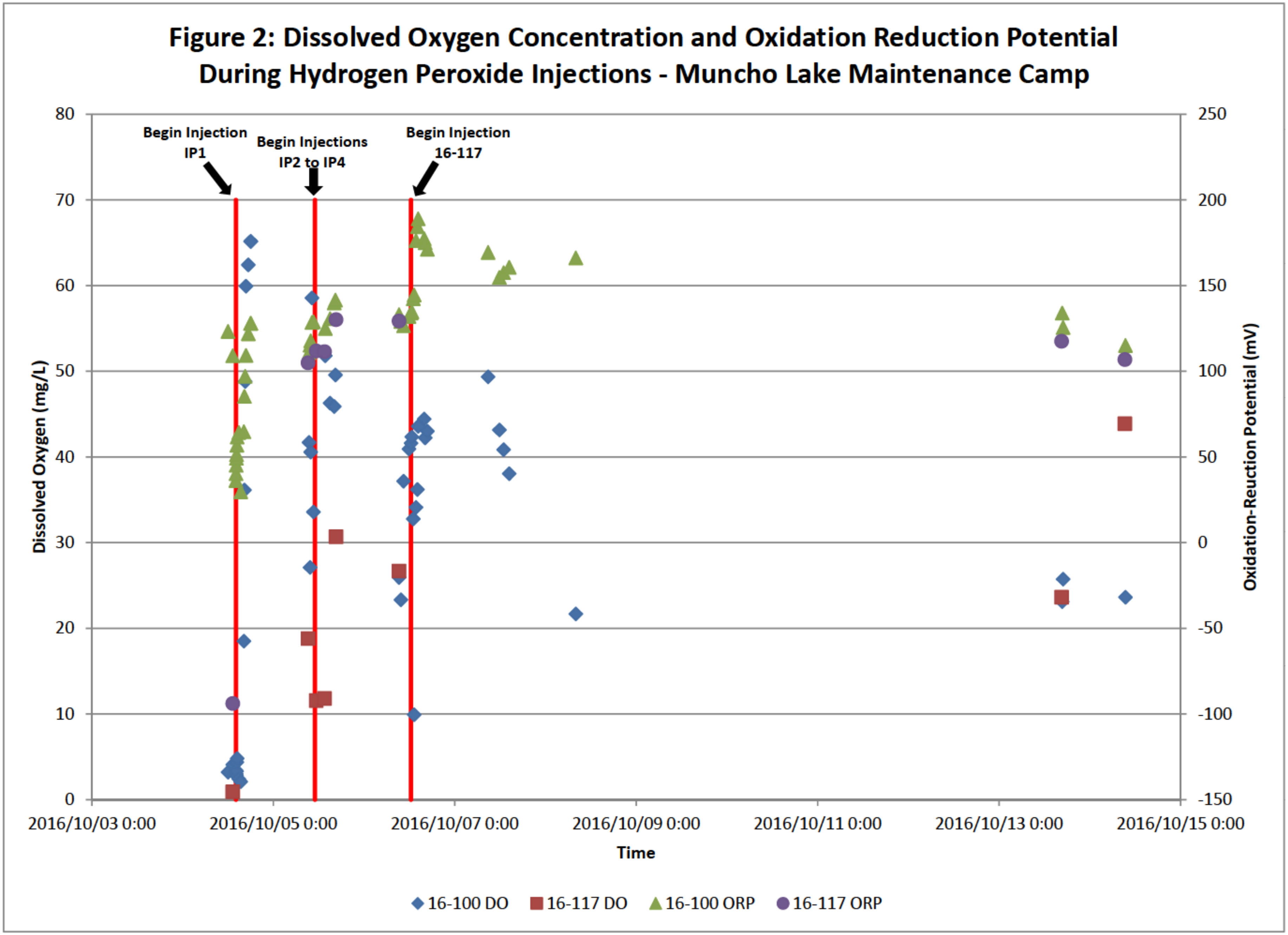
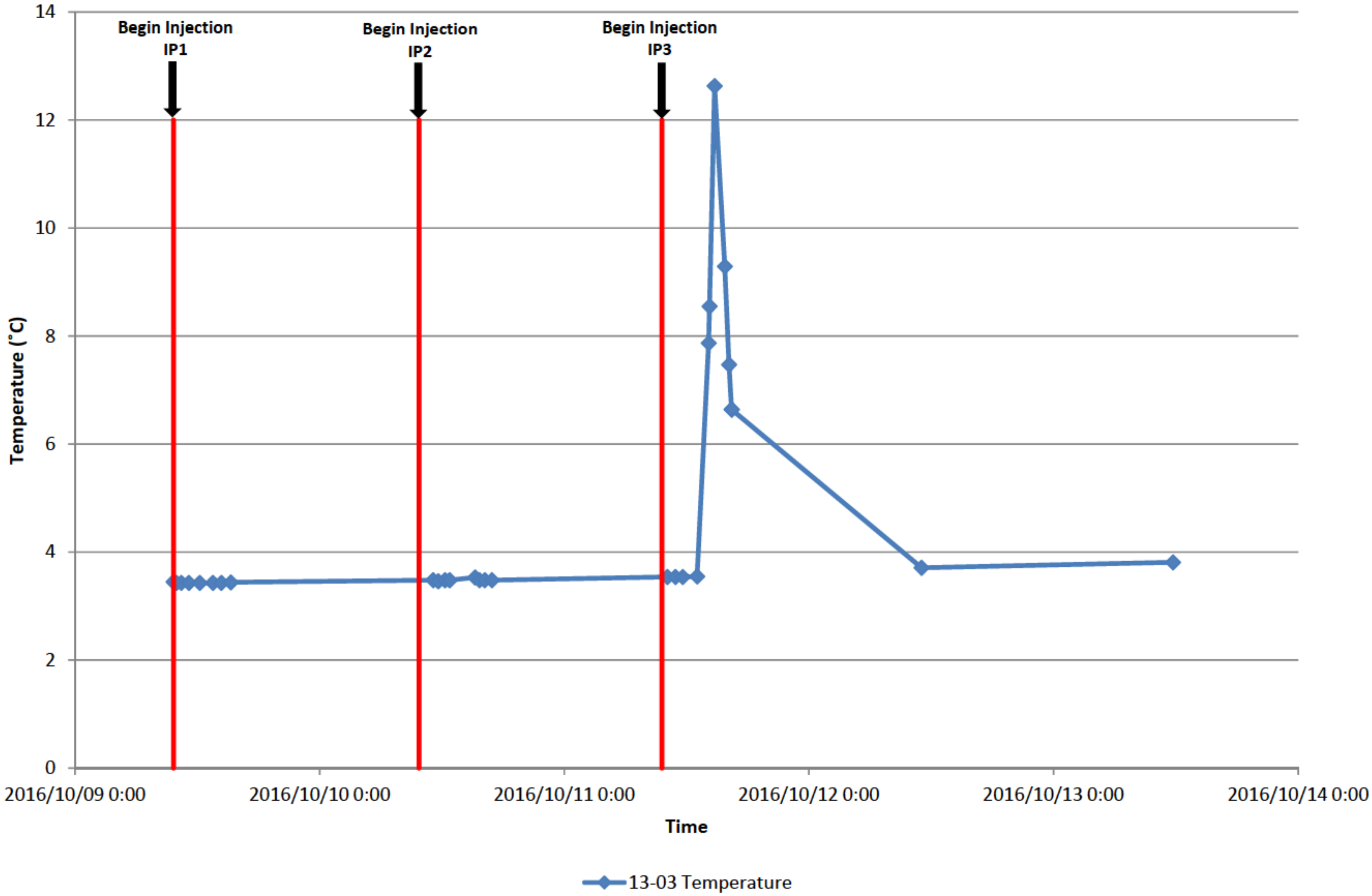


Figure 2: Dissolved Oxygen Concentration and Oxidation Reduction Potential
During Hydrogen Peroxide Injections - Muncho Lake Maintenance Camp
Begin Injection IP1
Begin Injections IP2 to IP4
Begin Injection 16-117
Dissolved Oxygen (mg/L)
Oxidation-Reuction Potential (mV)
80
70
60
50
40
30
20
10
0
250
200
150
100
50
0
-50
-100
-150
2016/10/03 0:00
2016/10/05 0:00
2016/10/07 0:00
2016/10/09 0:00
2016/10/11 0:00
2016/10/13 0:00
2016/10/15 0:00
Time
16-100 DO
16-117 DO
16-100 ORP
16-117 ORP

Figure 3: Groundwater Temperature During Hydrogen Peroxide Injections - Fireside Maintenance Camp



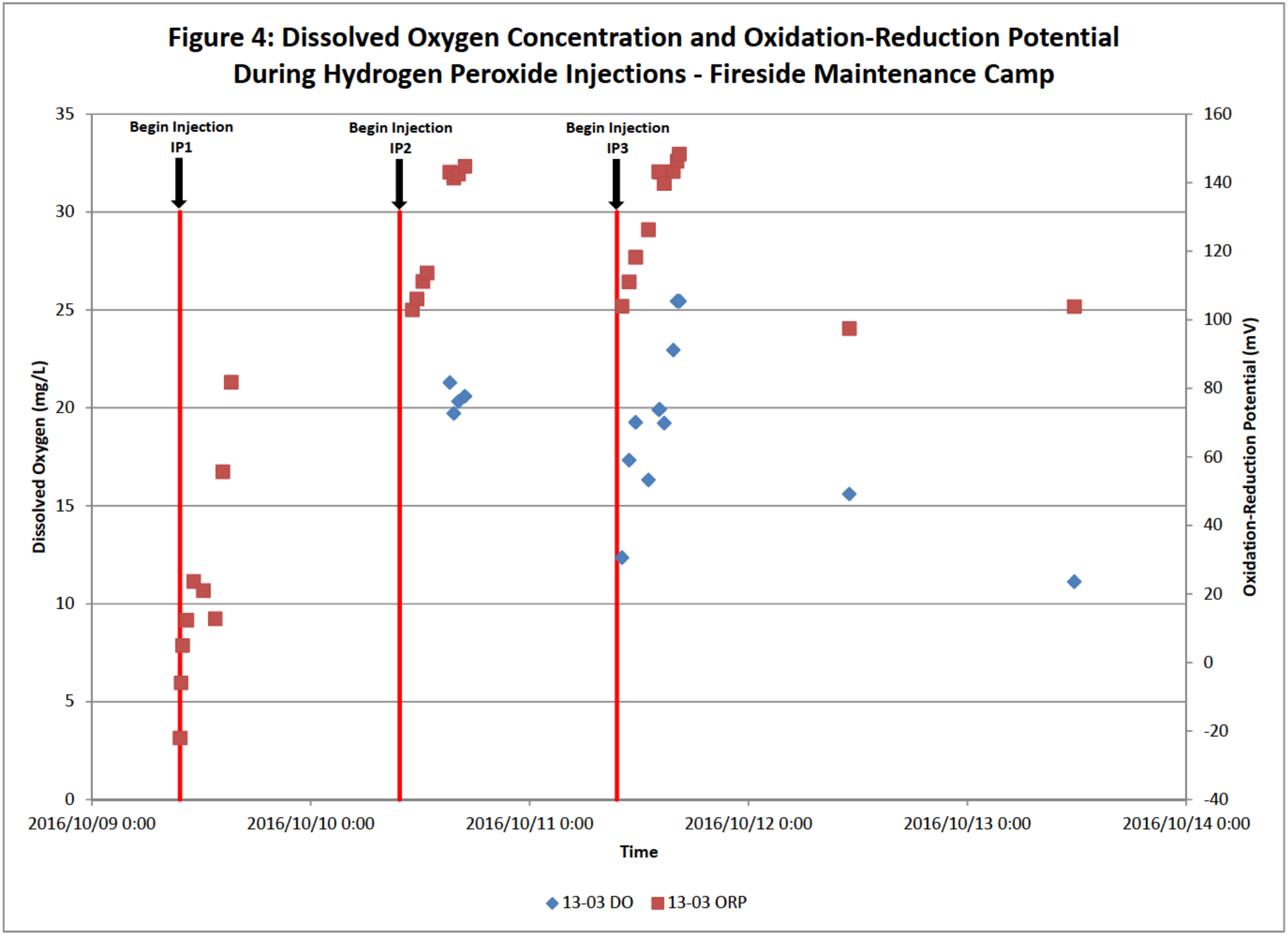


Figure 4: Dissolved Oxygen Concentration and Oxidation-Reduction Potential
During Hydrogen Peroxide Injections - Fireside Maintenance Camp
Begin Injection IP1
Begin Injection IP2
Begin Injection IP3
Dissolved Oxygen (mg/L)
Oxidation-Reduction Potential (mV)
35
30
25
20
15
10
5
0
160
140
120
100
80
60
40
20
0
-20
-40
2016/10/09 0:00
2016/10/10 0:00
2016/10/11 0:00
2016/10/12 0:00
2016/10/13 0:00
2016/10/14 0:00
Time
13-03 DO
13-03 ORP

Tables

Table 1: Muncho Lake Maintenance Camp – Summary of Analytical Results for Soil

Sample Location	Sample ID	Sample Date (yyyy mm dd)	Depth Interval (m)	Field Screen[a] (ppm)	Monocyclic Aromatic Hydrocarbons					Gross	Petroleum Hydrocarbon Fractions				MTBE
					Benzene µg/g	Ethylbenzen µg/g	Toluene µg/g	Xylenes µg/g	Styrene µg/g	VPH (C6-C10) µg/g	F1- µg/g	F2 (>C10-C16) µg/g	F3 (>C16-C34) µg/g	F4 (>C34-C50) µg/g	MTBE µg/g
BH16-116	BH16-116-01	2016 10 03	8.1 - 8.2	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	< 10	< 10	< 0.10
	BH16-116-02	2016 10 03	9.0 - 9.1	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	< 10	< 10	< 0.10
	BH16-116-03	2016 10 03	9.8 - 9.9	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	< 10	< 10	< 0.10
	BH16-116-04	2016 10 03	11.4 - 11.6	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	55	***57***	***3,300***	860	< 10	< 0.10
	BH16-116-05	2016 10 03	12.6 - 12.8	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	< 10	< 10	< 0.10
BH16-117	BH16-117-01	2016 10 04	9.4 - 9.6	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	16	< 10	< 0.10
	BH16-117-02	2016 10 04	10.2 - 10.4	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	46	***48***	***2,000***	860	< 10	< 0.10
	BH16-117-03	2016 10 04	11.0 - 11.1	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	19	22	***270***	120	< 10	< 0.10
	BH16-117-04	2016 10 04	12.2 - 12.3	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	22	25	***220***	110	< 10	< 0.10
BH16-119	BH16-119-01	2016 10 07	10.8 - 11.0	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	21	22	***890***	410	< 10	< 0.10
	BH16-119-02	2016 10 07	11.6 - 11.7	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	120	***130***	***2,300***	860	< 10	< 0.10
	BH16-119-03	Duplicate	11.6 - 11.7	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	100	***110***	***1,800***	710	< 10	< 0.10
	QA/QC RPD%				*	*	*	*	*	18	17	24	19	*	*
BH16-120	BH16-120-1	2016 10 13	9.4 - 9.6	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	< 10	< 10	< 10	< 10	< 10	< 0.10
	BH16-120-2	2016 10 13	10.2 - 10.4	-	< 0.0050	< 0.010	< 0.020	< 0.040	< 0.030	30	***31***	***2,700***	1,500	< 10	< 0.10
	BH16-120-3	2016 10 13	11.3 - 11.4	-	0.0080	< 0.010	< 0.020	< 0.040	< 0.030	22	23	***4,300***	1,700	< 20	< 0.10
Federal Guideline/Standard															
CCME CEQG/CWS Residential Coarse-Grained Surface (sample depth < 1.5m)[b]					0.03	0.082	0.1	11	5	n/a	30	150	300	2,800	n/a
CCME CEQG/CWS Residential Coarse-Grained Subsoil (sample depth > 1.5m)[b]					0.03	0.082	0.1	11	5	n/a	30	150	2,500	10,000	n/a
BC Standard															
CSR Residential Land Use (RL) (sample depth < 3.0m)[c]					0.04	1	1.5	5	5	200	n/a	n/a	n/a	n/a	320
CSR Commercial Land Use (CL) (sample depth > 3.0m)[c]					0.04	7	2.5	20	50	200	n/a	n/a	n/a	n/a	700

Associated Maxxam file(s): B690914, B692253.
All terms defined within the body of SNC-Lavalin's report.
< Denotes concentration less than indicated detection limit or RPD less than indicated value.
- Denotes analysis not conducted.
n/a Denotes no applicable standard/guideline.
RPD Denotes relative percent difference.
* RPDs are not calculated where one or more concentrations are less than five times RDL.
RDL Denotes reported detection limit.

BOLD Concentration greater han CCME CEQG/CWS Residential Land Use (RL) standard.

SHADOW Concentration greater han CSR Residen ial Land Use (RL) Standard (Commercial Land Use [CL] below 3.0 m).

[a] Field screening results are measured based on a 'dry headspace' method using a combustible gas meter calibrated to a hexane standard.
[b] Pathways: Contact (Direct/Eco), Management Limit, Protec ion of Groundwater for Aquatic Life, Vapour Inhalation, Protec ion of Potable Groundwater.
[c] The site-specific factors used for determining the matrix standards for this site include: intake of contaminated soil, groundwater used for drinking water, toxicity to soil invertebrates and plants, and groundwater flow to surface water used by freshwater aquatic life (whichever is most stringent).

Table 2: Muncho Lake Maintenance Camp - Hydrogen Peroxide Injection Results

Activity	Date	Time	Injection Location	Injection Concentration (% m/m)	Injection Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Temperature (Deg C)	Specific Conductance (mS/cm^c)	Conductivity (mS/cm)	TDS (g/L)	Salinity	Dissolved Oxygen (% Saturation)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	Observations/Notes
IP 1 start of advancement	2016/10/04	13:06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.25" injection rod used (MC5 system)
IP 1 completion	2016/10/04	13:14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Injection rod dr ven to 12.2 m- raised approximately 0.05 m
Pre-injection monitoring (baseline)	2016/10/04	12:00	-	-	-	-	-	16-100	6.42	-	0.203	-	-	-	3.22	7.48	123.3	-
Pre-injection monitoring (baseline)	2016/10/04	13:15	-	-	-	-	-	16-100	6.4	-	0.198	-	-	-	4.09	7.72	109.1	-
Pre-injection monitoring (baseline)	2016/10/04	13:15	-	-	-	-	-	16-117	6.54	-	0.608	-	-	-	0.93	11.72	-93.8	Post well construction and development
Pre-injection monitoring (baseline)	2016/10/04	14:05	-	-	-	-	-	16-100	6.39	-	0.203	-	-	-	4.35	8.81	36.3	-
Injection of 10% H_2O_2 at IP1 commenced	2016/10/04	14:06	IP1	~11.5%	0	-	-	-	-	-	-	-	-	-	-	-	-	Start of injection at IP1
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:07	IP1	~11.5%	-	-	-	16-100	6.39	-	0.202	-	-	-	3.43	8.62	40.3	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:10	IP1	~11.5%	0	6.7	10	16-100	6.39	-	0.202	-	-	-	3.02	8.51	45.2	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:13	IP1	~11.5%	40.5	10	24	16-100	6.39	-	0.202	-	-	-	2.82	8.42	49.3	2 RV pumps used for injection
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:15	IP1	~11.5%	-	-	-	16-100	6.39	-	0.202	-	-	-	3.32	8.41	51.4	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:16	IP1	~11.5%	-	-	-	-	-	-	-	-	-	-	-	-	-	Bubbling/bypass around IP1 at surface
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:19	IP1	~11.5%	87.5	7.73	24	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:20	IP1	~11.5%	-	-	-	16-100	6.4	-	0.202	-	-	-	4.39	8.33	56.9	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:25	IP1	~11.5%	-	-	-	16-100	6.42	-	0.201	-	-	-	4.82	8.27	61.7	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:28	IP1	~11.5%	162.9	7.77	24	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:42	IP1	~11.5%	267.6	8.04	30	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	14:52	IP1	~11.5%	-	-	-	16-100	6.42	-	0.2	-	-	-	2.42	8.1	64.3	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	15:08	IP1	~11.5%	485.7	8	30	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	15:22	IP1	~11.5%	-	-	-	16-100	6.43	-	0.2	-	-	-	2.12	8	29.7	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	15:32	IP1	~11.5%	663.7	7.32	22	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	15:43	IP1	~11.5%	742.6	13.2	4	-	-	-	-	-	-	-	-	-	-	Raised injection rod to 12.0 m (i.e. by 0.15 m)
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:11	IP1	~11.5%	1106.7	13.6	4	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:12	IP1	~11.5%	-	-	-	16-100	6.4	0.296	0.191	0.192	0.14	152.7	18.51	7.92	64.8	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:20	IP1	~11.5%	-	-	-	16-100	6.4	0.293	-	-	0.14	293.3	36.15	7.87	85.4	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:31	IP1	~11.5%	-	-	-	16-100	6.4	0.291	-	-	0.14	396.8	48.82	7.83	97.1	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:45	IP1	~11.5%	1452.8	12.1	4	16-100	6.41	0.285	0.184	-	0.14	486.2	59.94	7.76	109.3	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	16:56	IP1	~11.5%	1582	12.3	2	16-100	-	-	-	-	-	-	-	-	-	Raised injection rod to 11.85 m (i.e. by 0.15 m)
Injection of 11.5% H_2O_2 at IP1	2016/10/04	17:22	IP1	~11.5%	1923	13	0	16-100	6.42	0.285	0.184	0.186	0.14	507.1	62.43	7.68	121.9	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	17:31	IP1	~11.5%	1999	21.2	10	16-100	-	-	-	-	-	-	-	-	-	Swapped 3/4" injection hose for 1" injection hose
Injection of 11.5% H_2O_2 at IP1	2016/10/04	18:00	IP1	~11.5%	2590	22.4	8	16-100	6.43	0.293	0.189	0.191	0.14	529.7	65.17	7.64	128	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	18:00	IP1	~11.5%	2590	22.4	8	16-100	6.43	0.293	0.189	0.191	0.14	529.7	65.17	7.64	128	-
Injection of 11.5% H_2O_2 at IP1	2016/10/04	18:00	IP1	~11.5%	2618	22.4	8	16-100	-	-	-	-	-	-	-	-	-	Injection stopped
IP2 advancement	2016/10/05	9:00	IP2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Injection rod (2.25") dr ven to 12.3 m at IP2.
Monitoring at MW 16-117	2016/10/05	9:10	-	-	-	-	-	16-117	6.33	-	0.183	-	-	-	18.82	8.02	105	-
Injection of 11.5% H_2O_2 at IP1	2016/10/05	9:26	IP1	~11.5%	2618	20	16	16-100	6.42	0.315	0.203	0.205	0.15	339.4	41.71	7.88	110.9	Injection restarted
Injection of 11.5% H_2O_2 at IP1	2016/10/05	9:42	IP1	~11.5%	2951.9	20.5	16	16-100	6.47	0.322	0.208	0.209	0.15	220.8	27.12	7.76	115.3	-
Injection of 11.5% H_2O_2 at IP1	2016/10/05	9:52	IP1	~11.5%	3129.9	13.2	10	16-100	6.47	0.327	0.211	0.212	0.16	329.9	40.58	7.71	117.8	2 RV pumps used for injection
Injection of 11.5% H_2O_2 at IP1	2016/10/05	10:12	IP1	~11.5%	3399.5	13.5	8	16-100	6.48	0.329	0.212	0.214	0.16	479	58.57	7.57	128.5	-
Injection of 10% H_2O_2 at IP1	2016/10/05	10:36	IP1	~11.5%	3440.3	13.5	-	16-100	6.45	0.314	0.203	0.204	0.15	274.2	33.59	7.73	128.9	Injection at IP1 ended
Injection of VTX at IP2	2016/10/05	11:00	IP2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Injection/application of 40L VTX mixed with 120L H_2O at IP2 after raising IP2 to 12.15 m. Unable to inject VTX via submersible or drum pump. Proceeded to pour VTX solution down injection tubing.

Table 2 (Cont'd): Muncho Lake Maintenance Camp - Hydrogen Peroxide Injection Results

Activity	Date	Time	Injection Location	Injection Concentration (% m/m)	Injection Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Temperature (Deg C)	Specific Conductance (mS/cm^c)	Conductivity (mS/cm)	TDS (g/L)	Salinity	Dissolved Oxygen (% Saturation)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	Observations/Notes
Post development monitoring at 16-117	2016/10/05	11:19	-	-	-	-	-	16-117	6.34	0.288	0.185	0.187	0.14	93.8	11.58	8.13	111.9	-
Injection of 11.5% H2O2 at IP2	2016/10/05	12:57	IP2	~11.5%	0	6.3	48	-	-	-	-	-	-	-	-	-	-	Injection into IP2 post VTX application noted to be at slow rate and high pressure.
Injection of 11.5% H2O2 at IP2	2016/10/05	13:31	IP2	~11.5%	103	2.5	35-50	16-117	6.34	0.288	0.185	0.187	0.14	96	11.83	8.11	111.5	-
Injection of 11.5% H2O2 at IP2 ended	2016/10/05	13:40	IP2	~11.5%	177	4.3	-	-	-	-	-	-	-	-	-	-	-	Raised injection rod to 12.0 m (i.e. by 0.15 m) - did not notice significant increase in flow or decrease in pressure. Stopped injections at IP2.
Monitoring post injection at IP2	2016/10/05	13:44	IP2	-	-	-	-	16-100	6.48	0.34	0.22	0.221	0.16	417.9	51.82	7.84	125	-
Installation of IP3 approximately 1.0 m SSE of IP2 and injection of 11.5% H2O2	2016/10/05	13:50	IP3	~11.5%	0	21	10	-	-	-	-	-	-	-	-	-	-	Injection at IP3 noted to be completed at similar flow rate and pressure as IP1.
Injection of 11.5% H2O2 at IP3 ended	2016/10/05	14:30	IP3	~11.5%	900	21	10	-	-	-	-	-	-	-	-	-	-	Injection ended
Installation of IP4 approximately 0.15 m W of IP2 and injection of 11.5% H2O2	2016/10/05	14:39	IP4	~11.5%	0	22.1	10	-	-	-	-	-	-	-	-	-	-	IP4 injection rod advanced to 12.2 m and raised to 12.05 m before commencing with H2O2 injection.
Injection of 11.5% H2O2 at IP4	2016/10/05	14:59	IP4	~11.5%	440	22	10	16-100	6.53	0.329	0.213	0.14	0.16	376.8	46.29	7.83	130.7	No residual pressure observed in IP2 and IP3 which remained in place during injection at IP4
Injection of 11.5% H2O2 at IP4	2016/10/05	16:06	IP4	~11.5%	1596	22	10	16-100	6.54	0.32	0.211	0.212	0.16	374	45.9	7.68	139.9	Bubbling/gurgling heard at 16-117
Injection of 11.5% H2O2 at IP4 ended	2016/10/05	16:25	IP4	~11.5%	2071	-	-	16-100	6.52	0.338	0.218	0.219	0.16	403.3	49.58	7.66	141.6	Completed injection at 1P4
Monitoring post injection at IP4	2016/10/05	16:34	-	-	-	-	-	16-117	6.33	0.279	0.18	0.183	0.13	248.9	30.7	7.98	130.2	-
Post injection monitoring at MW16-117 (following day)	2016/10/06	9:14	-	-	-	-	-	16-117	6.33	0.284	0.183	0.184	0.14	216.6	26.69	8.17	129.4	-
Post injection monitoring at MW16-100 (following day)	2016/10/06	9:14	-	-	-	-	-	16-100	6.6	0.328	0.213	0.213	0.16	212.1	25.94	7.9	133.1	-
Injection of 11.5% H2O2 at MW16-117	2016/10/06	9:20	MW16-117	~11.5%	0	18.8	16	-	-	-	-	-	-	-	-	-	-	During removal of IP2 liquids (11.5% peroxide) were noted to come out when breaking the rods suggesting IP2 was plugged. Following the removal of the last rod it was noted the bottom rod was plugged with sand/fines. This was considered the cause of difficulty with injecting VTX and H2O2 at this location.
Injection of 11.5% H2O2 at MW16-117	2016/10/06	9:34	MW16-117	~11.5%	255	14.7	8	-	-	-	-	-	-	-	-	-	-	-
Injection of 11.5% H2O2 at MW16-117 ended	2016/10/06	9:44	MW16-117	~11.5%	304	-	-	16-100	6.58	0.328	0.213	0.214	0.16	190.8	23.34	7.77	129.1	Injection of 11.5% H2O2 at MW16-117 ended.
Continued monitoring at MW16-100	2016/10/06	10:26	-	-	-	-	-	16-100	6.54	0.312	0.202	0.203	0.15	302.8	37.18	7.88	126.6	-
Continued monitoring at MW16-100	2016/10/06	11:52	-	-	-	-	-	16-100	6.52	0.295	0.191	0.192	0.14	339.4	40.94	7.92	132	-
Injection of 20% H2O2 at MW16-117	2016/10/06	12:25	MW16-117	~20%	0	8.4	4	16-100	6.52	0.291	0.188	0.189	0.14	339.1	41.62	7.93	134	Started injection of 20% H2O2 at MW16-117. Low flow noted l kely associated with pump issue as injection pressure noted to remain low.
Injection of 20% H2O2 at MW16-117	2016/10/06	12:37	MW16-117	~20%	120.2	14.3	10	16-100	6.54	0.29	0.188	0.189	0.14	345.2	42.35	7.93	134.8	Continued to troubleshoot low flow associated with pump issues.
Injection of 20% H2O2 at MW16-117	2016/10/06	13:00	MW16-117	~20%	470	14.8	10	16-100	6.6	0.302	0.196	0.197	0.14	268.1	32.78	7.84	142.4	Continued to troubleshoot low flow associated with pump issues. Was able to increase flow to 21 L/min.
Injection of 20% H2O2 at MW16-117	2016/10/06	13:14	MW16-117	~20%	661.7	20.9	20	16-100	6.59	0.313	0.203	0.203	0.15	81.4	9.93	7.76	144.6	-
Injection of 20% H2O2 at MW16-117	2016/10/06	13:43	MW16-117	~20%	1205.3	20.5	18	16-100	6.58	0.329	0.213	0.213	-	274.8	34.13	7.79	176.3	-
Injection of 20% H2O2 at MW16-117	2016/10/06	14:06	MW16-117	~20%	1701.8	20.7	18	16-100	6.59	0.327	0.212	0.212	0.16	294.8	36.21	7.76	184.4	-

Table 2 (Cont'd): Muncho Lake Maintenance Camp - Hydrogen Peroxide Injection Results

Activity	Date	Time	Injection Location	Injection Concentration (% m/m)	Injection Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Temperature (Deg C)	Specific Conductance (mS/cm^c)	Conductivity (mS/cm)	TDS (g/L)	Salinity	Dissolved Oxygen (% Saturation)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	Observations/Notes
Injection of 20% H2O2 at MW16-117 ended	2016/10/06	14:18	MW16-117	~20%	1833.2	-	-	16-100	6.58	0.327	0.212	0.212	0.16	355.6	43.58	7.83	189	Injection of 20% H2O2 at MW16-117 ended.
Continued monitoring at MW16-100	2016/10/06	15:54	-	-	-	-	-	16-100	6.5	0.294	0.19	0.191	0.14	362	44.44	7.92	177.4	-
Continued monitoring at MW16-100	2016/10/06	16:09	-	-	-	-	-	16-100	6.5	0.292	0.189	0.19	0.14	343.9	42.24	7.93	175	-
Post injection monitoring at MW16-117	2016/10/06	16:19	-	-	-	-	-	16-117	15.3	-	-	-	-	-	-	6.52	-	Temperature collected from purge water
Continued monitoring at MW16-100	2016/10/06	16:44	-	-	-	-	-	16-100	6.5	0.289	0.187	0.188	0.14	350.2	43.02	7.93	171.3	-
Continued monitoring at MW16-100	2016/10/07	8:48	-	-	-	-	-	16-100	6.56	0.29	0.188	0.189	0.14	401.5	49.36	8.19	169.4	-
Continued monitoring at MW16-100	2016/10/07	11:47	-	-	-	-	-	16-100	6.51	0.285	0.186	0.186	0.14	351.6	43.16	7.97	154.8	-
Continued monitoring at MW16-100	2016/10/07	12:54	-	-	-	-	-	16-100	6.52	0.286	0.185	0.186	0.14	332.8	40.86	7.97	157.6	-
Continued monitoring at MW16-100	2016/10/07	14:23	-	-	-	-	-	16-100	6.53	0.286	0.185	0.186	0.14	310.2	38.06	7.97	160.7	-
Post injection monitoring at MW16-117	2016/10/07	15:18	-	-	-	-	-	16-117	7.9	-	-	-	-	-	-	-	-	Temperature collected from purge water
Continued monitoring at MW16-100	2016/10/08	8:00	-	-	-	-	-	16-100	7.12	-	0.195	-	-		21.69	8.09	166.2	Temperature appeared to be stratified. 7.12 Deg C ~ middle of screen. 6.8-6.9 Deg C at base of screen.
Continued monitoring at MW16-117	2016/10/08	8:05	-	-	-	-	-	16-117	9.3	-	-	-	-	-	-	7.71	-	Temperature collected from purge water
Continued monitoring at MW16-117	2016/10/13	16:30	-	-	-	-	-	16-117	6.48	-	0.184	-	-	-	23.65	8.05	117.6	-
Continued monitoring at MW16-100	2016/10/13	16:40	-	-	-	-	-	16-100	7.42	-	0.208	-	-		23.12	7.7	134	-
Continued monitoring at MW16-100	2016/10/13	16:54	-	-	-	-	-	16-100	7.42	-	0.201	-	-		25.75	7.42	125.6	-
Continued monitoring at MW16-117	2016/10/14	9:15	-	-	-	-	-	16-117	6.58	-	0.182	-	-	-	43.89	7.93	106.9	-
Continued monitoring at MW16-100	2016/10/14	9:24	-	-	-	-	-	16-100	7.57	0.336	0.224	0.218	0.16	197.6	23.64	7.67	115.1	-
Monitoring at MW16-116	2016/10/14	9:40	-	-	-	-	-	16-116	6.57	0.287	0.186	0.187	0.14	83.4	10.21	8.19	99	-

Table 3: Muncho Lake Maintenance Camp – Pump Test Results

Activity	Date	Time	Test Time (s)	Test Time (min)	Pumping Location	Pump Rate (GPM)	Pump Rate (L/min)	Pumped Volume (G)	Pumped Volume (L)	Monitoring Location	Depth to Water (m)	Drawdown (m)	Observations/Notes
Monitoring Static Conditions	2016/10/06	10:35	-	-	-	-	-	-	-	MW 16-116	8.324	-	Pump well MW 16-116
Monitoring Static Conditions	2016/10/06	9:08	-	-	-	-	-	-	-	MW 16-102	8.15	-	Deep observation well MW 16-102. Logger G1875 deployed at 9:24 at approximately 10.6 m depth.
Monitoring Static Conditions	2016/10/06	9:12	-	-	-	-	-	-	-	MW 16-118	8.356	-	Shallow observation well MW 16-118. Logger C8737 deployed at 9:36 at approximately 9.8 m depth.
Pump Test	2016/10/06	10:35	19	0.32	MW 16-116	3.5	13.25	1.11	4.20	-	-	-	Start of pump test - first attempt
Pump Test	2016/10/06	10:35	40	0.67	MW 16-116	4.9	18.55	2.82	10.69	MW 16-116	8.35	0.026	-
Pump Test	2016/10/06	10:37	120	2	MW 16-116	4.9	18.55	9.36	35.41	MW 16-116	8.36	0.036	-
Pump Test	2016/10/06	10:42	420	7	MW 16-116	0	0	33.86	128.15	MW 16-116	8.324	0	Pump off - recovery to static in PW. Re-start test at 10:44
Pump Test	2016/10/06	10:44	30	0.5	MW 16-116	5.33	20.17	2.67	10.09	MW 16-116	8.363	0.039	Start of pump test - second attempt
Pump Test	2016/10/06	10:45	60	1	MW 16-116	5.33	20.17	5.33	20.17	MW 16-116	8.366	0.042	-
Pump Test	2016/10/06	10:45	90	1.5	MW 16-116	6	22.71	8.33	31.53	MW 16-116	8.368	0.044	-
Pump Test	2016/10/06	10:46	120	2	MW 16-116	6.21	23.50	11.44	43.28	MW 16-116	8.368	0.044	-
Pump Test	2016/10/06	10:48	240	4	MW 16-116	6.21	23.50	23.86	90.29	MW 16-116	8.37	0.046	-
Pump Test	2016/10/06	10:55	660	11	MW 16-116	0	0	67.33	254.83	MW 16-116	8.324	0	Pump off - recovery to static in PW. Re-start test at 10:55
Pump Test	2016/10/06	10:55	20	0.33	MW 16-116	5.33	20.17	1.78	6.72	MW 16-116	8.356	0.032	Start of pump test - third attempt
Pump Test	2016/10/06	10:58	180	3	MW 16-116	0	0	15.99	60.52	MW 16-116	8.324	0	Pump off - recovery to static in PW. Re-start test at 10:58
Pump Test	2016/10/06	10:58	20	0.33	MW 16-116	5.43	20.55	1.81	6.85	MW 16-116	8.358	0.034	Start of pump test - final attempt
Pump Test	2016/10/06	10:59	40	0.67	MW 16-116	5.43	20.55	3.62	13.70	MW 16-116	8.365	0.041	-
Pump Test	2016/10/06	11:00	90	1.5	MW 16-116	6.14	23.24	8.74	33.07	MW 16-116	8.368	0.044	-
Pump Test	2016/10/06	11:00	105	1.75	MW 16-116	6.2	23.47	10.29	38.94	MW 16-116	8.368	0.044	-
Pump Test	2016/10/06	11:03	300	5	MW 16-116	6.2	23.47	30.44	115.20	MW 16-116	8.368	0.044	-
Pump Test	2016/10/06	11:07	495	8.25	MW 16-116	6.2	23.47	50.59	191.47	MW 16-118	8.361	0.005	-
Pump Test	2016/10/06	11:09	630	10.5	MW 16-116	6.2	23.47	64.54	244.27	MW 16-102	8.162	0.012	-
Pump Test	2016/10/06	11:23	1500	25	MW 16-116	6.2	23.47	154.44	584.54	MW 16-102	8.165	0.015	-
Pump Test	2016/10/06	11:28	1770	29.5	MW 16-116	6.2	23.47	182.34	690.14	MW 16-118	8.362	0.006	-
Pump Test	2016/10/06	11:41	2526	42.1	MW 16-116	6.2	23.47	260.46	985.83	MW 16-116	-	-	End of pump test/start of recovery test
Recovery Test	2016/10/06	11:43	2670	44.5	MW 16-116	0	0	260.46	985.83	MW 16-118	8.36	0.004	-
Recovery Test	2016/10/06	11:46	2820	47	MW 16-116	0	0	260.46	985.83	MW 16-102	8.152	0.002	-
Recovery Test	2016/10/06	11:54	3345	55.75	MW16-116	0	0	260.46	985.83	MW 16-116	8.326	0.002	-
Recovery Test	2016/10/06	12:11	4320	72	MW16-116	0	0	260.46	985.83	MW 16-116	8.326	0.002	-
Recovery Test	2016/10/06	12:13	4500	75	MW16-116	0	0	260.46	985.83	MW 16-118	8.36	0.004	-
Recovery Test	2016/10/06	12:15	4620	77	MW16-116	0	0	260.46	985.83	MW 16-102	8.152	0.002	-

Table 4: Muncho Lake Maintenance Camp - Surfactant Application Results

Activity	Date	Time	Injection/ Pumping Location	Injection Concentration	Injection/ Pumped Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Depth to Water (m)	TDS (ppm)	pH	Observations/Notes
Pre-injection monitoring (baseline)	2016/10/06	9:08	-	-	-	-	-	16-102	8.15	-	-	-
Pre-injection monitoring (baseline)	2016/10/06	9:10	-	-	-	-	-	16-116	8.324	250	9.1	-
Pre-injection monitoring (baseline)	2016/10/06	9:12	-	-	-	-	-	16-118	8.356	-	-	-
Mixing and injection of Task and KOH (postassium hydroxide) - Batch 1 Start	2016/10/06	13:24	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	0	11.1	4	-	-	-	-	Batch prepared for injection in 16-116. Mixture based on Mark Hasegawa's recommendations following bench scale testing. Surfactant solution had TDS of 20,000 ppm and pH of 13.2
Injection of Task and KOH (postassium hydroxide) - Batch 1	2016/10/06	13:43	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	304	17	0	-	-	-	-	-
Monitoring of 16-118	2016/10/06	13:51	16-116	-	-	-	-	16-118	8.355	-	-	Clear - no odour
Injection of Task and KOH (postassium hydroxide) - Batch 1	2016/10/06	14:19	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	891	16.9	0	16-118	-	120	-	16-118 was noted to be turbid/brown due to disturbance
End of injection Batch 1 of Task and KOH (postassium hydroxide)	2016/10/06	14:35	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	1329	-	-	-	-	-	-	-
Monitoring of 16-102	2016/10/06	14:35	16-116	-	-	-	-	16-102	-	~1150	12.75	16-102 was purged and noted to be bubbly with strong surfactant odour. TDS was diluted 3x as out of range.
Monitoring of 16-102	2016/10/06	15:06	16-116	-	-	-	-	16-102	-	~1950	12	Based on monitoring at 16-102 Mark Hasegawa estimated 16-102 had 1/6th initial TDS injection concentration at 16-116. TDS was diluted 3x as out of range.
Mixing and injection of Task and KOH (postassium hydroxide) - Batch 2 Start	2016/10/06	15:55	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	1329	23.8	16	-	-	-	-	Different pump used for injection into 16-102 (hence higher injection rate)
Monitoring of 16-118	2016/10/06	15:58	16-116	-	-	-	-	16-118	-	160	9	-
Monitoring of 16-102	2016/10/06	15:58	16-116	-	-	-	-	16-102	-	-	13	-
Monitoring of 16-102	2016/10/06	16:30	16-116	-	-	-	-	16-102	-	~2250	-	Based on monitoring at 16-102 Mark Hasegawa estimated 16-102 had 25% of initial injection concentration at 16-116. TDS was diluted 3x as out of range.
End of injection Batch 2 of Task and KOH (postassium hydroxide)	2016/10/06	16:40	16-116	~1350 L H_2O: 40 L Task: 10 kg KOH: 30 L 7% Acetic Acid	2702	-	-	-	-	-	-	End of surfactant injection at 16-116
Monitoring of 16-118	2016/10/06	17:00	-	-	-	-	-	16-118	-	180	9	-
Monitoring of 16-102	2016/10/06	17:00	-	-	-	-	-	16-102	-	2200	12.8	-
Pre-pump (pull) test monitoring (baseline)	2016/10/07	8:45	-	-	-	-	-	16-118	8.391	-	-	No product detected
Pre-pump (pull) test monitoring (baseline)	2016/10/07	8:47	-	-	-	-	-	16-116	8.354	-	-	No product detected
Pre-pump (pull) test monitoring (baseline)	2016/10/07	8:49	-	-	-	-	-	16-102	8.182	141	8.8	No product detected
Start of pump (pull) test. Pump from 16-102	2016/10/07	8:50	16-102	-	0	22.74	-	16-102	-	180	9.8	Pumping started at 16-102 based on recommendation from Mark Hasegawa
Monitoring of 16-116	2016/10/07	8:50	16-102	-	-	-	-	16-116	-	250	10.2	-
Monitoring of 16-102	2016/10/07	9:15	16-102	-	-	-	-	16-102	-	220	10.2	-
End of pump (pull) test from 16-102	2016/10/07	9:38	16-102	-	432	-	-	-	-	-	-	Sample collected
Start of pump (pull) test. Pump from 16-116	2016/10/07	9:46	16-116	-	0	22.5	-	-	-	-	-	Discharge from 16-116 quite foamy, no free oil observed
Monitoring of 16-102	2016/10/07	9:56	16-116	-	-	-	-	16-116	-	350	11.2	-
Continued pumping (pull) test from 16-116	2016/10/07	9:59	16-116	-	311	-	-	-	-	-	-	Sample collected
Monitoring of 16-116	2016/10/07	10:05	16-116	-	-	-	-	16-116	-	260	10.6	-
Monitoring of 16-118	2016/10/07	10:05	16-116	-	-	-	-	16-118	-	151	8.9	-
Continued pumping (pull) test from 16-116	2016/10/07	10:21	16-116	-	731	-	-	-	-	-	-	Sample collected
Continued pumping (pull) test from 16-116	2016/10/07	10:36	16-116	-	1056	23.1	-	-	-	-	-	Sample collected
Monitoring of 16-116	2016/10/07	10:38	16-116	-	-	-	-	16-116	-	204	10.3	-
Continued pumping (pull) test from 16-116	2016/10/07	11:07	16-116	-	1698	-	-	-	-	-	-	Sample collected
Monitoring of 16-116	2016/10/07	11:23	16-116	-	-	-	-	16-116	-	195	10.3	-
Monitoring of 16-116	2016/10/07	11:36	16-116	-	-	-	-	16-116	-	199	8.98	pH on other meter was 10.39
Monitoring of 16-118	2016/10/07	11:45	16-116	-	-	-	-	16-118	-	137	8.9	-
Continued pumping (pull) test from 16-116	2016/10/07	11:47	16-116	-	2611	23.3	-	-	-	-	-	Foam evident in pumped water - no free oil evident
Monitoring of 16-102	2016/10/07	11:52	16-116	-	-	-	-	16-102	-	148	8.75	pH on other meter was 10.36. Bubbles in water
Continued pumping (pull) test from 16-116	2016/10/07	12:15	16-116	-	3123	-	-	-	-	-	-	Sample collected
Continued pumping (pull) test from 16-116	2016/10/07	12:54	16-116	-	4036	23.1	-	-	-	-	-	Suds still evident in pumped water
Monitoring of 16-116	2016/10/07	12:57	16-116	-	-	-	-	16-116	-	166	9	-
Monitoring of 16-116	2016/10/07	13:32	16-116	-	-	-	-	16-116	-	162	9.1	-
Monitoring of 16-118	2016/10/07	13:35	16-116	-	-	-	-	16-118	-	137	8.78	-
Monitoring of 16-102	2016/10/07	13:37	16-116	-	-	-	-	16-102	-	144	8.78	-
Continued pumping (pull) test from 16-116	2016/10/07	13:46	16-116	-	4961	-	-	-	-	-	-	Suds still evident in pumped water, sample collected
Ended pumping (pull) test from 16-116	2016/10/07	13:49	16-116	-	5253	-	-	-	-	-	-	Push test ended
Energetics pumped out open top tank	2016/10/08	7:55	-	-	-	-	-	-	-	-	-	Approximately 6.5 m^3 removed from tank.

Table 5: Muncho Lake Maintenance Camp – Summary of Analytical Results for Groundwater – Surfactant Application

Sample Location	Sample ID	Sample Date (yyyy mm dd)	Monocyclic Aromatic Hydrocarbons: Benzene µg/L	Ethylbenzene µg/L	Toluene µg/L	Xylenes µg/L	Styrene µg/L	Gross Parameters: VH (C6-C10) µg/L	VPH (C6-C10) µg/L	Petroleum Hydrocarbon Fractions: F1- µg/L	F2 (>C10-C16) µg/L	F3 (>C16-C34) µg/L	F4 (>C34-C50) µg/L	MTBE: MTBE µg/L
MW16-102	MW16-102-161007-1	2016 10 07	< 0.40	< 0.40	< 0.40	1.4	< 0.40	< 300	< 300	< 300	***2,000***	< 200	< 200	< 4.0
MW16-116	MW16-116-161006INITIAL	2016 10 06	< 0.40	< 0.40	< 0.40	< 0.40	< 0.40	< 300	< 300	< 300	< 150	< 200	< 200	< 4.0
	MW16-116-161007-1	2016 10 07	< 0.40	< 0.40	0.44	6.2	< 0.40	340	330	330	***8,700***	550	< 200	< 4.0
	MW16-116-161007-2	2016 10 07	< 0.40	< 0.40	< 0.40	5.1	< 0.40	< 300	< 300	< 300	***7,900***	1,000	< 200	< 4.0
	MW16-116-161007-3	2016 10 07	< 0.40	< 0.40	< 0.40	3.6	< 0.40	< 300	< 300	< 300	***5,000***	610	< 200	< 4.0
	MW16-116-161007-4	2016 10 07	< 0.40	< 0.40	< 0.40	2.8	< 0.40	< 300	< 300	< 300	***3,300***	210	< 200	< 4.0
	MW16-116-161007-5	2016 10 07	< 0.40	< 0.40	< 0.40	1.4	< 0.40	< 300	< 300	< 300	***2,100***	< 200	< 200	< 4.0
Federal Guideline														
Canadian Drinking Water Quality Guidelines (CDWQG)			5	1.6	24	20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15
FGQG Tier 2 Residential Land Use (RL)[a]			140	16,000	83	3,900	72	n/a	n/a	810	1,300	n/a	n/a	340
BC Standard														
CSR Drinking Water (DW)			5	2.4	24	300	n/a	15,000[c]	n/a	n/a	n/a	n/a	n/a	15
CSR Aquatic Life (AW)[b]			4,000	2,000	390	n/a	720	15,000[c]	1,500	n/a	n/a	n/a	n/a	34,000

Associated Maxxam file(s): B690914.
All terms defined within the body of SNC-Lavalin's report.
< Denotes concentration less than indicated detection limit or RPD less than indicated value.
\- Denotes analysis not conducted.
n/a Denotes no applicable standard/guideline.
RPD Denotes relative percent difference.
* RPDs are not calculated where one or more concentrations are less than five times RDL.
RDL Denotes reported detection limit.

SHADED	Concentration greater than Canadian Drinking Water Quality Guidelines (CDWQG) Guideline
BOLD	Concentration greater than FGQG Tier 2 Residential Land Use (RL) Guideline
OUTLINE	Concentration greater than CSR Drinking Water (DW) standard
SHADOW	Concentration greater than CSR Aquatic Life (AW) standard

[a] Pathways Included: Freshwater Aquatic Life - Coarse, Inhalation - Coarse, Soil Organisms Direct Contact - Coarse (whichever is most stringent).
[b] Standard to protect freshwater aquatic life.
[c] Applicable at all sites irrespective of water use.

Table 6: Fireside Maintenance Camp - Hydrogen Peroxide Injection Results

Activity	Date	Time	Injection Location	Injection Concentration (%m/m)	Injection Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Depth to Water (m)	Temperature (Deg C)	Specific Conductance (mS/cm^c)	Conductivity (mS/cm)	TDS (g/L)	Salinity	Dissolved Oxygen (% Saturation)	Dissolved Oxygen (mg/L)	pH	ORP	Observations/Notes
IP 1 start of advancement	2016/10/09	8:30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.25" injection rod used (MC5 system). Injection rod driven to 29.3 m - raised to 29 m.
Pre-injection monitoring (baseline)	2016/10/09	9:40	-	-	-	-	-	13-03	29.02	3.45	1.262	0.742	0.821	0.63	4.4	0.57	7.42	-22	Probe set at depth of ~30 m.
Injection of 11.5% H2O2 at IP1 commenced	2016/10/09	9:40	IP1	~11.5%	0	22.6	18	-		-	-	-	-	-	-	-	-	-	-
Monitoring at 13-03	2016/10/09	9:47	IP1	~11.5%	-	-	-	13-03	-	3.43	1.261	0.741	0.819	0.63	1.4	0.18	7.43	-5.9	-
Monitoring at 13-03	2016/10/09	9:57	IP1	~11.5%	-	-	-	13-03	-	3.43	1.26	0.741	0.819	0.63	1	0.14	7.42	5	-
Injection of 11.5% H2O2 at IP1	2016/10/09	10:00	IP1	~11.5%	340	18	24	-	-	-	-	-	-	-	-	-	-	-	Some bypass noted at ground surface. Tightened rods but limited flow still noted.
IP2 advancement start	2016/10/09	10:04	IP1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monitoring at 13-03, Injection of 11.5% H2O2 at IP1	2016/10/09	10:25	IP1	~11.5%	782	15.5	38	13-03	-	3.43	1.258	0.74	0.818	0.62	0.6	0.08	7.4	12.4	-
IP2 advancement end	2016/10/09	10:28	IP1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.25" injection rod used (MC5 system). Injection rod driven to 29 m
Monitoring at 13-03, Injection of 11.5% H2O2 at IP1	2016/10/09	11:10	IP1	~11.5%	1451	15.1	-	13-03	-	3.43	-	0.738	-	-	-	0.05	7.39	23.7	Bypass continued to be noted
Monitoring at 13-03, Injection of 11.5% H2O2 at IP1	2016/10/09	12:14	IP1	~11.5%	2266	14.2	38	13-03	-	3.43	1.253	0.737	0.814	0.62	0.4	0.05	7.39	21	Bypass continued to be noted
Monitoring at 13-03, Injection of 11.5% H2O2 at IP1	2016/10/09	13:32	IP1	~11.5%	2824	13.4	23	13-03	-	3.43	1.251	0.736	0.813	0.62	0.3	0.04	7.39	12.8	Bypass continued to be noted
Injection of 11.5% H2O2 at IP1 ended	2016/10/09	14:00	IP1	~11.5%	3333	-	-	-	-	-	-	-	-	-	-	-	-	-	End of peroxide injection at IP1
Monitoring at 13-03	2016/10/09	14:21	-	-	-	-	-	13-03	-	3.43	1.241	0.73	0.807	0.62	2.8	0.37	7.42	55.7	-
Monitoring at 13-03	2016/10/09	15:17	-	-	-	-	-	13-03	-	3.44	0.661	0.389	0.436	0.32	3.6	0.47	7.42	81.8	-
IP2 depth adjustment	2016/10/10	9:30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.25" injection rod used (MC5 system). Injection rod driven to 29.3 and - raised to 29 m.
Injection of 200 L VTX at IP2 commenced	2016/10/10	9:45	IP2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200 L of VTX solution (160 L water mixed with 40 L VTX) injected using submersible pump pumping from bucket
Injection of 11.5% H2O2 at IP2 commenced	2016/10/10	10:50	IP2	~11.5%	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monitoring at 13-03	2016/10/10	11:08	IP2	-	-	-	-	13-03	-	3.48	-	0.723	-	-	-	0.14	7.46	102.9	-
Injection of 11.5% H2O2 at IP2	2016/10/10	11:28	IP2	~11.5%	608	26.2	8	-	-	-	-	-	-	-	-	-	-	-	No bypass noted
Monitoring at 13-03	2016/10/10	11:38	IP2	-	-	-	-	13-03	-	3.46	-	0.726	-	-	-	0.11	7.46	106.1	-
Monitoring at 13-03	2016/10/10	12:18	IP2	-	-	-	-	13-03	-	3.48	-	0.717	-	-	-	0.13	7.45	111.2	-
Monitoring at 13-03	2016/10/10	12:45	IP2	-	-	-	-	13-03	-	3.48	-	0.71	-	-	-	0.15	7.46	113.7	-
Injection of 11.5% H2O2 at IP2 ended	2016/10/10	15:00	IP2	~11.5%	3485	26.2	-	-	-	-	-	-	-	-	-	-	-	-	-
Monitoring at 13-03	2016/10/10	15:15	-	-	-	-	-	13-03	-	3.53	-	0.703	-	-	-	21.3	7.14	143.1	DO probe reconditioned and recalibrated after readings were noted to out of the expected range and after the sensor when calibrated was noted to be out of range.
Monitoring at 13-03	2016/10/10	15:41	-	-	-	-	-	13-03	-	3.48	-	0.696	-	-	-	19.73	7.21	141.4	-
Monitoring at 13-03	2016/10/10	16:12	-	-	-	-	-	13-03	-	3.48	-	0.694	-	-	-	20.34	7.21	142.6	-
Monitoring at 13-03	2016/10/10	16:54	-	-	-	-	-	13-03	-	3.48	-	0.695	-	-	-	20.6	7.21	144.8	-
IP3 advancement	2016/10/11	9:15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.25" injection rod used (MC5 system). Injection rod driven to 29.3 and - raised to 29 m.
Injection of 20% H2O2 at IP3 commenced	2016/10/11	9:35	IP3	~20%	0	18.4	24	-	-	-	-	-	-	-	-	-	-	-	-
Injection of 20% H2O2 at IP3	2016/10/11	9:52	IP3	~20%	408	18.6	18	-	-	-	-	-	-	-	-	-	-	-	-
Monitoring at 13-03	2016/10/11	10:07	IP3	-	-	-	-	13-03	-	3.54	-	0.72	-	-	-	12.36	7.26	104	-
Monitoring at 13-03	2016/10/11	10:54	IP3	-	-	-	-	13-03	-	3.54	-	0.717	-	-	-	17.34	7.22	111.1	-
Injection of 20% H2O2 at IP3 ended	2016/10/11	11:16	IP3	~20%	1798	-	-	-	-	-	-	-	-	-	-	-	-	-	Injection ended - limited bypass noted towards end of injection
Monitoring at 13-03	2016/10/11	11:37	-	-	-	-	-	13-03	-	3.54	-	0.707	-	-	-	19.27	7.21	118.3	-
Monitoring at 13-03	2016/10/11	13:02	-	-	-	-	-	13-03	-	3.55	-	0.689	-	-	-	16.33	7.22	126.3	-
Monitoring at 13-03	2016/10/11	14:10	-	-	-	-	-	13-03	-	7.87	-	0.768	-	-	-	19.91	7.24	143.3	-
Monitoring at 13-03	2016/10/11	14:15	-	-	-	-	-	13-03	-	8.55	-	0.78	-	-	-	19.94	7.24	143.1	-
Monitoring at 13-03	2016/10/11	14:45	-	-	-	-	-	13-03	-	12.63	-	0.895	-	-	-	19.23	7.22	139.8	-
Monitoring at 13-03	2016/10/11	15:45	-	-	-	-	-	13-03	-	9.29	-	0.818	-	-	-	22.96	7.25	143.3	-
Monitoring at 13-03	2016/10/11	16:10	-	-	-	-	-	13-03	-	7.47	-	0.768	-	-	-	25.46	7.25	146.3	-
Monitoring at 13-03	2016/10/11	16:25	-	-	-	-	-	13-03	-	6.64	-	0.745	-	-	-	25.46	7.25	148.4	-
Monitoring at 13-03	2016/10/12	11:03	-	-	-	-	-	13-03	-	3.71	-	0.715	-	-	-	15.61	7.28	97.5	-
Monitoring at 13-03	2016/10/13	11:43	-	-	-	-	-	13-03	-	3.81	-	0.713	-	-	-	11.13	7.28	103.9	-

Table 7: Fireside Maintenance Camp – Pump Test Results

Activity	Date	Time	Test Time (s)	Test Time (min)	Pumping Location	Pump Rate (GPM)	Pump Rate (L/min)	Pumped Volume (G)	Pumped Volume (L)	Monitoring Location	Depth to Water (m)	Drawdown (m)	Observations/Notes
Monitoring Static Conditions	2016/10/09	11:40	-	-	-	-	-	-	-	MW 13-06	31.855	-	Pump well MW 13-06
Monitoring Static Conditions	2016/10/09	11:33	-	-	-	-	-	-	-	MW 14-10	32.41	-	Deep observation well MW 14-10. Logger G1875 deployed at 11:31 at approximately 33.5 m depth.
Monitoring Static Conditions	2016/10/09	11:20	-	-	-	-	-	-	-	MW 16-38	31.646	-	Shallow observation well MW 16-38. Logger C8737 deployed at 10:57 at approximately 32.5 m depth.
Pump Test	2016/10/09	11:43	0	0	MW 13-06	4.5	17.03	-	-	-	-	-	Beginning of pump test
Pump Test	2016/10/09	11:54	670	11.17	MW 13-06	4.5	17.03	50.25	190.20	MW 13-06	33.259	1.404	-
Pump Test	2016/10/09	11:55	735	12.25	MW 13-06	4.73	17.90	55.37	209.59	MW 13-06	33.265	1.41	-
Pump Test	2016/10/09	11:57	810	13.5	MW 13-06	4.73	17.90	61.29	231.97	MW 13-06	33.282	1.427	-
Pump Test	2016/10/09	12:04	1260	21	MW 13-06	4.75	17.98	96.91	366.81	MW 13-06	33.315	1.46	-
Pump Test	2016/10/09	12:07	1425	23.75	MW 13-06	4.75	17.98	109.97	416.25	MW 16-38	31.725	0.079	-
Pump Test	2016/10/09	12:11	1620	27	MW 13-06	4.75	17.98	125.41	474.68	MW 14-10	32.419	0.009	-
Pump Test	2016/10/09	12:13	1800	30	MW 13-06	0	0	139.66	528.62	-	-	-	Pump sputtered and shut off
Pump Test	2016/10/09	12:15	1920	32	MW 13-06	4.39	16.62	148.44	561.85	-	-	-	Pump re-started
Pump Test	2016/10/09	12:22	2340	39	MW 13-06	4.39	16.62	179.17	678.16	MW 13-06	33.155	1.3	-
Pump Test	2016/10/09	12:33	3000	50	MW 13-06	4.39	16.62	227.46	860.94	MW 13-06	33.2	1.345	-
Pump Test	2016/10/09	12:43	3540	59	MW 13-06	4.42	16.73	267.24	1011.51	MW 13-06	33.217	1.362	-
Pump Test	2016/10/09	13:16	5580	93	MW 13-06	4.42	16.73	417.52	1580.32	MW 13-06	33.273	1.418	-
Pump Test	2016/10/09	13:32	5940	99	MW 13-06	4.42	16.73	444.04	1680.70	MW 13-06	33.31	1.455	-
Pump Test	2016/10/09	13:42	7140	119	MW 13-06	4.39	16.62	531.84	2013.02	MW 13-06	33.3	1.445	-
Pump Test	2016/10/09	13:45	7320	122	MW 13-06	4.39	16.62	545.01	2062.87	MW 13-06	33.3	1.445	-
Pump Test	2016/10/09	13:49	7560	126	MW 13-06	4.39	16.62	562.57	2129.33	MW 16-38	31.765	0.119	Steady state in PW
Pump Test	2016/10/09	13:52	7740	129	MW 13-06	4.39	16.62	575.74	2179.18	MW 14-10	32.419	0.009	Steady state in PW
Pump Test	2016/10/09	13:54	7800	130	MW 13-06	4.39	16.62	580.13	2195.80	MW 13-06	33.3	1.445	Steady state in PW
Pump Test	2016/10/09	13:54	7800	130	MW 13-06	0	0	580.13	2195.80	-	-	-	End of pump test/start of recovery test
Recovery Test	2016/10/09	14:02	8265	137.75	MW 13-06	0	0	580.13	2195.80	MW 13-06	31.999	0.144	-
Recovery Test	2016/10/09	14:03	8301	138.35	MW 13-06	0	0	580.13	2195.80	MW 13-06	31.997	0.142	-
Recovery Test	2016/10/09	14:05	8520	142	MW 13-06	0	0	580.13	2195.80	MW 16-38	31.71	0.064	-
Recovery Test	2016/10/09	15:42	14340	239	MW 13-06	0	0	580.13	2195.80	MW 16-38	31.666	0.02	-
Recovery Test	2016/10/09	15:47	14640	244	MW 13-06	0	0	580.13	2195.80	MW 14-10	32.413	0.003	-

Table 8: Fireside Maintenance Camp - Surfactant Application Results

Activity	Date	Time	Injection/ Pumping Location	Injection Concentration	Injection/ Pumped Volume (L)	Injection Flowrate (L/min)	Injection Pressure (PSI)	Monitoring Location	Depth to Water (m)	Conductivity (mS/cm)	Temperature (Deg C)	pH	Observations/Notes
Mixing and injection of Iveysol 106 and water - Batch 1 Start	2016/10/10	15:45	16-38	~1000 L H_2O: 20 L Iveysol 106	0	6	~30	-	-	-	-	-	Surfactant batch mixed in accordance with Iveysol's recommendation (1 x 20 L pail with 1,000 L H_2O).
Mixing and injection of Iveysol 106 and water - Batch 1 Ended	2016/10/10	18:20	16-38	~1000 L H_2O: 20 L Iveysol 106	1081	8	~30	-	-	-	-	-	Injection into 16-38 noted to require relatively high pressure to achieve flow (30 psi for 6-8 L/min)
Pump (pull) test from 13-06 commenced	2016/10/11	9:44	13-06	-	0	16.2	-	-	-	-	-	-	Pumping reduced to 14.1 then increased to 15.9 within 5 minutes after start. Initial water appeared clear and had bubbles and slight surfactant odor when pumped
Pump (pull) test from 13-06	2016/10/11	9:49	13-06	-	-	-	-	13-06	-	-	-	-	High miniscus observed on waterproof paper as per Iveysol recommendation for monitoring for the presence of Iveysol. High miniscus suggests low surfactant concentration
Pump (pull) test from 13-06	2016/10/11	9:53	13-06	-	254	15.9	-	13-06	-	-	-	-	1st sample collected. High miniscus observed.
Pump (pull) test from 13-06	2016/10/11	10:05	13-06	-	462	15.9	-	13-06	-	1.3	3.9	7.42	High miniscus observed.
Pump (pull) test from 13-06	2016/10/11	10:30	13-06	-	-	-	-	13-06	-	1.3	4.6	7.26	High miniscus observed.
Pump (pull) test from 13-06	2016/10/11	10:38	13-06	-	-	-	-	13-06	-	-	-	-	2nd sample collected.
Pump (pull) test from 13-06	2016/10/11	10:47	13-06	-	-	-	-	13-06	-	-	-	-	High miniscus observed. Suds observed in pumped groundwater
Pump (pull) test from 13-06	2016/10/11	11:30	13-06	-	1838	15.9	-	13-06	-	-	-	-	High miniscus observed. Suds observed in pumped groundwater
Pump (pull) test from 13-06	2016/10/11	11:44	13-06	-	-	-	-	13-06	-	-	-	-	3rd sample collected. Sample included 1 L plastic bottle for surfactant analysis
Pump (pull) test from 13-06	2016/10/11	12:03	13-06	-	-	-	-	13-06	-	-	-	-	High miniscus observed.
Pump (pull) test from 13-06	2016/10/11	12:40	13-06	-	-	-	-	16-38	-	-	-	-	Sample collected form 16-38. Sample had suds and high miniscus observed.
Pump (pull) test from 13-06	2016/10/11	12:50	13-06	-	-	-	-	13-06	-	-	-	-	4th sample collected.
Pump (pull) test from 13-06 ended	2016/10/11	14:38	13-06	-	4798	-	-	13-06	-	-	-	-	5th sample collected. Less suds observed in pumped water. High miniscus observed.
Energetics pumped out open top tank	2016/10/11	16:00	-	-	-	-	-	-	-	-	-	-	Approximately 7 m^3 removed from tank.

Table 9: Fireside Maintenance Camp - Summary of Analytical Results for Groundwater - Surfactant Application

Sample Location	Sample ID	Sample Date (yyyy mm dd)	Monocyclic Aromatic Hydrocarbons					Gross Parameters		Petroleum Hydrocarbon Fractions				MTBE	MBAS
			Benzene µg/L	Ethylbenzen µg/L	Toluene µg/L	Xylenes µg/L	Styrene µg/L	VH (C6-C10) µg/L	VPH (C6-C10) µg/L	F1- µg/L	F2 (>C10-C16) µg/L	F3 (>C16-C34) µg/L	F4 (>C34-C50) µg/L	MTBE µg/L	MBAS[d] µg/L
BH13-06	MW13-06-161009	2016 10 09	< 0.40	< 0.40	< 0.40	< 0.40	< 0.40	< 300	< 300	< 300	630	< 200	< 200	< 4.0	-
	MW13-06-161011-1	2016 10 11	< 0.40	< 0.40	< 0.40	< 0.40	< 0.40	< 300	< 300	< 300	830	< 200	< 200	< 4.0	-
	MW13-06-161011-2	2016 10 11	< 0.40	< 0.40	< 0.40	0.47	< 0.40	< 300	< 300	< 300	710	< 200	< 200	< 4.0	-
	MW13-06-161011-3	2016 10 11	< 0.40	< 0.40	< 0.40	2.2	< 0.40	< 300	< 300	< 300	670	< 200	< 200	< 4.0	< 50
	MW13-06-161011-4	2016 10 11	< 0.40	< 0.40	< 0.40	2.1	< 0.40	< 300	< 300	< 300	700	< 200	< 200	< 4.0	-
	MW13-06-161011-5	2016 10 11	< 0.40	< 0.40	< 0.40	0.53	< 0.40	< 300	< 300	< 300	860	< 200	< 200	< 4.0	-
	MW13-06-161121	2016 11 21	< 0.40	< 0.40	< 0.40	< 0.40	< 0.40	< 300	< 300	< 300	730	250	< 200	< 4.0	-
IW16-38	MW16-38-161011	2016 10 11	0.40	**2.1**	1.9	**50**	< 0.40	1,500	1,400	***1,500***	***2,300***	600	< 200	< 4.0	-
	MW16-38-161027/28	2016 10 27/28	< 0.40	0.96	1.1	**27**	< 0.40	670	640	670	***3,200***	1,500	< 200	< 4.0	
Federal Guideline															
Canadian Drinking Water Quality Guidelines (CDWQG)			5	1.6	24	20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15	n/a
FGQG Tier 2 Residential Land Use (RL)[a]			140	16,000	83	3,900	72	n/a	n/a	810	1,300	n/a	n/a	340	n/a
BC Standard															
CSR Drinking Water (DW)			5	2.4	24	300	n/a	15,000[c]	n/a	n/a	n/a	n/a	n/a	15	n/a
CSR Aquatic Life (AW)[b]			4,000	2,000	390	n/a	720	15,000[c]	1,500	n/a	n/a	n/a	n/a	34,000	n/a

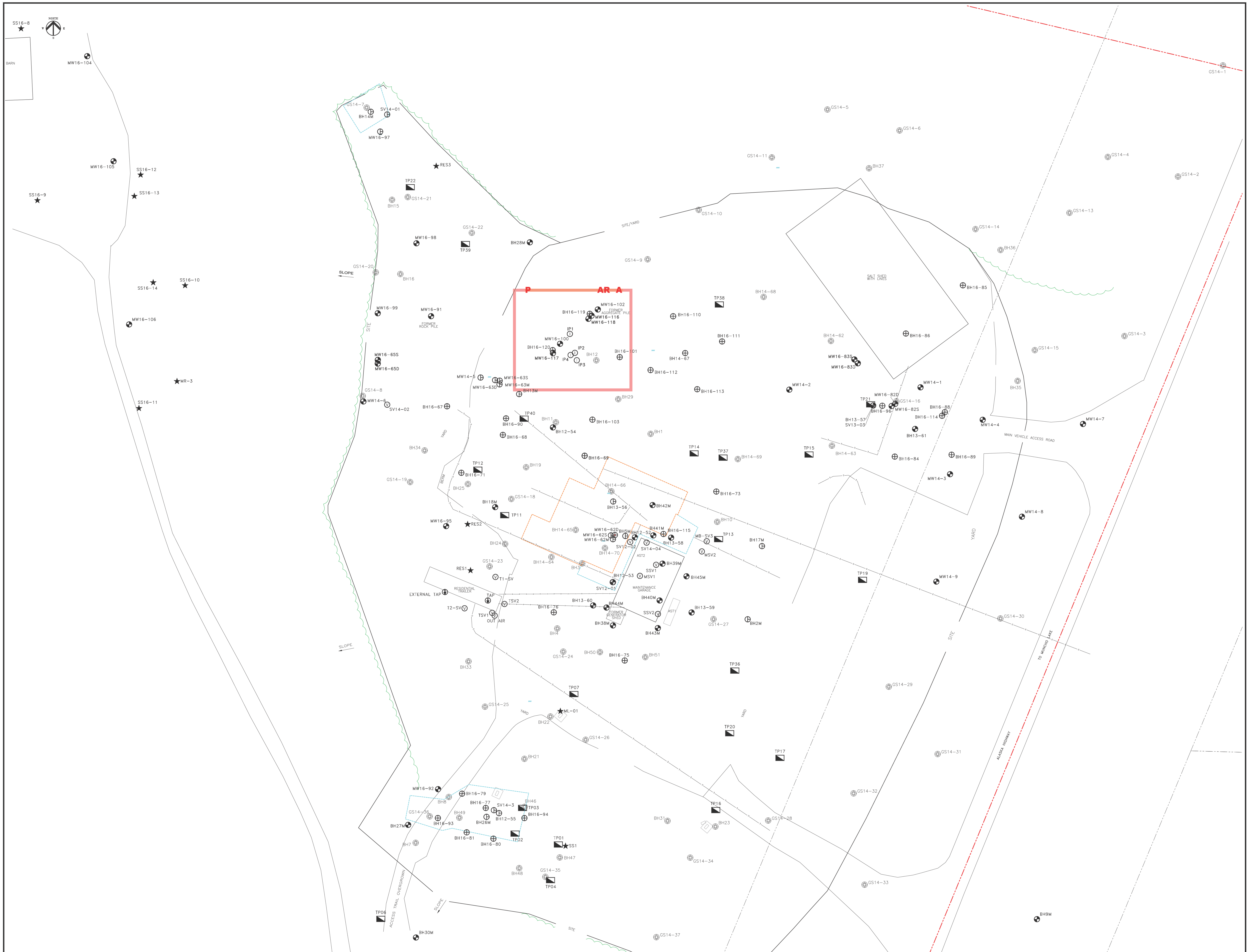
Associated Maxxam file(s): B690897, B696711, B6A5716.
All terms defined within the body of SNC-Lavalin's report.
< Denotes concentration less than indicated detection limit or RPD less than indicated value.
- Denotes analysis not conducted.
n/a Denotes no applicable standard/guideline.
RPD Denotes relative percent difference.
* RPDs are not calculated where one or more concentrations are less than five times RDL.
RDL Denotes reported detection limit.

SHADED	Concentration greater than Canadian Drinking Water Quality Guidelines (CDWQG) Guideline
BOLD	Concentration greater than FGQG Tier 2 Residential Land Use (RL) Guideline
OUTLINE	Concentration greater than CSR Drinking Water (DW) standard
SHADOW	Concentration greater than CSR Aquatic Life (AW) standard

[a] Pathways Included: Freshwater Aquatic Life - Coarse, Inhalation - Coarse, Soil Organisms Direct Contact - Coarse (whichever is most stringent).
[b] Standard to protect freshwater aquatic life.
[c] Applicable at all sites irrespective of water use.
[d] Methylene Blue Active Surfactants.

Drawings

- 635031-801 – Site Plan – Muncho Lake
- 635031-802 – Site Plan – Muncho Lake Pilot Testing
- 636200-501 – Site Plan – Fireside
- 636200-502 – Site Plan – Fireside Pilot Testing



SUBJECT PROPERTY LIMITS	MONITORING WELL
LOT LINE	BOREHOLE
COMMUNICATIONS LINE	BOREHOLE BY OTHERS
ELECTRICAL LINE	DESTROYED MONITORING WELL
UNKNOWN UTILITY	SURFACE SAMPLE
APPROXIMATE LIMITS OF 2003 EXCAVATION	DRINKING WATER WELL OUTLET
APPROXIMATE LIMITS OF 2004 EXCAVATION	TEST PIT
TREE LINE	VAPOUR WELL
	INJECTION WELL
	FORMER AST

1. ORIGINAL DRAWING IN COLOUR.
2. LOCATION OF EXISTING UTILITIES SHOWN ARE APPROXIMATE ONLY AND SHOULD BE CONFIRMED PRIOR TO INTRUSIVE WORK. NOT ALL UTILITIES MAY BE SHOWN.
3. TO BE PRINTED ON A 43"x36" SHEET SIZE. IF PRINTED ON A DIFFERENT SIZE SHEET, SCALE NUMBER WILL BE WRONG BUT SCALE BAR WILL REMAIN ACCURATE.

No.	DATE	DESCRIPTION
–	–	–

REV.	DATE	DESCRIPTION	BY	CHK
2	2017-05-19	ISSUED TO CLIENT	DM	FG
1	2017-02-08	ISSUED TO CLIENT AS DRAFT	BB	FG
0	2016-07-25	ISSUED TO CLIENT	AJK	BH

SNC·LAVALIN

CLIENT NAME:

PROJECT LOCATION: MUNCHO LAKE ALASKA HIGHWAY, BC

TITLE: P A

DWN BY: BB | SCALE: 1:300 | DATE: 2017-02-08 | DWG No: | REV.:

CHK'D: FG | PLOT: 20170519.1116 | 635031R18_800_SERIES

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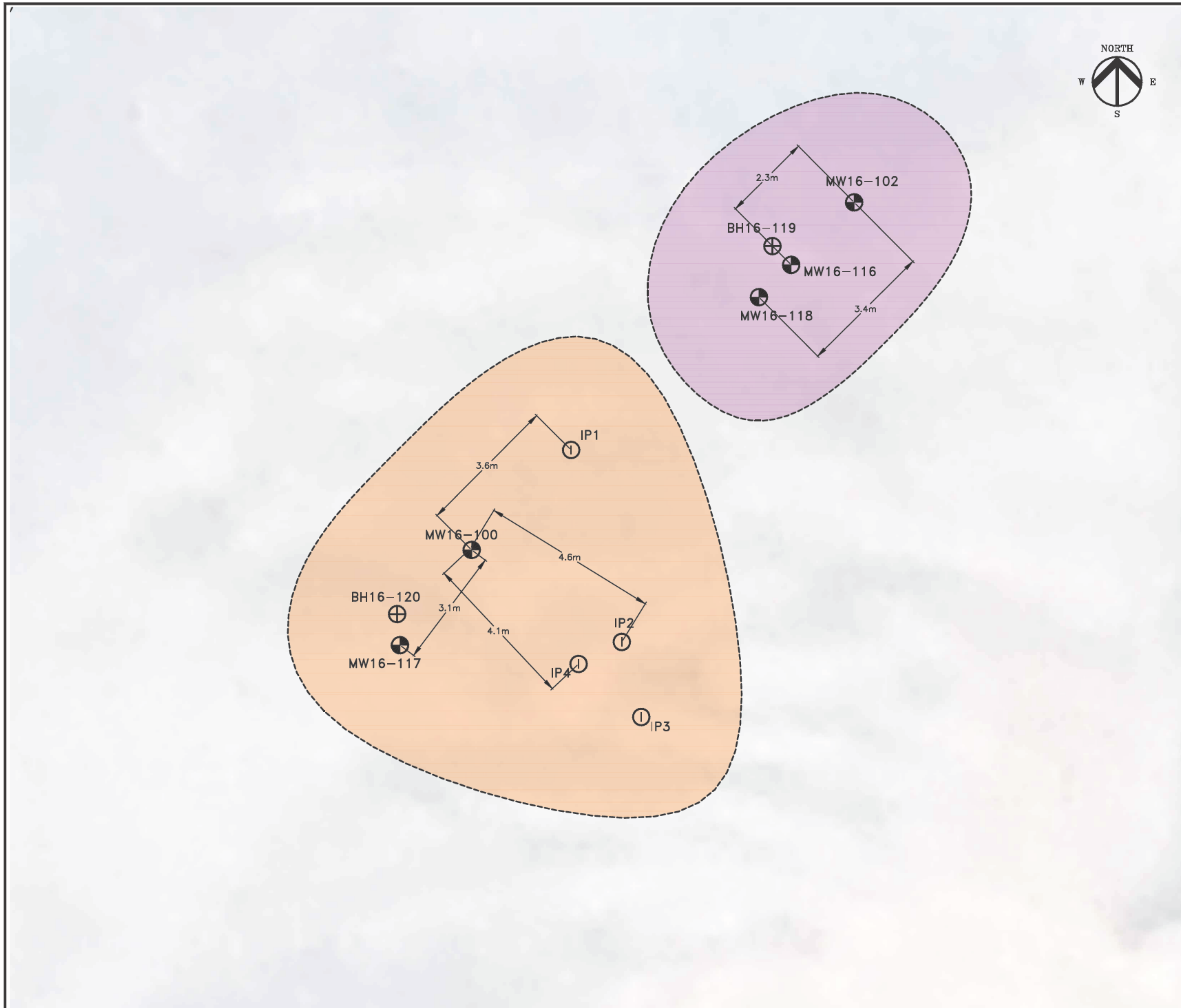


LEGEND

- MONITORING WELL
- BOREHOLE
- INJECTION POINT
- HYDROGEN PEROXIDE TEST AREA
- SURFACTANT TEST AREA

NOTES

1. ORIGINAL DRAWING IN COLOUR.
2. LOCATION OF EXISTING UTILITIES SHOWN ARE APPROXIMATE ONLY AND SHOULD BE CONFIRMED PRIOR TO INTRUSIVE WORK. NOT ALL UTILITIES MAY BE SHOWN.

REFERENCE DRAWINGS

DWG. NO.	DATE	DESCRIPTION
–	–	–

REVISIONS

REV.	DATE	DESCRIPTION	BY	CHK
2	2017–05–19	ISSUED TO CLIENT	DM	FG
1	2017–02–08	ISSUED TO CLIENT AS DRAFT	BB	FG
0	2016 12 01	ISSUED TO CLIENT AS DRAFT	BB	FG

0 1 2 3 4 5 METRES

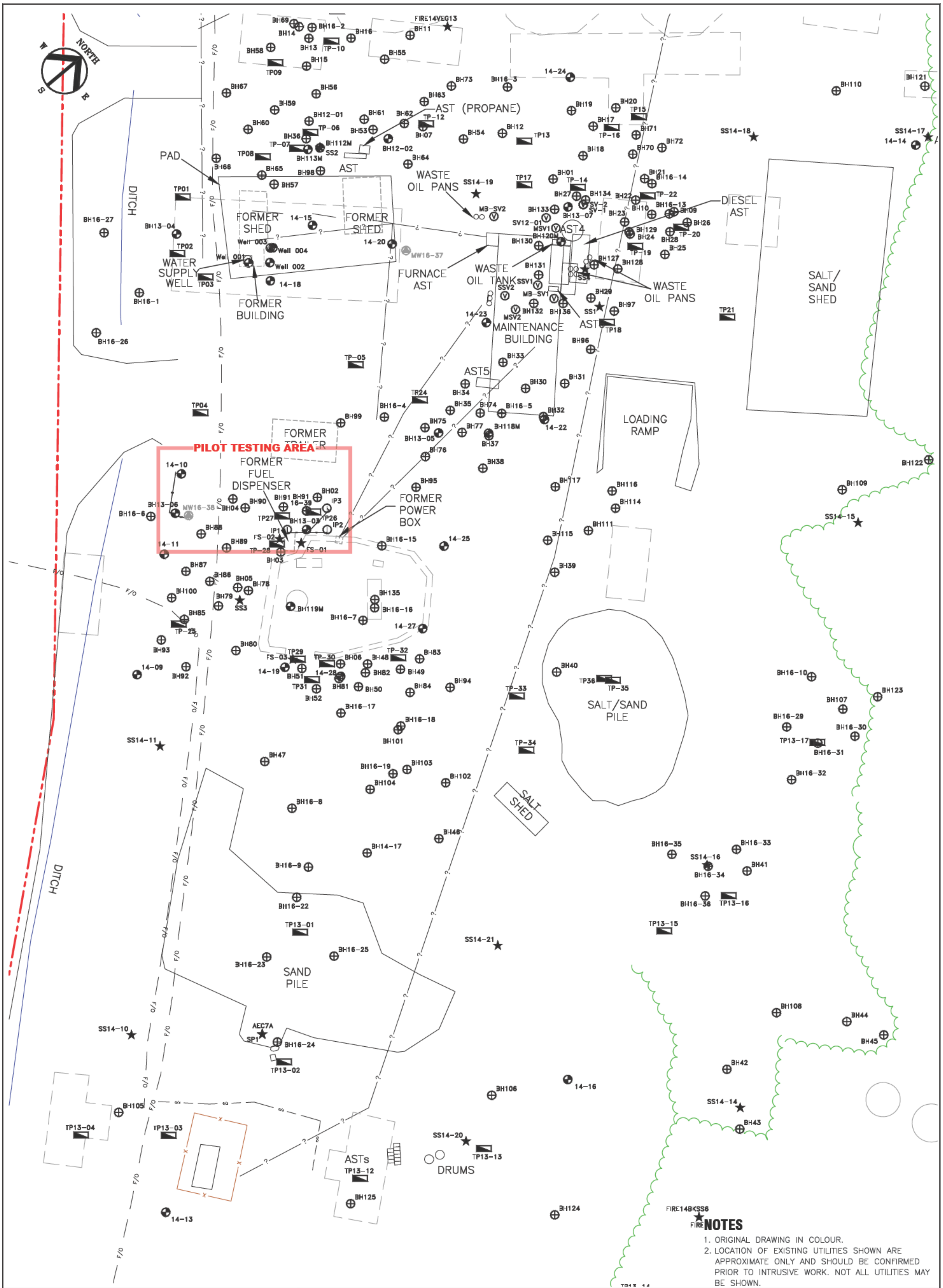
SNC • LAVALIN

CLIENT NAME: PUBLIC WORKS AND GOVERMENT SERVICES CANADA

PROJECT LOCATION: MUNCHO LAKE ALASKA HIGHWAY, BC

TITLE: **SITE PLAN - MUNCHO LAKE PILOT TESTING**

DWN BY: BB	SCALE: 1:100	DATE: 2017–02–08	SERIES No: REV.: 2
CHK'D: FG	PLOT: 20170519.1106	635031R18_800_SERIES	635031-802



NOTES

1. ORIGINAL DRAWING IN COLOUR.
2. LOCATION OF EXISTING UTILITIES SHOWN ARE APPROXIMATE ONLY AND SHOULD BE CONFIRMED PRIOR TO INTRUSIVE WORK. NOT ALL UTILITIES MAY BE SHOWN.

LEGEND

0 10 30 METRES

	SUBJECT PROPERTY LIMITS		MONITORING WELL
	UNKNOWN UTILITY		SOIL VAPOUR WELL
	TREE LINE		BOREHOLE
	FENCE		TESTPIT
	FIBRE OPTIC LINE		SURFACE SAMPLE
	FORMER SITE CONFIGURATION		MONITORING WELL WITH INJECTION WELL CONSTRUCTION
	SITE FEATURE		INJECTION POINT
	REMOVED FACILITIES		

REFERENCE DRAWINGS

DWG. NO.	DATE	DESCRIPTION
–	–	–

REVISIONS

REV.	DATE	DESCRIPTION	BY	CHK
3	2017-05-19	ISSUED TO CLIENT	DM	FG
2	2017-02-08	ISSUED TO CLIENT AS DRAFT	BB	FG
1	2016-12-01	ISSUED TO CLIENT AS DRAFT	BB	FG
0	2016-07-15	INTERNAL REVIEW	DRB	MG

SNC · LAVALIN

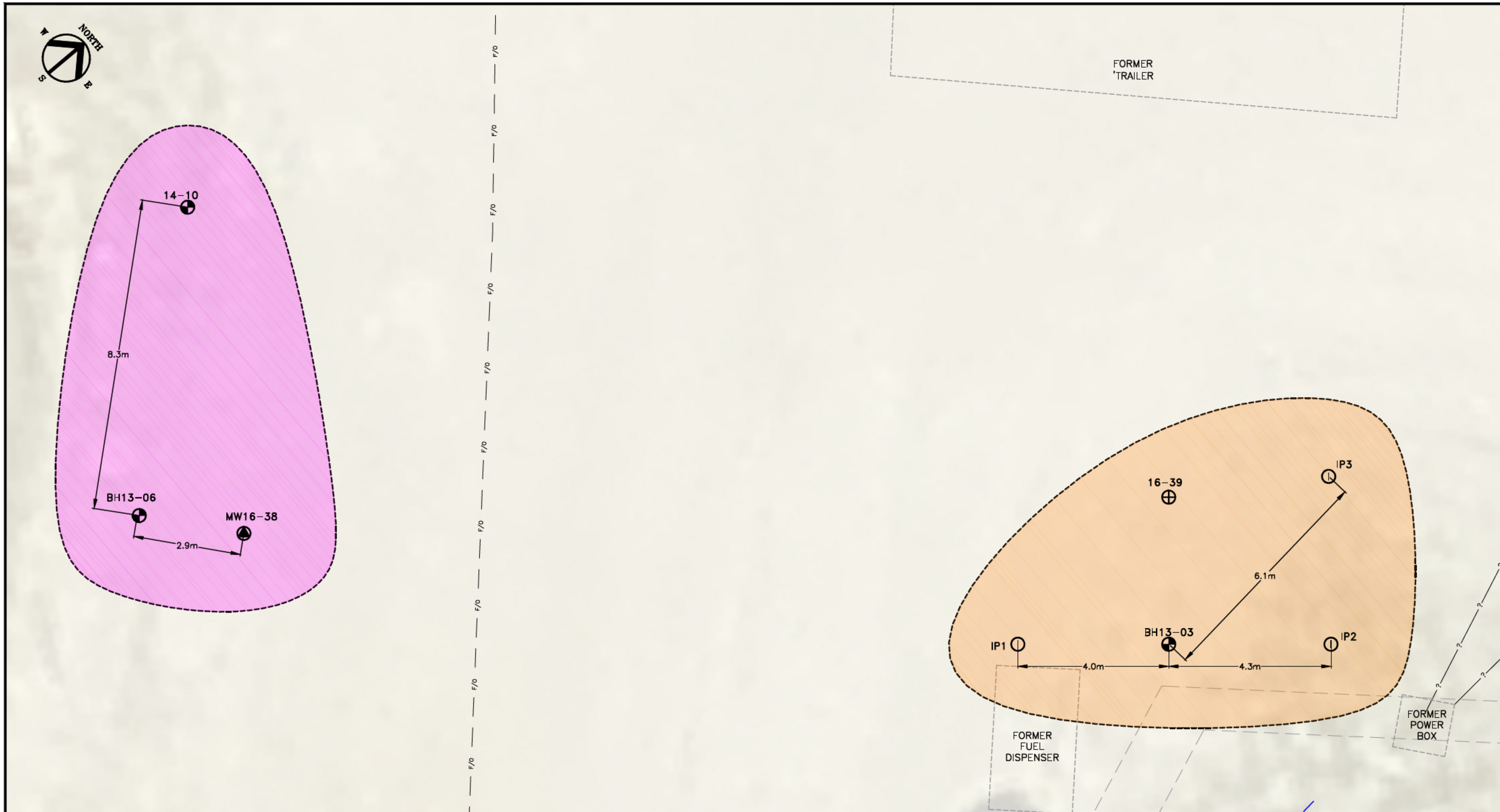
CLIENT NAME: PUBLIC WORKS AND GOVERNMENT SERVICES CANADA

PROJECT LOCATION: FIRESIDE MAINTENANCE CAMP ALASKA HIGHWAY, BC

TITLE:

SITE PLAN

DWN BY: BB	SCALE: 1:750	DATE: 2017-02-08	DWG No: 636200-501 REV.: 3
CHK'D: FG	PLOT: 20170519.1136	CADFILE: 636200R10	



LEGEND

0 1 2 3 4 5 METRES

Symbol	Description
— F/O —	FIBER OPTIC LINE
— ? —	UNKNOWN UTILITY
	FORMER SITE CONFIGURATION
	REMOVED FACILITIES
	MONITORING WELL
	MONITORING WELL WITH INJECTION WELL CONSTRUCTION
	INJECTION POINT
	BOREHOLE LOCATION
	HYDROGEN PEROXIDE TEST AREA
	SURFACTANT TEST AREA

NOTES

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2. LOCATION OF EXISTING UTILITIES SHOWN ARE APPROXIMATE ONLY AND SHOULD BE CONFIRMED PRIOR TO INTRUSIVE WORK. NOT ALL UTILITIES MAY BE SHOWN.

REFERENCE DRAWINGS

DWG. NO.	DATE	DESCRIPTION
–	–	–

REVISIONS

REV.	DATE	DESCRIPTION	BY	CHK
3	2017–05–19	ISSUED TO CLIENT	DM	FG
2	2017–02–08	ISSUED TO CLIENT AS DRAFT	BB	FG
1	2016–12–01	ISSUED TO CLIENT AS DRAFT	BB	FG
0	2016–07–07	INTERNAL REVIEW	DRB	TM

SNC·LAVALIN

CLIENT NAME: PUBLIC WORKS AND GOVERNMENT SERVICES CANADA

PROJECT LOCATION: FIRESIDE MAINTENANCE CAMP ALASKA HIGHWAY, BC

TITLE: **SITE PLAN - FIRESIDE MAINTENANCE CAMP PILOT TESTING**

DWN BY: BB	SCALE: 1:100	DATE: 2017–02–08	DWG No: 636200-502 REV.: 3
CHK'D: FG	PLOT: 20170519.1143	CADFILE: 636200R10	

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Appendix I

Borehole Logs (Muncho Lake and Fireside Maintenance Camps)

SNC•LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-116**
	Location **Muncho Lake Maintenance Camp, BC**	PAGE 1 OF 2

Drilling Contractor		Date Monitored	2016 10 04	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	FG/CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 03
Pipe/Slotted Pipe Dia (m)	0 05/0 05	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale; ● Reading outside indicated scale

Solid PVC; Slotted PVC

Well Name 1: MW16-116

Depth in Metres	Soil Description	Sample Number	% Recovery	Soil Vapour (ppm)
0	GRAVEL some sand trace silt grey damp		80	
	SAND some gravel trace silt grey damp			
	SAND fine grained some gravel trace silt grey dry			
1	Below 0 8 m - brown			
	SAND and GRAVEL fine grained sand fine and coarse gravel subangular grey/brown dry		80	
2	SAND fine grained some gravel to gravelly subangular grey/brown compact dry Between 2 1 m and 2 4 m - some pink gravel some pink sand fine grained			
3	Below 3 0 m - trace cobbles		80	
4			80	
5	Between 4 9 m and 5 2 m - medium to coarse grained sand some gravel brown damp Between 5 2 m and 5 3 m - grey/white Between 5 3 m and 5 6 m - fine to coarse grained sand some silt brown moist to wet Below 5 6 m - trace silt dry			
6	Between 6 1 m and 6 7 m - fine to coarse grained sand some silt brown red/orange staining moist to wet		70	
	Below 6 7 m - gravelly			
7	At 7 3 m - some pink colouration At 7 6 m - rock		60	
8	Below 7 9 m - grey/white	116-01		0
	Below 8 5 m - fine to coarse grained sand subangular to subrounded gravel brown moist			
9	Below 9 1 m - well graded wet	116-02	80	0
10	Between 9 7 m and 10 4 m - medium to coarse grained sand	116-03		0

Soil Vapour scale: 10, 10^2, 10^3, 10^4

Well construction: ROAD BOX; CONCRE E; SAND; BEN ONI E; GROU; BEN ONI E

NOTES
Bo ded samp e denotes samp e ana yzed.

SNC·LAVALIN

Client
Public Works and Gov't Services Canada

Location
Muncho Lake Maintenance Camp, BC

Borehole No. : BH16-116

Drilling Contractor		Date Monitored	2016 10 04	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	FG/CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 03
Pipe/Slotted Pipe Dia (m)	0 05/0 05	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

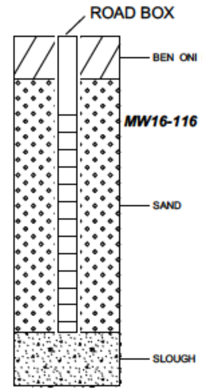
○ Reading within indicated scale
● Reading outside indicated scale

Soil Vapour (ppm): 10, 10^2, 10^3, 10^4

Solid PVC; Slotted PVC

Well Name 1: MW16-116

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery
10	SAND fine grained some gravel to gravelly subangular grey/brown compact dry *(continued)*					60
11	Below 11 3 m - hydrocarbon-like odour grey staining			**116-04**		
12	Below 12 2 m - fine and coarse gravel very loose no odour			**116-05**		90
13	Bottom of hole at 13 0 m					



14
15
16
17
18
19
20

NOTES
Bo ded samp e denotes samp e ana yzed.

SNC·LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-117**
	Location **Muncho Lake Maintenance Camp, BC**	PAGE 1 OF 2

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 04
Pipe/Slotted Pipe Dia (m)	0 05/0 05	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale; ● Reading outside indicated scale

Solid PVC; Slotted PVC

Well Name 1: MW16-117

Depth in Metres	Soil Description	Sample Number	% Recovery	Soil Vapour (ppm)
0	SAND fine to coarse grained gravelly fine and coarse subangular grey/brown compact dry		80	
1.2	S LT some gravel fine and coarse subangular dark brown hard damp organics (wood debris) Below 1 5 m - light brown wet		80	
1.8	SAND fine to coarse grained some gravel fine and coarse subangular trace cobbles grey/brown compact dry Between 3 0 m and 3 4 m - fine grained sand some silt grey loose		80	
4.3	S LT trace sand fine grained brown medium plasticity wet			
4.5	SAND fine to coarse grained gravelly fine and coarse subangular to subrounded grey/brown compact dry Below 4 9 m - medium to coarse grained sand		80	
5.2	S LT some sand fine grained brown no plasticity moist			
5.4	SAND fine to coarse grained some gravel to gravelly fine and coarse subangular to subrounded grey/brown compact dry Between 6 1 m and 6 3 m - fine grained sand some silt At 6 2 m - rock red Below 6 2 m - medium to coarse grained sand		80	
7	S LT some sand fine grained trace gravel coarse subangular brown low plasticity wet			
7.3	SAND medium to coarse grained some gravel fine and coarse subangular to subrounded trace to some silt brown moist Below 7 3 m - dry		80	
8	ROCK			
8.1	SAND fine to coarse grained some gravel subangular to subrounded trace to some silt trace cobbles brown compact dry Below 7 9 m - orange staining damp to moist Below 8 4 m - wet		80	
9.2	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subangular to subrounded brown wet hydrocarbon-like odour	117-01		0
10				

Well construction: ROAD BOX; CONCRE E; SAND; GROU; BEN ONI E; SAND; MW16-117

NOTES
Bo ded samp e denotes samp e ana yzed.

QA FG 2016 12 13 Print Date 2016-12-14

SNC·LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-117**
	Location **Muncho Lake Maintenance Camp, BC**	PAGE 2 OF 2

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 04
Pipe/Slotted Pipe Dia (m)	0 05/0 05	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

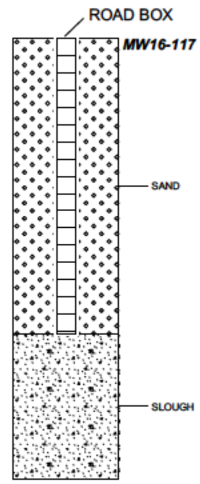
○ Reading within indicated scale; ● Reading outside indicated scale

Solid PVC; Slotted PVC

Well Name 1: MW16-117

Depth in Metres	Soil Description	Sample Interval Core Run	Sample Number	% Recovery	Soil Vapour (ppm)
10	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subangular to subrounded brown wet hydrocarbon-like odour *(continued)* Below 10 1 m - grey hydrocarbon-like staining		117-02		0
11	SAND fine to medium grained dark grey very loose hydrocarbon-like odour		117-03	20	0
	GRAVEL fine and coarse subangular to subrounded some sand fine to coarse grained grey very loose hydrocarbon-like odour				
12–13	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subangular to subrounded grey hydrocarbon-like odour Below 12 3 m - brown no odour Between 12 5 m and 12 8 m - silty		117-04	40	0
	Bottom of hole at 13 7 m				

Depth scale: 14, 15, 16, 17, 18, 19, 20



NOTES
Bo ded samp e denotes samp e ana yzed.

SNC·LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-118**
	Location **Muncho Lake Maintenance Camp, BC**	PAGE 1 OF 1

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 04
Pipe/Slotted Pipe Dia (m)	0 05/0 05	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale
● Reading outside indicated scale

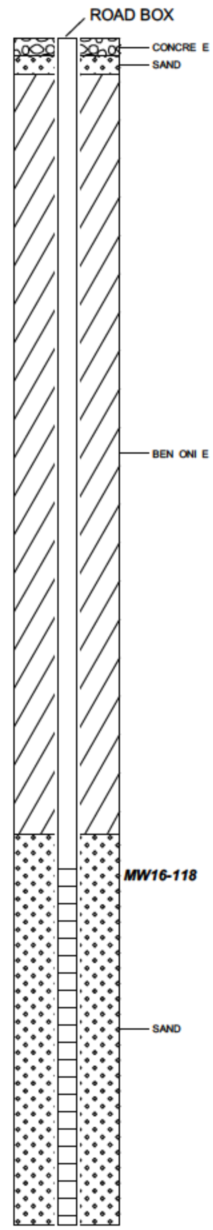
Soil Vapour (ppm): 10, 10^2, 10^3, 10^4

Solid PVC; Slotted PVC

Well Name 1: MW16-118

Columns: Depth in Metres | Soil Description | Stratigraphy Plot | Sample nterval Core Run | Sample Number | Blow Count | % Recovery | Soil Vapour (ppm)

Depth in Metres	Soil Description
0	GRAVEL some sand trace silt grey damp
	SAND some gravel trace silt grey damp
	SAND fine grained some gravel trace silt grey dry
	Below 0 8 m - brown
1	
	SAND and GRAVEL fine grained sand fine and coarse gravel subangular grey/brown dry
2	SAND fine grained some gravel to gravelly subangular grey/brown compact dry Between 2 1 m and 2 4 m - some pink gravel some pink sand fine grained
3	Below 3 0 m - trace cobbles
4	
5	Between 4 9 m and 5 2 m - medium to coarse grained sand some gravel brown damp Between 5 2 m and 5 3 m - grey/white Between 5 3 m and 5 6 m - fine to coarse grained sand some silt brown moist to wet Below 5 6 m - trace silt dry
6	Between 6 1 m and 6 7 m - fine to coarse grained sand some silt brown red/orange staining moist to wet
	Below 6 7 m - gravelly
7	At 7 3 m - some pink colouration At 7 6 m - rock
8	Below 7 9 m - grey/white
	Below 8 5 m - fine to coarse grained sand subangular to subrounded gravel brown moist
9	Below 9 1 m - well graded wet
	Between 9 7 m and 10 4 m - medium to coarse grained sand
10	Bottom of hole at 10 0 m



NOTES

SNC·LAVALIN	Client: **Public Works and Gov't Services Canada**	**Borehole No. : BH16-119**
	Location: **Muncho Lake Maintenance Camp, BC**	PAGE 1 OF 2

Drilling Contractor
Drilling Method D 45 Dual ube
Borehole Dia (m) 0 11
Pipe/Slotted Pipe Dia (m) none/none

Date Monitored n/a
Ground Sur ace Elev (m) n/a
op o Casing Elev (m) n/a
Northing n/a Easting n/a

Project Number 635031
Borehole Logged By CMH
Date Drilled 2016 10 07
Log yped By NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale
● Reading outside indicated scale

Soil Vapour (ppm): 10, 10^2, 10^3, 10^4

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery
0	GRAVEL some sand trace silt grey damp					
	SAND some gravel trace silt grey damp					
	SAND fine grained some gravel trace silt grey dry Below 0 8 m - brown					
1	SAND and GRAVEL fine grained sand fine and coarse gravel subangular grey/brown dry					
2	SAND fine grained some gravel to gravelly subangular grey/brown compact dry Between 2 1 m and 2 4 m - some pink gravel some pink sand fine grained Between 2 7 m and 3 0 m - some grey/white Below 3 0 m - trace cobbles Between 4 9 m and 5 2 m - medium to coarse grained sand some gravel brown damp Between 5 2 m and 5 3 m - grey/white Between 5 3 m and 5 6 m - fine to coarse grained sand some silt brown moist to wet Below 5 6 m - trace silt dry Between 6 1 m and 6 7 m - fine to coarse grained sand some silt brown red/orange staining moist to wet Below 6 7 m - gravelly At 7 3 m - some pink colouration At 7 6 m - rock Below 7 9 m - grey/white Below 8 5 m - fine to coarse grained sand subangular to subrounded gravel brown moist					
9	SAND fine to coarse grained gravelly fine and coarse subangular to subrounded brown loose wet					
10						

BEN ONI E

NOTES
Bo ded samp e denotes samp e ana yzed.
*denotes b nd f e d dup cate.
119 03 s a b nd f e d dup cate of 119 02.

SNC·LAVALIN	Client: **Public Works and Gov't Services Canada**	**Borehole No. : BH16-119**
	Location: **Muncho Lake Maintenance Camp, BC**	PAGE 2 OF 2

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 07
Pipe/Slotted Pipe Dia (m)	none/none	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

Reading within indicated scale; Reading outside indicated scale

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery	Soil Vapour (ppm) 10 10^2 10^3 10^4
10	SAND fine to coarse grained gravelly fine and coarse subangular to subrounded brown loose wet *(continued)* Between 10 1 m and 10 6 m - medium to coarse grained sand Below 10 7 m - surfactant-like odour Below 10 8 m - surfactant-like odour hydrocarbon-like odour grey hydrocarbon-like staining			**119-01** 119-02 *119-03			
12	GRAVEL fine and coarse subangular to subrounded some sand to sandy medium to coarse grained trace cobbles very loose surfactant-like odour wet						
13	S LT sandy fine grained trace gravel fine and coarse subangular to subrounded brown no plasticity no surfactant-like odour						
	SAND medium to coarse grained gravelly fine and coarse subangular to subrounded brown loose						
13.7	Bottom of hole at 13 7 m						

BEN ONI E

NOTES
Bo ded samp e denotes samp e ana yzed.
*denotes b nd f e d dup cate.
119 03 s a b nd f e d dup cate of 119 02.

SNC·LAVALIN

Client: **Public Works and Gov't Services Canada**	**Borehole No. : BH16-120**
Location: **Muncho Lake Maintenance Camp, BC**	PAGE 1 OF 2

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 13
Pipe/Slotted Pipe Dia (m)	none/none	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale; ● Reading outside indicated scale

Depth in Metres	Soil Description	Sample Number	% Recovery
0	SAND fine to coarse grained gravelly fine and coarse subangular grey/brown compact dry		
1.2	S LT some gravel fine and coarse subangular dark brown hard damp organics (wood debris) Below 1 5 m - light brown wet		
1.8	SAND fine to coarse grained some gravel fine and coarse subangular trace cobbles grey/brown compact dry Between 3 0 m and 3 4 m - fine grained sand some silt grey loose		
4.3	S LT trace sand fine grained brown medium plasticity wet		
4.5	SAND fine to coarse grained gravelly fine and coarse subangular to subrounded grey/brown compact dry Below 4 9 m - medium to coarse grained sand		
5.2	S LT some sand fine grained brown no plasticity moist		
5.4	SAND fine to coarse grained some gravel to gravelly fine and coarse subangular to subrounded grey/brown compact dry Between 6 1 m and 6 3 m - fine grained sand some silt At 6 2 m - rock red Below 6 2 m - medium to coarse grained sand		
6.9	S LT some sand fine grained trace gravel coarse subangular brown low plasticity wet		
7.3	SAND medium to coarse grained some gravel fine and coarse subangular to subrounded trace to some silt brown moist Below 7 3 m - dry		
8	ROCK		
8.1	SAND fine to coarse grained some gravel subangular to subrounded trace to some silt trace cobbles brown compact dry Below 7 9 m - orange staining damp to moist Below 8 4 m - wet		
9.1	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subangular to subrounded brown loose wet Below 9 3 m - hydrocarbon-like odour Between 9 3 m and 9 5 m - grey hydrocarbon-like staining	120-01	60
10			

Columns: Stratigraphy Plot; Sample nterval Core Run; Sample Number; Blow Count; % Recovery; Soil Vapour (ppm) 10 10^2 10^3 10^4

BEN ONI E

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Bo ded samp e denotes samp e ana yzed.

SNC·LAVALIN

Client	Borehole No. : BH16-120
Public Works and Gov't Services Canada	
Location	PAGE 2 OF 2
Muncho Lake Maintenance Camp, BC	

Drilling Contractor		Date Monitored	n/a	Project Number	635031
Drilling Method	D 45 Dual ube	Ground Sur ace Elev (m)	n/a	Borehole Logged By	CMH
Borehole Dia (m)	0 11	op o Casing Elev (m)	n/a	Date Drilled	2016 10 13
Pipe/Slotted Pipe Dia (m)	none/none	Northing n/a	Easting n/a	Log yped By	NDS

Drilling Legend: Sample Interval; Direct Push

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

○ Reading within indicated scale
● Reading outside indicated scale

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery	Soil Vapour (ppm) 10 10^2 10^3 10^4
10	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subangular to subrounded brown loose wet *(continued)* Between 10 1 m and 10 7 m - grey hydrocarbon-like staining Below 10 7 m - grey very loose hydrocarbon-like odour			120-02		20	
11				120-03			
12	Below 12 2 m - no recovery					0	
13							
13.7	Bottom of hole at 13 7 m						

BEN ONI E

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15
16
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NOTES
Bo ded samp e denotes samp e ana yzed.

QA FG 2016 12 13 Print Date 2016-12-14

SNC·LAVALIN

Client	Borehole No. : BH16-39
Public Works and Gov't Services Canada	
Location	PAGE 1 OF 3
Fireside Maintenance Camp, BC	

Drilling Contractor		Date Monitored	n/a	Project Number:	636200
Drilling Method	DT45 Dual Tube/ODEX	Ground Surface Elev. (m)	n/a	Borehole Logged By:	CMH
Borehole Dia. (m)	0.11	Top of Casing Elev. (m)	n/a	Date Drilled:	2016 10 10
Pipe/Slotted Pipe Dia. (m)	none/none	Northing: n/a	Easting: n/a	Log Typed By:	NDS

Drilling Legend: Sample nterval; Direct Push; Odex

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

Reading within indicated scale; Reading outside indicated scale

Soil Vapour (ppm): 10, 10^2, 10^3, 10^4

Depth in Metres	Soil Description	% Recovery
0	SAND and GRAVEL fine to coarse grained sand fine and coarse gravel subrounded to subangular brown loose dry	0
	S LT some sand fine grained light brown compact low plasticity damp	
1	Below 0 9 m - sandy	
	SAND fine to coarse grained gravelly fine and coarse subrounded grey/brown loose dry Below 1 5 m - fine to medium grained sand trace silt	80
2		
3		80
	Below 3 7 m - fine to coarse grained sand trace cobbles	
4		80
5	At 5 2 m - rock	
6		80
7	Below 7 3 m - medium to coarse grained sand Below 7 6 m - some gravel rounded	80
8		
9	At 8 8 m - rock Between 9 1 m and 10 1 m - medium grained sand trace gravel no silt damp	80
10		

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QA FG 2016 12 14 Print Date 2016-12-14

SNC·LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-39**
	Location **Fireside Maintenance Camp, BC**	PAGE 2 OF 3

Drilling Contractor		Date Monitored	n/a	Project Number:	636200
Drilling Method	DT45 Dual Tube/ODEX	Ground Surface Elev. (m)	n/a	Borehole Logged By:	CMH
Borehole Dia. (m)	0.11	Top of Casing Elev. (m)	n/a	Date Drilled:	2016 10 10
Pipe/Slotted Pipe Dia. (m)	none/none	Northing: n/a	Easting: n/a	Log Typed By:	NDS

Drilling Legend
- Sample nterval
- Direct Push
- Odex

Water/NAPL Leve s
- Water Level 1
- Water Level 2
- NAPL
- NAPL

- Reading within indicated scale
- Reading outside indicated scale

Soil Vapour (ppm): 10, 10^2, 10^3, 10^4

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery
10	SAND fine to coarse grained gravelly fine and coarse subrounded grey/brown loose dry *(continued)* Below 10 1 m - some gravel to gravelly subangular to subrounded					80
11	At 11 0 m - some orange staining					
12	At 12 2 m - refusal of DT45					
	SAND gravelly brown dry					
13–20						

BEN ONI E

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SNC·LAVALIN	Client **Public Works and Gov't Services Canada**	**Borehole No. : BH16-39**
	Location **Fireside Maintenance Camp, BC**	PAGE 3 OF 3

Drilling Contractor		Date Monitored	n/a
Drilling Method	DT45 Dual Tube/ODEX	Ground Surface Elev. (m)	n/a
Borehole Dia. (m)	0.11	Top of Casing Elev. (m)	n/a
Pipe/Slotted Pipe Dia. (m)	none/none	Northing: n/a	Easting: n/a

Project Number:	636200
Borehole Logged By:	CMH
Date Drilled:	2016 10 10
Log Typed By:	NDS

Drilling Legend: Sample nterval; Direct Push; Odex

Water/NAPL Leve s: Water Level 1; Water Level 2; NAPL; NAPL

Reading within indicated scale; Reading outside indicated scale

Depth in Metres	Soil Description	Stratigraphy Plot	Sample nterval Core Run	Sample Number	Blow Count	% Recovery	Soil Vapour (ppm) 10 10² 10³ 10⁴
20	SAND gravelly brown dry *(continued)*						
24.4	Below 24 4 m - medium grained sand trace to some gravel dark grey hydrocarbon-like odour						
25.3	Below 25 3 m - some gravel to gravelly						
26.8	Bottom of hole at 26 8 m						

BEN ONI E

NOTES

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