Remedial Options Feasibility Analysis

Baker Lake Old Plant
Baker Lake, Nunavut

Draft

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1 INTRODUCTION

Nunami Stantec Ltd. (Nunami) was retained by Qulliq Energy Corporation (QEC) to conduct a Remedial Options Feasibility Analysis (ROFA) for the remediation of selected areas associated with the QEC Old Power Plant properties located in Baker Lake, Nunavut (herein referred to as the Site). The work for this Project is being completed under Change Order #1 to QEC Contract 201594, approved on May 6, 2016.

This report presents a summary of potential remedial options including a summary of their approximate costs, timelines, and challenges. The remedial options were developed based on data generated through a review of previous environmental reports and the results of the Preliminary Human Health and Environmental Risk Assessment (HHERA) completed by Nunami in 2016.

2 OBJECTIVE AND SCOPE OF WORK

2.1 Objective

The objective of the ROFA was to review potential remedial options for an impacted soil "hot spot" identified from the Preliminary HHERA (Nunami 2016), including identification of the proposed recommended remedial approach. In addition, the project objectives included estimation of the costs to replace the existing Waterloo Emitter™ system which has now been depleted, as well as evaluate alternative potential options for management of environmental impacts along the downgradient shoreline from the site. Please note that this evaluation of shoreline protection measures is provided for general information purposes only, since completion of the proposed field sampling program and Final HHERA in 2016 is intending to determine whether shoreline protection measures are required.

2.2 Scope of Work

The scope of work for the ROFA consisted of the following:

- Reviewing available documents to determine approximate areas of impact. For the purposes of this assessment, QEC requested that the ROFA be focused on the following areas;
    - The preliminary HHERA determined that a "hot spot" at the BL-TP33 location poses a potential risk to human receptors through direct contact with soil and recommended soil remediation or risk management to protect human receptors in the area. For the purposes of this ROFA, Nunami has assumed that the estimated volume of impacted soil is 50 m^3. As requested by QEC, this ROFA is focused on remedial options (i.e., removal and/or treatment), as opposed to risk management options that could enable the impacted soil to remain in place (such as relocation and/or capping to eliminate potential exposure pathways).
    - The shoreline area of Baker Lake: A Waterloo Emitter™ system was installed in 2008 along the downgradient shoreline to intercept potential contaminant plume migration. However, the system is no longer operational and a suitable replacement should be recommended. QEC has requested a cost estimate to replace the existing system with a similarly designed Waterloo Emitter™ system, as well as identify potential alternative options for plume containment along the shoreline should this be necessary based on future assessment information results.
- Assessing industry accepted remedial options with respect to their applicability to the Site.
- Evaluating potentially applicable technologies for the Site, including providing a Class "D" cost estimate, timelines, and challenges with each option.
- Preparing this ROFA.

3 BACKGROUND

The Site is located in the Hamlet of Baker Lake in the Kivalliq region of Nunavut, on the shore of Baker Lake, approximately 300 km inland from the west coast of Hudson Bay. The Site consists of multiple areas, including the old power plant site, the MOT compound, the Federal and Territorial Government former tank farm, and the shoreline.

Nunami was retained by QEC to conduct a preliminary human health and ecological risk assessment (HHERA) of the Site. Prior to conducting the preliminary HHERA, Nunami prepared a Gap Analysis to review the adequacy of the existing data for the risk assessment. Multiple data gaps were identified and Nunami proceeded with the HHERA as a preliminary step in the evaluation of the potential toxicological risks to human and/or ecological receptors associated with chemical impacts at the Site. The preliminary HHERA was conducted using analytical data from soil, groundwater and sediment samples collected between 2013 and 2015.

The Human Health Risk Assessment (HHRA) identified petroleum hydrocarbon (PHC) concentrations in soil exceeded the applicable Canadian Council of Ministers of the Environment (CCME) Canada Wide Standards (CWS), pathway-specific Tier I Levels for the protection of indoor air inhalation. One soil sample, located at test pit BL-TP33 exceeding the CCME-CWS, pathway-specific Tier I Levels for direct contact. PHC in soil were identified as the contaminants of potential concern (COPCs) for the HHRA.. The Ecological Risk Assessment (ERA) identified PHCs as COPCs in groundwater and sediment. The HHERA recommended that soil, groundwater and sediment impacts at the Site be delineated to applicable guidelines and that a hydrogeological investigation be conducted to assess plume stability and unique conditions at the Site.

4 REGULATORY FRAMEWORK

In Canada, guidance documents have been published by various agencies to help maintain, improve and/or protect environmental quality and human health in the context of contaminated sites. The territorial and federal guidelines used to assess the Site previously have been carried forward in the ROFA and will be the basis for determining waste and hazard components. Generally the applicable guidelines included:

- Nunavut Environmental Guideline for Contaminated Site Remediation (GN, 2010)
- CCME Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME, 2006)
- CCME Canadian Soil Quality Guidelines for benzene, toluene, ethylbenzene, and xylene (BTEX) (CCME, 2007a)
- CCME Canada Wide Standards for Petroleum Hydrocarbons(PHC) (CCME, 2008)
- CCME Environmental Quality Guidelines (CCME, 2007c)
- CCME Canadian Sediment Quality Guidelines (SQG) for the Protection of Freshwater Aquatic Life (CCME, 1995)
- CCME Canadian Water Quality Guidelines for the Protection of Freshwater Aquatic Life (CCME, 2007d)

It should be noted that the HHERA is currently being conducted for the Site and is in preliminary status only. If required, site specific remedial targets (SSRTs) could be calculated as part of the HHERA which will determine concentrations at which risk to human and ecological health is anticipated to be low. As such, when SSRTs are finalized, the waste and hazard components requiring remediation and the estimated volumes of impacted material should be revised and the remedial options presented in this report should be revisited to determine if the recommendations are still appropriate.

5 REMEDIAL OPTIONS ASSESSMENT

The objectives for the remediation of the two identified areas at the Site include:

- Remediate the identified “hot spot” area on the Site to meet the applicable CCME-CWS guidelines.
- Prevent migration of groundwater hydrocarbon impacts to Baker Lake.
- Implement a cost effective remedial solution.

The process of evaluating potential remedial options for the Site was conducted using a two-step elimination process. The first step consisted of eliminating a range of remedial technologies that are not likely to be implementable at the Site (based on general site conditions, impacted media, contaminants of concern (COCs) etc.). The second step consisted of a more detailed review and elimination of technologies based on site-specific conditions. Finally, the overall scope of the project was reviewed and a remedial option was recommended.

5.1 Step 1 - Preliminary Elimination

To initiate the process of evaluating potential remedial options for the Site, Stantec referenced the Federal Remediation Technologies Roundtable (FRTR) Treatment Technologies Screening Matrix (FRTR Remediation Technologies Screening Matrix and Reference Guide, Version 4.0), which lists 59 industry-standard technologies suitable for most petroleum and/or hazardous waste sites requiring remediation. Each technology was reviewed with respect to factors such as technical practicality and feasibility for each affected media (soil and groundwater). A complete list and brief description of each remedial option is presented in Table 1, Appendix A.

This review resulted in the preliminary elimination of some technologies from further consideration. The removed options included technologies such as phytoremediation and constructed wetlands, which are not considered practical for the Site. Technologies requiring significant infrastructure and/or a large footprint were eliminated. Additionally, a high level review of a number of parameters such as operating and maintenance costs, capital costs, time, and applicability to COCs was conducted to further eliminate options.

The preliminary option evaluation resulted in a short list of potentially applicable technologies carried forward to the second stage of review. The rationale for the preliminary elimination is summarized in Tables 2 and 3, Appendix A.

5.2 Step 2 – Secondary Elimination

Remedial options retained from Step 1 were further assessed for the ability to meet site specific evaluation criteria, including:

- Site specific physical conditions including:

- Site constraints
- Soil types
- Soil/groundwater concentrations

- Mitigate or remove potential risks to human health and/or the environment.
- Ability to reach remedial targets (by assessing the likelihood of success/proven technology).

A secondary elimination was conducted based on the results of this evaluation, which reduced the list of remedial options further to those considered practical to implement as presented in Table 1 in Section 6.2 and Table 2 in Section 7.2.

6 REMEDIAL OPTIONS EVALUATION – TP 33 HOTSPOT

6.1.1 Excavate and Treat On-site

This option is only applicable to PHC impacted soil. The soil would be excavated, placed in a designated area and treated. Three options have been identified for on-site treatment of the impacted soil: Option 1 – landfarming; Option 2 - biopiling, and Option 3 - chemical oxidation. A review of these three options is presented below.

Some advantages associated with these options are their effectiveness at addressing PHC contamination and their ability to treat contamination on-site, eliminating the need for material hauling. The main disadvantages associated with these options are that they require repeat visits to the treatment area for effective remediation to occur which would significantly increase logistical requirements and associated costs.

For the purposes of this analysis, Nunami has assumed that the soil in the BL-TP33 area would be excavated and hauled to a small temporary treatment cell, approximately 20 m x 15 m in size, to be constructed on QEC property in Baker Lake. The treatment cell area would need to include a security fence to prevent public access to the treatment area while remediation was in progress.

6.1.1.1 Option 1 - Excavation and Landfarming

Landfarming is a process in which hydrocarbon contaminated soils is spread in a 0.3 – 1.0 m layer and nutrients (i.e., fertilizers) are added. The soils are mixed for aeration to promote microbial activity, volatilization, and bioremediation/biodegradation. Additional measures, such as adding bulking agents to increase aeration, biostimulation, adding lime to adjust pH, or adding substrates, can be used to decrease the time required to degrade the contaminants. After soil contaminant levels decrease below the applicable criteria the soil would be spread and contoured to match the surrounding environment and no further monitoring would be required.

6.1.1.2 Option 2 - Excavation and Biopiles

A biopile is a remediation approach where soil is aerated to enhance the microbial activity that degrades the contaminants. Aeration can be completed mechanically (with an excavator), actively (using blowers) or passively (perforated pipes placed throughout the biopile connected to vertical pipes and a fan system). Compared to landfarming, biopiles require less surface area to treat a comparable volume of soil since the soil is laid in windrows rather than a uniform layer and will not freeze as quickly.

As with landfarming, bacteria or fertilizers may be added to the biopiles (depending on the design) to increase the rate of hydrocarbon degradation. In Nunami’s experience, hydrocarbons have typically been shown to decrease below the criteria within 5 years and in some cases sooner than landfarms, and with predominantly lighter-range hydrocarbons can be effective in as little as one year of operation. Given the time requirements to treat soil, the biopiles must be constructed and operated within the first year of construction to minimize maintenance/monitoring trips.

6.1.1.3 Option 3 - Excavation and On-Site Chemical Oxidation

An alternative method of remediation is through the use of a chemical oxidation technology, which can be applied in-situ or ex situ for soil and/or groundwater remediation. Chemicals such as RegenOX® or peroxide and permanganate have been used in situ through direct-injection techniques at PHC impacted sites to oxidize PHCs and to promote the bio-degradation of PHCs.. Similarly, the technology can be applied ex situ, whereby the soils are excavated and oxidation chemicals are mixed with the soils in a lined cell, tank, etc.

The chemical products react with the PHCs converting them to carbon dioxide and water, as well as smaller hydrocarbon chains (which would be more amendable to biodegradation and volatilization). In this ex situ option, a small lined containment cell would be constructed for placement of the excavated soils and subsequent mixing with the oxidants. For simplicity, Nunami recommends the use of hydrogen peroxide for chemical oxidation purposes. The main advantage of chemical oxidation relative to other options is the potentially reduced treatment time. The disadvantages are that multiple dosing events may be required to achieve the specified treatment criteria. Another disadvantage is the high cost of procurement and shipping of the oxidizing chemicals to the site, along with potential restrictions associated with shipping of the chemicals.

6.1.2 Option 4 - Excavation and Offsite Disposal

The hydrocarbon impacted soil would be containerized and transported via ship to a licensed disposal facility in Southern Canada. This method would remove the waste from the Site entirely but due to the high cost of shipping this option may prove to be cost prohibitive.

6.2 Remedial Cost Comparison

The approximate costs for the four options presented above are noted in Table 1 below.

Table 1 – Remedial Cost Comparison

Remedial Option	Item	Cost	Comments and Assumptions
Option 1 - Excavation and Landfarm	Capital Costs:	$1,000 – 60 mil HDPE Liner $20,000 – Granular fill $4,000 - Fencing	• 1 Nunami representative onsite for 3 days for excavation supervision and construction work • Approximately 50 m^3 of soil excavated from BL-TP33 area • 15 confirmatory samples collected from excavation boundaries • 6 baseline soil samples collected from containment cell footprint prior to construction • Containment cell approximately 15m x 20m in size • Cell contains soil layer approximately 10m long, 15m wide, and 0.3m high • 15 samples collected from the cell • Assume 5 year treatment cycle • Assume 3 soil sampling events (1 day onsite) per year at the containment cell to monitor hydrocarbon concentrations, on a monthly basis during the summer. • Nunami will train QEC personnel onsite to maintain landfarm and QEC personnel will collect samples after first year of treatment • Mob/demob and sampling events priced on a per event basis • Landfarm turning event priced on a per event basis • Containment cell decommissioned once hydrocarbon concentrations meet guideline criteria • Collect baseline soil samples after decommissioning • Liner can be disposed of at the local solid waste facility
	Consulting Costs:	$5,000 – Design Services $10,000 – Regulatory Services $6,250 – Mob/demob (3x) $1,800 – Confirmatory boundary sampling at excavation $3,600 – Construction supervision $1,500 – Landfarm sampling events (3x) $2,800 – Soil sample analysis	
	Construction Costs:	$4,500 – Impacted soil excavation $2,500 – Backfill excavation $10,000 – Containment cell construction $1,000 – Landfarm turning event (3x) $2,500 – Containment cell decommissioning	
Option 1 Total Cost		**$93,950**	
Option 2 - Excavation and Biopile	Capital Costs	$1,000 – 60 mil HDPE Liner $250 – Tarps to cover piles $20,000 – Granular fill $4,000 - Fencing $5,500 – Piping and blower	• Excavation, sampling, and backfill details as above • Containment cell details as above • 3 biopiles approximately 15m long, 1.5m high, and 1.5m wide all contained in one cell • Assume 3 year treatment cycle, 3 sampling events per year

		pump	• 5 samples collected from each Biopile • Containment cell decommissioned once hydrocarbon concentrations meet guideline criteria • Liner and piping can be disposed of at the local solid waste facility
	Consulting Costs:	$15,000 – Design Services $10,000 – Regulatory Services $6,250 – Mob/demob (3x) $1,800 – Boundary sampling at excavation $3,600 – Construction supervision $1,500 – Biopile sampling events (3x) $2,800 – Soil sample analysis	
	Construction Costs:	$4,500 – Impacted soil excavation $2,500 – Backfill excavation $10,000 – Containment cell construction $6,500 – Setup and testing of piping and blower system $1,500 – Annual maintenance (3x) $2,500 – Containment cell decommissioning	
Option 2 Total Cost		**$102,700**	
Option 3 - Excavation and Ex-situ Chemical Treatment	Capital Costs:	$58,000 – 35% Hydrogen Peroxide Reagent and shipment $1,000 - HDPE Liner $4,000 - Fencing $20,000 – Granular fill	• Excavation, sampling, and backfill details as above • Containment cell details as above • Each dosing round uses reagent diluted to a concentration of 10%. • Assume 1 year treatment cycle • Assume 3 dosing rounds and subsequent soil sampling events (1 day onsite) per year at the containment cell to monitor hydrocarbon concentrations, on a monthly to 6 week basis. • Containment cell decommissioning as above
	Consulting Costs:	$15,000 – Design Services $10,000 – Regulatory Services $6,250 – Mob/demob (3x) $1,800 – Confirmatory boundary sampling at excavation $2,400 – Construction supervision	

		$1,400 – Reagent dosing events (3x) $1,500 – Soil sampling events (3x) $2,800 – Soil sample analysis	
	Construction Costs:	$4,500 – Impacted soil excavation $2,500 – Backfill excavation $10,000 – Containment cell construction $2,500 – Soil dosing event (3x) $2,500 – Containment cell decommissioning	
Option 3 Total Cost		**$164,450**	
Option 4 - Excavation and Off-site Disposal	Capital Costs:	$1000 – Soil bags $10,000 – Granular Fill $175,000 – Shipment and disposal of soil	• Excavation, sampling, and backfill details as above • Impacted soil loaded into UN rated bags for shipment to southern disposal facility via sealift • Assume 50 bags • $3500/bag shipment and disposal
	Consulting Costs:	$6,250 – Mob/demob $5,000 – Boundary sampling at excavation $1,200 – Soil sample analysis	
	Construction Costs:	$5,500 – Impacted soil excavation and fill soil bags $2,500 – Backfill excavation	
Option 4 Total Cost		**$206,450**	

6.3 Discussion and Recommended Remedial Approach

Based on Nunami's review of the above options, the recommended remedial option is to excavate the impacted soil and landfarming. This option was chosen for the following reasons:

- High level of Certainty for Reaching Guideline Criteria– This option involves removing impacted soil and actively treating it, which provides the best chance of reaching guideline criteria.
- Cost – Lowest cost option to implement and lowest cost to operate. The Biopile option has a similar cost to implement, but requires ongoing maintenance of the blower system. The offsite shipment option and chemical treatment option both have large capital expenditures related to shipment of materials on/offsite.
- Logistics – This option requires the lowest amount of capital investment and the required materials can be cost effectively delivered to site. Site personnel can be trained to maintain the containment cell and regularly collect samples for analysis.

6.3.1 Regulatory Considerations

Nunami assumes that the containment cell, proposed as part of the remedial options, would be constructed on land held by QEC. If this is not the case, QEC would likely need to enter into discussions with the Hamlet regarding the potential location of a treatment location within the Hamlet boundaries. The operational parameters, such as the capacity and operational responsibility for the facility would be determined during this process.

During the planning process, it could be beneficial to enter into discussions with other Government of Nunavut departments, such as the Nunavut Housing Corporation or CGS Petroleum Products Division. These departments often deal with impacted soil as part of their operations and would occasionally require the use of a treatment cell within the community. The construction and operation of the treatment cell could then be funded on a cooperative basis between the interested parties.

The specific regulatory approval requirements for the treatment cell would be determined during the detailed design phase, including the location of the selected site for proposed treatment operations. Nunami assumes that regulatory approvals may include, but not be limited to:

- Written confirmation from the Nunavut Planning Commission (NPC) confirming that NPC's requirements under the Nunavut Land Claims Agreement (NLCA) regarding land use plan conformity (Article 11 of the NLCA) have been addressed. This indicates that the proposed land use conforms to the Keewatin Land Use Plan.
- Written confirmation from the Nunavut Impact Review Board (NIRB) confirming that NIRB's requirements under the NLCA regarding development impact assessment (Part 4, Article 12 of the NLCA) have been addressed.
- A Water Licence issued by the Nunavut Water Board (NWB), for water use and deposit of wastes in conjunction with an industrial undertaking.

Further discussions with NWB and NIRB would be required to define information requirements as the project details are developed. For the purpose of this analysis, Nunami has included a cost for development of Water License amendment application.

7 REMEDIAL OPTIONS EVALUATION – BAKER LAKE SHORELINE

Below is a discussion of each remedial option considered to be potentially applicable for the shoreline area.

7.1.1 Option A - Monitored Natural Attenuation

Potential health risks to human and ecological receptors are evaluated both qualitatively and quantitatively on a site-specific basis. This analysis provided by the risk assessment is used to develop a risk management plan for the site that outlines management options for the identified risks, and outlines requirements for future monitoring, if necessary. A risk management plan, which can include engineering or administrative controls, can be an acceptable management option in some cases where active remediation is not feasible from a cost and/or technical perspective. This approach would be acceptable at the Site only after consultation with the GN Department of the Environment to address any potential remaining exposure hazards.

If monitoring demonstrates that natural attenuation at the Site is insufficient to reduce the concentrations that meet the guideline criteria, then alternative methods of remediation may be required.

7.1.2 Option B - Replace and Reinstall Waterloo Emitter™

The Waterloo Emitter™ is a device designed to release oxygen into contaminated groundwater to encourage the growth of microorganisms required for in-situ bioremediation. The Waterloo Emitter™ consists of silicone tubing coiled around a PVC frame which introduces a steady supply of oxygen into the aquifer by diffusion through the pressurized silicone tubing.

A Waterloo Emitter™ system was installed at the Site in 2008 and consisted of two arrays of horizontal lengths of slotted pipe installed in a trench approximately 25m north of the Baker Lake shoreline. The emitter units were installed inside the lengths of slotted pipe and connected to oxygen tanks, located inside a control cabin, with tubing and a manifold. Two monitoring wells were installed upgradient of the array and two monitoring wells were installed downgradient of the array. Water samples were collected from the wells to monitor dissolved oxygen and PHC concentrations in the groundwater.

The installed system is no longer in operation and requires replacement.

The main advantage of the system is that it can be an efficient method to release gaseous amendments to groundwater, due to diffusion-based delivery and is most effective in highly permeable soils.

The disadvantages of the system are that it is highly dependent on appropriate hydraulic design and has limited effectiveness when used inside a well screen due to limited dispersion and diffusion in most unconsolidated settings. For aerobic biodegradation, other oxygen delivery methods are generally more cost-effective (such as air sparging). The initial capital expenditure and set up cost is high compared to other methods.

7.1.3 Option C - Excavate Interception Trench and Pump and Treat

The interception trench will be approximately 100m long and would be excavated to depth until refusal on frozen soil. Following refusal, a rock hammer would be used to further advance the trench bottom into frozen material. A 60 mil High Density Polyethylene (HDPE) liner would be installed along the down gradient side of the trench, which would be scored into the bedrock and/or permafrost and allowed to re-freeze while the remaining liner was placed vertically on the opposite side of the trench and left open temporarily to observe for water. The liner is intended to create a physical barrier intercept groundwater flow prior to reaching the shoreline area. Water collecting in the trench would be pumped out into a suitable container for storage and treatment, if needed.

The interception trench would be equipped with a perforated pipe connected to a recovery well that would be installed in the trench to monitor and pump any accumulated water. The recovery well will be constructed using perforated polyvinyl chloride (PVC) pipe to allow water to infiltrate into the well. The well would be capped and periodically monitored for fluid levels.

Prior to constructing the interception trench a silt fence along the high water line would be installed for sediment and erosion control during excavation operations. The silt fence is trenched into the soil and the bottom edge of the silt fence is set 0.015 meters into the soil and then backfilled. The silt fence captures any sediment from remedial activities which might become entrained in surface water flowing into the lake or be blown across the surface by the wind.

Water collected from the trench recovery well(s) would be pumped through an activated carbon filter treatment system. Treated water samples would be collected and submitted for laboratory analysis to confirm treatment prior to discharge.

The advantage of this option is that it has low initial capital expenditure and low maintenance costs.

The disadvantage of this option is higher operational cost, since water must be regularly pumped out of the trench recovery well(s), treated, sampled, and then discharged. Alternative methods of remediation may be required if the volume of water pumped from the wells exceeds the available storage and treatment capacity.

7.2 Remedial Cost Comparison

The approximate costs for the four options scenario are noted in Table 2 below:

Table 2 – Remedial Cost Comparison

Remedial Option	Item	Cost	Comments and Assumptions
Option A - Monitored Natural Attenuation	Capital Costs:		• Remove Waterloo Emitter control cabin and dispose of materials at local solid waste facility • Ongoing monitoring of existing wells • Assumes completion of HHERA and development of Risk Management Plan
	Consulting Costs:	$6,250 – Mob/demob $20,000 – Risk Management Plan $1,600 – Water sampling events $500 – Water sample analysis	
	Construction Costs:	$3,000 – Decommission Waterloo Emitter	
Option A – Total Cost		**$31,350**	
Option B - Replacement of Waterloo Emitter	Capital Costs:	$80,000 – Waterloo Emitters plus shipment $2,500 – Oxygen tanks, tubing and manifold	• 80 Waterloo Emitter units to be installed in existing buried tubing array • New oxygen tanks, new tubing and manifold • Commission system • Ongoing annual maintenance as with previously installed system • Collect water samples from the monitoring wells
	Consulting Costs:	$3,000 – Design Services $6,250 – Mob/demob $16,500 – Set up new emitter array $700 – Water sample analysis	
	Construction Costs:	$3,500 – transport and set up materials for array	
Option B – Total Cost		**$112,450**	
Option C - Interception Trench (Pump and Treat)	Capital Costs:	$2,000 – 60 mil HDPE Liner $600 – Well supplies $15,000 – Water Treatment System plus shipment $30,000 – Granular fill	• Excavate Waterloo Emitter system and dispose of materials • Clean up trench • Install Liner in trench and backfill • Install recovery wells • Pump water from recovery wells on monthly basis during summer
	Consulting Costs:	$10,000 – Design Services	

		$10,000 – Regulatory Services $6,250 – Mob/demob $3,600 – Construction supervision $2,800 – Water sample analysis	• Treat water as needed, submit samples prior to discharge
	Construction Costs:	$5,500 – Decommission Waterloo Emitter System $4,500 – Backfill trench $1,500 – Recovery well installation $2,500 – Commission water treatment system	
Option C – Total Cost		**$94,250**	

7.3 Discussion of Recommended Remedial Approach

As discussed previously, the requirements for any treatment and/or interception of groundwater potentially migrating from the Site to Baker Lake would be assessed following completion of the proposed 2016 field work and final HHERA study. However, in the event that a remedial system was required to address groundwater migration from the Site to Baker Lake, then Nunami's recommended option would be to remove the Waterloo Emitter™ system, re-excavate, and install an interception trench along the same location. The interception trench would be completed with a pumping and treatment system at the site to mitigate hydrocarbon impacts in the collected water. This option was chosen for the following reasons:

- The existing Waterloo Emitter™ trench can be re-used or modified into an interception trench/hydraulic barrier between the site and downgradient Baker Lake;
- This technology is a proven remedial approach for groundwater plume containment and has proven effective in cold climates;
- The technology is relatively simple to construct and operate.
- The system is comparatively inexpensive to install and operate and can be operated by QEC personnel with a minimum amount of training.
- Monitoring costs are low and field methods are simplistic.
- The system can be easily upgraded or reduced should site conditions dictate a change in containment or treatment requirements
- System components are readily available in the south, if not locally, and can be shipped easily to the site by air or sea lift.
- Used activated carbon filtration from water treatment operations can be added to and treated by the Biopile or Landfarm to be constructed on site.

Based on recent discussions with QEC, Nunami understands that permafrost mounding along the shoreline during the summer months may be acting as a physical barrier for groundwater flow to Baker Lake. The presence of the permafrost mounding will be assessed during the proposed 2016 summer field program. This information, combined with completion of groundwater flow modelling could eliminate the need for construction of an interception trench, or possibly eliminate the requirements for active pumping of the recovery wells within the trench.

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10 CLOSURE

This report documents work that was performed in accordance with generally accepted professional standards at the time and location in which the services were provided. No other representations, warranties or guarantees are made concerning the accuracy or completeness of the data or conclusions contained within this report, including no assurance that this work has uncovered all potential liabilities associated with the identified property.

This report provides an evaluation of selected environmental conditions associated with the identified portion of the sites as reported in previous reports provided to Nunami. There are no assurances regarding the accuracy and completeness of this information. All information received from the client or third parties in the preparation of this report has been assumed by Stantec to be correct. Stantec assumes no responsibility for any deficiency or inaccuracy in information received from others.

Conclusions made within this report consist of Nunami's professional opinion as of the time of the writing of this report, and are based solely on the scope of work described in the report, the limited data available and the results of the work. They are not a certification of the property's environmental condition. This report should not be construed as legal advice.

This report has been prepared for the exclusive use of the client identified herein and any use by any third party is prohibited. Nunami assumes no responsibility for losses, damages, liabilities or claims, howsoever arising, from third party use of this report.

The information provided in the reports completed by others, listed in the References. These reports were assumed to provide correct/accurate information. Where data gaps existed, assumptions were made to generate volumes of impacted materials (where delineation had not been achieved).

The conclusions are based on the site conditions described in the previous reports reviewed by Nunami at the time the work was performed at the specific testing and/or sampling locations, and conditions may vary among sampling locations. Factors such as areas of potential concern identified in previous studies, site conditions (e.g., utilities) and cost may have constrained the sampling locations used in the previous assessment. In addition, analysis has been carried out for only a limited number of chemical parameters, and it should not be inferred that other chemical species are not present. Due to the nature of the investigation and the limited data available, Nunami does not warrant against undiscovered environmental liabilities nor that the sampling results are indicative of the condition of the entire site. As the purpose of this report is to review provided reports and assess remedial options, the identification of possible environmental risks not summarized in the previous reports is beyond the scope of this assessment.

Should additional information become available which differs significantly from our understanding of conditions presented in this report, Nunami specifically disclaims any responsibility to update the conclusions in this report.

Respectfully Submitted,

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APPENDIX A Remedial Options Tables

Table 1 - TECHNOLOGIES LIST AND DESCRIPTIONS

Technology (per media) [1]	Brief Description
Soil/Groundwater	
In Situ Biological Treatment	
Bioventing	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.
Enhanced Bioremediation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants or immobilization of inorganic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.
Monitored Natural Attenuation[2]	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.
Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. Contaminants may be either organic or inorganic.
In Situ Physical/Chemical Treatment	
Chemical Oxidation	Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.
Electrokinetic Separation	The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.
Fracturing	Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.
Soil Flushing	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.
Soil Vapor Extraction	Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells. This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
In Situ Thermal Treatment	
Thermal Treatment	Steam/hot air injection or electrical resistance/electromagnetic/fiber optic/radio frequency heating is used to increase the volatilization rate of semi-volatiles and facilitate extraction.
Ex Situ Biological Treatment (assuming excavation)	
Biopiles	Excavated soils are mixed with soil amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps.
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes. Proper amendment selection ensure adequate porosity and provides a balance of carbon and nitrogen to promote thermophilic, microbial activity.
Landfarming	Contaminated soil, sediment, or sludge is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.

Technology (per media) [1]	Brief Description
Slurry Phase Biological Treatment	An aqueous slurry is created by combining soil, sediment, or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of the process, the slurry is dewatered and the treated soil is disposed of.

Technology (per media) [1]	Brief Description
Ex Situ Physical/Chemical Treatment (assuming excavation)	
Chemical Extraction	Waste contaminated soil and extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
Chemical Reduction /Oxidation	Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.
Dehalogenation	Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.
Separation	Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).
Soil Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
Ex Situ Thermal Treatment (assuming excavation)	
Hot Gas Decontamination	The process involves raising the temperature of the contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.
Incineration	High temperatures, 870-1,200 °C (1,600- 2,200 °F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.
Open Burn/Open Detonation	In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave. In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is generally initiated by the detonation of an energetic charge.
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
Containment	
Landfill Cap	Landfill caps are used for contaminant source control.
Landfill Cap Enhancements/Alternatives	The purpose of landfill cover enhancement is to reduce or eliminate contaminant migration (e.g. percolation). Water harvesting and vegetative cover are two ways for landfill cover enhancements. Water harvesting uses runoff enhancement to manage landfill site water balance. Vegetative cover reduces soil moisture via plant uptake and evapotranspiration.
Other Treatment	
Excavation, Retrieval, Off-Site Disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.
Allu Bucket[2]	An allu bucket can be attached to a loader or excavator and operates by breaking up and aerating the soil to promote the volatilization.
Human Health and Ecological Risk Assessment[2]	Each site is assessed to evaluate quantitative and qualitative factors that would further facilitate remedial option selection and implementation.
Sheet Pile Flow Through Wall[2]	Mitigates impacted sediment and surface water from migrating further, permitting flow of water; resists impacts weather conditions (freeze/thaw).

Technology (per media) [1]	Brief Description
Groundwater/Surface Water	
In Situ Biological Treatment	
Enhanced Bioremediation	The rate of bioremediation of organic contaminants by microbes is enhanced by increasing the concentration of electron acceptors and nutrients in ground water, surface water, and leachate. Oxygen is the main electron acceptor for aerobic bioremediation. Nitrate serves as an alternative electron acceptor under anoxic conditions.
Monitored Natural Attenuation	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.
Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and destroy organic/inorganic contamination in ground water, surface water, and leachate.
In Situ Physical/Chemical Treatment	
Air Sparging	Air is injected into saturated matrices to remove contaminants through volatilization.
Bioslurping	Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soils. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.
Chemical Oxidation	Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.
Directional Wells (enhancement)	Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.
Dual Phase Extraction	A high vacuum system is applied to simultaneously remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.
Thermal Treatment	Steam is forced into an aquifer through injection wells to vaporize volatile and semi volatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.
Hydrofracturing Enhancements	Injection of pressurized water through wells cracks low permeability and over-consolidated sediments. Cracks are filled with porous media that serve as substrates for bioremediation or to improve pumping efficiency.
In-Well Air Stripping	Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.
Passive/Reactive Treatment Walls	These barriers allow the passage of water while causing the degradation or removal of contaminants.
Ex Situ Biological Treatment	
Bioreactors	Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix.
Constructed Wetlands	The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals, explosives, and other contaminants from influent waters. The process can use a filtration or degradation process.

Technology (per media) [1]	Brief Description
Ex Situ Physical/Chemical Treatment (assuming pumping)	
Adsorption/ Absorption	In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase.
Advanced Oxidation Processes	Advanced Oxidation Processes including ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank. If ozone is used as the oxidizer, an ozone destruction unit is used to treat collected off gases from the treatment tank and downstream units where ozone gas may collect, or escape.
Air Stripping	Volatile organics are partitioned from extracted ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.
Granulated Activated Carbon/Liquid Phase Carbon Adsorp	Ground water is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.
Groundwater Pumping/Pump & Treat	Ground water pumping is a component of many pump-and-treat processes, which are some of the most commonly used ground water remediation technologies at contaminated sites.
Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.
Precipitation/Coagulation/Flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation.
Separation	Separation techniques concentrate contaminated waste water through physical and chemical means.
Sprinkler Irrigation	The process involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system.
Containment	
Physical Barriers	These subsurface barriers consist of vertically excavated trenches filled with slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards ground water flow.
Deep Well Injection	Deep well injection is a liquid waste disposal technology. This alternative uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.
Air Emissions/Off-Gas Treatment	
Biofiltration	Vapor-phase organic contaminants are pumped through a soil bed and sorb to the soil surface where they are degraded by microorganisms in the soil.
High Energy Destruction	The high energy destruction process uses high-voltage electricity to destroy VOCs at room temperature.
Membrane Separation	This organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane (a diffusion process analogous to putting hot oil on a piece of waxed paper).
Oxidation	Organic contaminants are destroyed in a high temperature 1,000°C (1,832 °F) combustor. Trace organics in contaminated air streams are destroyed at lower temperatures, 450 °C (842 °F), than conventional combustion by passing the mixture through a catalyst.
Scrubbers	Scrubber is an air washer with refinement device which is used for cleaning gases from soluble or particulates. It even treats fumes on line.
Vapor Phase Carbon Adsorption	Off-gases are pumped through a series of canisters or columns containing activated carbon to which organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.
Other Treatment	
Human Health and Ecological Risk Assessment[2]	Each site is assessed to evaluate quantitative and qualitative factors that would further facilitate remedial option selection and implementation.

Notes:
1 - List of 59 remedial technologies references from the United States Federal Remediation Technologies Roundtable, “Remediation Technologies Screening Matrix and Reference Guide, Version 4.0” accessed at *http://www.frtr.gov/matrix2/top_page.html* , August 21, 2013.

Technology (per media) [1]	Brief Description

2 - Remediation technique added to supplement those listed in the "Remediation Technologies Screening Matrix and Reference Guide, Version 4.0", referenced above.

Table 2 TECHNOLOGIES RATIONALE IN SITE-SPECIFIC EVALUATION
Solids (Soil)

Technology (per media)	Advantages/Limitations/Comments	Reasons for Removal (Primary/Secondary Exclusions)
In Situ Biological Treatment		
Enhanced Bioremediation	**Advantages:** Potential to decrease size of remedial excavation, where required. Effective for PHC contaminants as nutrients/microorganisms could enhance remediation. **Limitations:** Uncertain inorganic effectiveness - inorganic contaminants and application will dictate success. Drilling required to inject liquid mixture. Requires infrastructure and O&M. High overall costs. **Comments:** Free product and high contaminant concentrations can limit the effectiveness. Bench-scale testing required. Potential permits required to inject liquid into subsurface.	Additional testing required to determine baseline and final ecology. Colder climate may also prohibit enhanced biodegradation due to limited microbial activity.
Phytoremediation	**Advantages:** Potential to decrease size of remedial excavation, where required. Effective for PHC removal. **Limitations:** Requires forestation/vegetation. Only effective for plant root zone. Requires O&M and has high capital and overall costs. Low rate of system reliability. Requires longer than average time to remediate. Plant/flora disposal required as this becomes impacted. **Comments:** Impractical for Project.	Requires forestation/vegetation. Limited by type of flora that will succeed in soils present and climate (growing season). Only effective for plant root zone. Technically difficult to implement and maintain. Requires lengthy O&M.
In Situ Physical/Chemical Treatment		
Electrokinetic Separation	**Advantages:** **Limitations:** Below average effectiveness for PHC contaminant remediation. Requires significant infrastructure. **Comments:** Impractical for Project.	Difficult to implement and costly to install and operate. Below average effectiveness for PHC removal.
Fracturing	**Advantages:** Average effectiveness for PHC contaminant remediation. **Limitations:**Fractures will close in non-clayey areas. Has the potential to open new pathways for unwanted spread of contaminants. Requires supplemental remedial technology. **Comments:** Remediation technology required after fracturing (injection, extraction, etc.).	Requires supplemental remedial technologies. Average effectiveness for PHC removal.
Soil Flushing	**Advantages:** Average effectiveness for PHC contaminants. Potential to decrease size of remedial excavation, where required. **Limitations:** Requires O&M, significant drilling/infrastructure and liquid injection. **Comments:** Effects of chemical enhancement to environment unknown. Potential permits required to inject liquid into subsurface.	Not applicable and technically difficult to implement. Additional treatment of groundwater required due to leaching of contaminants from soil to groundwater.
Solidification/Stabilization	**Advantages:** Potential to decrease size of remedial excavation, where required. **Limitations:** Not effective for PHC contaminants. Requires O&M and significant drilling/infrastructure. Injection of stabilizing agent required. Costly to implement and maintain. **Comments:** Not applicable fo COCs at the Site. Potential additional approvals required for injection of stabilizing agent.	Not effective for PHC contaminants.
In Situ Thermal Treatment		
Thermal Treatment	**Advantages:** Expedited remediation for PHC contaminants. Potential to decrease size of remedial excavation, where required. **Limitations:** Requires significant infrastructure; high capital and O&M costs. **Comments:** Potential permitting required to implement. Average overall relative costs. Impractical for project.	Technically difficult and expensive to implement.

Technology (per media)	Advantages/Limitations/Comments	Reasons for Removal (Primary/Secondary Exclusions)
Ex Situ Biological Treatment (assuming excavation)		
Biopiles	**Advantages:** Effective for PHC contaminants. Relative to other technologies, low captial and O&M costs. **Limitations:** Excavation of impacted soils required. Longer timeframe may be required as material remains stagnant (no mixing). **Comments:** Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful). Must transport contaminated soil to compost.	Must transport contaminated soil to compost, due to space restrictions and potential exposure scenarios, this option could be applicable for the Site. Colder climate may also prohibit microbial activity which could render technology ineffective/cause increased time to closure.
Composting	**Advantages:** Effective for PHC contaminants. Relative to other technologies, low captial and O&M costs. **Limitations:** Costly to implement and maintain. Excavation and mixing of bulking agent required prior to composting. Lengthy O&M. **Comments:** Relies on balance of carbon and nitrogen to promote thermophilic, microbial activity. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful). Must transport contaminated soil off-site to compost, due to space restrictions. Not applicable for the Site.	Must transport contaminated soil off-site to compost, due to space restrictions. Not applicable for the Site. Colder climate may also prohibit microbial activity which could render technology ineffective/cause increased time to closure.
Landfarming	**Advantages:** Effective for PHC contaminants. Relative to other technologies, low captial and O&M costs. **Limitations:** Known as a medium to long-term treatment technology. Large footprint required to spread out contaminated soils. **Comments:** Must transport contaminated soil to landfarm, due to space limitations this option has drawbacks but could be applicable for the site but would be a viable option.	Must transport contaminated soil off-site to landfarm, due to space restrictions. Not applicable for the Site. Colder climate may also prohibit microbial activity which could render technology ineffective/cause increased time to closure.
Slurry Phase Biological Treatment	**Advantages:** Effective for PHC contaminants. **Limitations:** Excavation and mixing with additives required. High capital and O&M costs. **Comments:** Impractical for project - soil impacts are transferred to slurry, which requires extraction and treatment/disposal. Once excavated, thought must also be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement and costly to install and operate. Additional treatment/disposal of slurry required due to transfer of contaminants from soil to slurry.
Ex Situ Physical/Chemical Treatment (assuming excavation)		
Chemical Extraction	**Advantages:** Effective for PHC contaminants. **Limitations:** Requires excavation, mixing with chemical extractant, a mixing vessel, and separation of soil from extractant post remediation. Treatment/disposal of waste required. Several processes involved with associated infrastructure. **Comments:** Technically difficult to implement. Several processes involved in remediation. Locations to mix and separate soil from extractant required. Effects of chemical enhancement to environment unknown. Potential permits required to use chemicals on-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement, needs space on site for processing. Several complex processes involved in remediation. Costly to operate. Effects of chemical enhancement to environment unknown.
Chemical Reduction /Oxidation	**Advantages:** Expedited remediation. Effective for PHC contaminants. **Limitations:** Requires excavation, mixing with chemical reductant/oxidant, and O&M plan. Treatment/disposal of waste required. Several processes involved with associated infrastructure. Needs chemicals shipped to site which could be problematic. **Comments:** Technically difficult to implement. Several processes involved in remediation. Effects of chemical enhancement to environment unknown. Potential permits required to use chemicals on-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement, needs space on site for processing. Several complex processes involved in remediation. Costly to operate. Effects of chemical enhancement to environment unknown. Potential solution for site given spall quantity of soil if reagents can be shipped to site.
Dehalogenation	**Advantages:** No advantages with respect to project **Limitations:** Requires excavation and mixing with reagent. Several processes involved with associated infrastructure. **Comments:** Technically difficult to implement. Several processes involved in remediation. Locations to mix and separate soil required. Effects of chemical enhancement to environment unknown. Potential permits required to use chemicals on-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful). Low rate of system reliability.	Not effective for the removal of PHC impacts. Technically difficult to implement. Several complex processes involved in remediation. Costly to operate. Effects of chemical enhancement to environment unknown. Low rate of system reliability.
Separation	**Advantages:** Expedited remediation. Effective for PHC contaminants. **Limitations:** Requires excavation and physical and chemical separation. Several processes involved with associated infrastructure. High O&M costs. **Comments:** Technically difficult to implement. Several processes involved in remediation. Effects of chemical enhancement to environment unknown. Potential permits required to use chemicals on-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement. Several complex processes involved in remediation. Costly to operate. Effects of chemical enhancement to environment unknown.

Technology (per media)	Advantages/Limitations/Comments	Reasons for Removal (Primary/Secondary Exclusions)
Soil Washing	**Advantages:** Expedited remediation. Effective for PHC contaminants. **Limitations:** Only applicable for contaminants sorbed to fine-grained particles. Once removed, fine impacts sorbed to fine particles must be treated or disposed off-site. **Comments:** Technically difficult to implement. Several processes involved in remediation. Effects of chemical enhancement to environment unknown. Potential permits required to use chemicals on-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Not most applicable remediation for observed impacts. Only applicable for contaminants sorbed to fine-grained particles. Technically difficult to implement. Several complex processes involved in remediation. Costly to operate. Effects of chemical enhancement to environment unknown.
Ex Situ Thermal Treatment (assuming excavation)		
Hot Gas Decontamination	**Advantages:** Expedited remediation for certain contaminants; however, lower efficiency for PHC contaminants. **Limitations:** Lower than average efficiency for PHC contaminants. High cost to operate. **Comments:** Technically difficult to implement. Several processes involved in remediation. Appropriate vessel to heat soil must be located and brought to site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement. Not practically applicable remediation for observed impacts. Lower than average efficiency for PHC impact remediation. Several complex processes involved in remediation.
Incineration	**Advantages:** Expidited remediation. Effective for PHC contaminant remediation. **Limitations:** High capital and O&M costs. **Comments:** Technically difficult to implement. Several processes involved in remediation. Incinerator must be brought to site, or soils transported off-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement. High capital and O&M costs.
Open Burn/Open Detonation	**Advantages:** Expedited remediation for certain contaminants; however, lower than average efficiency for PHC contaminants. **Limitations:** Lower than average efficiency for PHC contaminants. High cost to operate. **Comments:** Technically difficult to implement. Several processes involved in remediation. Appropriate area to perform open burn must be located on or off-site. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement. Not most applicable remediation for observed impacts. Lower than average efficiency for PHC impact remediation.
Pyrolysis	**Advantages:** Expedited remediation. Effective for PHC contaminant remediation. **Limitations:** High capital and O&M costs. Long timeframe required. **Comments:** Technically difficult to implement. Several processes involved in remediation. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful). Disposal of coke byproduct must be determined. Low rate of system reliability.	Technically difficult to implement. Generation and disposal requirements of byproducts. Low rate of system reliability.
Thermal Desorption	**Advantages:** Expedited remediation. Effective for PHC contaminant remediation. **Limitations**: High capital and O&M costs. **Comments:** Technically difficult to implement. Several processes involved in remediation. Once excavated, thought must be given to the placement of excavated soil post treatment (leave in place, re-use on-site, or dispose of off-site if remediation option is not successful).	Technically difficult to implement. Generation and disposal requirements of byproducts.
Containment		
Landfill Cap	**Advantages:** Moderately effective for PHC impacts. Contains impacts while treatment is being applied. **Limitations:** Does not lessen toxicity, mobility, or volume of impacts; only mitigates migration of impacts. **Comments:** Cap cannot be comprimised by land use activities. Not applicable for the Site.	Does not remediate impacts. Continuous monitoring required.

Table 3 TECHNOLOGIES RATIONALE IN SITE SPECIFIC EVALUATION
Liquids (Water)

Technology (per media)	Advantages/Limitations/Comments	Reasons for Removal (Primary/Secondary Exclusions)
In Situ Biological Treatment		
Enhanced Bioremediation	**Advantages:** Effective for PHC contaminants as nutrients/microorganisms could enhance remediation. **Limitations:** Requires infrastructure and O&M. High overall costs. **Comments: If f**ree product and/or high contaminant concentrations are encountered, it can limit the effectiveness. Effects of nutrient enhancement to environment unknown. Bench-scale testing required. Potential permits required to inject liquid into subsurface.	Technically difficult to implement. Colder climate may also prohibit enhanced biodegradation due to limited microbial activity.
Phytoremediation	**Advantages:** Effective for PHC contaminants. **Limitations:** Requires forestation/vegetation. Only effective for plant root zone. Requires O&M and has high capital and overall costs. Low rate of system reliability. Requires longer than average time to remediate. **Comments:** Impractical for Project.	Requires forestation/vegetation. Limited by type of flora that will succeed in soils present and climate (growing season). Only effective for plant root zone. Technically difficult to implement and maintain. Requires lengthy O&M. Disposal of flora required post remediation as contaminants transfer from media to plant roots.
In Situ Physical/Chemical Treatment		
Air Sparging	**Advantages:** Expedited remediation for PHC impacted media. **Limitations:** Restricted to summer months only. Requires continual monitoring. **Comments:** Bench-scale testing required.	Restricted to summer remediation. Technically difficult to implement. Additional testing required to determine baseline and final ecology. Effects of enhancement to environment unknown.
Bioslurping	**Advantages:** Effective for PHC remediation. **Limitations:** Technically difficult to implement as it combines two remediation strategies. High operating costs. **Comments:** Technically impractical for Project constraints.	Restricted to summer remediation. Not most applicable remediation for Project.
Chemical Oxidation	**Advantages:** Expedited remediation. **Limitations:** Average to below average effectiveness for PHC contaminant remediation. Drilling required to inject liquid mixture. O&M required. **Comments:** Effects of chemical enhancement to environment unknown. Potential permits required to inject liquid into subsurface. Potential bench-scale testing required.	Not most applicable remediation for observed impacts. Difficult to implement. Effects of chemical enhancement to environment unknown.
Directional Wells (enhancement)	**Advantages:** Uncertain, not required on this site. **Limitations:** Infrastructure and drilling required for subsurface impacts. High overall costs. Technology alone does not remediate. **Comments:** Must be paired with a remedial strategy (chemical injection, pump and treat, etc.) to complete remediation.	Not most applicable remediation for observed impacts. Difficult to implement. Must be paired with additional remedial strategy (chemical injection, pump and treat, etc.) to complete remediation.
Thermal Treatment	**Advantages:** Expedited remediation for PHC contaminants. **Limitations:** Requires significant infrastructure. **Comments:** Potential permitting required to implement. Above average O&M and captial costs. Impractical for project.	Technically difficult to implement. Drilling and/or infrastructure required.
Hydrofracturing Enhancements	**Advantages:** Limited effectiveness for PHC impacts. **Limitations:** Infrastructure and drilling required for subsurface impacts. High overall costs. Fractures may collapse due to overburden pressure. **Comments:** Potential exists to open new pathways leading to the unwanted spread of contaminants.	Technically difficult to implement. Drilling and/or infrastructure required.
Passive/Reactive Treatment Walls (trap) or Sheet Pile Flow-Through Wall (funnel & gate)	**Advantages:** Effective for PHC contaminants. **Limitations:** Infrastructure required. Monitoring required to monitor effects to environment. **Comments:** Practical solution for the Project wither with Waterloo Emmitter or Funnel and gate reactive flow through barrier.	Technically difficult to implement and labor intensive but end result is passive with minimal O & M.

Technology (per media)	Advantages/Limitations/Comments	Reasons for Removal (Primary/Secondary Exclusions)
Ex Situ Biological Treatment		
Bioreactors	**Advantages:** Effective for PHC contaminants. **Limitations:** Infrastructure required. Monitoring required to monitor effects to environment. **Comments:** Impractical for Project.	Difficult to implement due to infrastructure required. High cost to install and operate.
Constructed Wetlands	**Advantages:** Limited effectiveness for PHC remediation. **Limitations:** Intricate artificial ecosystem development. Unknown effects to natural environment. System efficiency must be continually monitored. **Comments:** Consideration must be made for artificial wetland disposal once remediation is complete. Remediation efficiency could be limited by temperature in Project area.	Not applicable as the installation of a constructed wetland in the Project area is not practical.
Ex Situ Physical/Chemical Treatment (assuming pumping)		
Adsorption/ Absorption	**Advantages:** **Limitations:** Limited effectiveness for PHC impacts. High O&M costs and long remedial timeframe. **Comments:** Contaminated media often requires further treatment / disposal as hazardous waste.	Limited ffectiveness for PHC remediation.
Advanced Oxidation Processes	**Advantages:** Effective for PHC impacts. **Limitations:** High capital and O&M costs. Long timeframe for remediation (>10 years). **Comments:**Pretreatment of impacted water may be required. Requires handling and storage of oxidizers	High capital and O&M costs. Timeframe may not be suitable for future site developments.
Air Stripping	**Advantages:** **Limitations:** Not effective for PHC remediation. High O&M costs and lengthy remedial time. Off-gases may require treatment. **Comments:** Not applicable for site COCs.	Not effective for PHC impacts.
Granulated Activated Carbon/Liquid Phase Carbon Adsorption	**Advantages:** Effective for PHC remediation. High system reliability. **Limitations:** High O&M costs and lengthy remedial time **Comments:** Pore size, quality of carbon, as well as operating temperature will impact process performance. All spent carbon must be properly disposed of.	High O&M costs. Timeframe may not be suitable for future site developments.
Ion Exchange	**Advantages:** **Limitations:** Not effective for PHC remediation. High O&M costs and lengthy remedial time. **Comments:** Not applicable for site COCs.	Not effective for PHC remediation. High O&M costs and lengthy remedial time.
Precipitation/Coagulation/Flocculation	**Advantages:** **Limitations:** Not effective for PHC remediation. High O&M costs and lengthy remedial time. **Comments:** Not applicable for site COCs.	Not effective for PHC remediation. High O&M costs and lengthy remedial time.
Separation	**Advantages:** Effective for PHC remediation. Shorter timeframe required. **Limitations:** High captial and O&M costs. **Comments:** Mainly used as a pre-treatment or post-treatment process to remove contaminants from waste water.	High capital and O&M costs.
Sprinkler Irrigation	**Advantages:** **Limitations:** Performance can be affected by temperature. Lengthy remedial time required. **Comments:** Regulatory approval may be difficult to obtain for this technology as there is a potential for direct release of contaminants into the atmosphere.	Performance may be affected by temperature. Lengthly remedial timeframe required.
Containment		
Physical Barriers (Booms, skirts, sheet pile flow through walls)	**Advantages:** Keeps impacted groundwater from migrating off-site, or from migrating on to the Site. Low cost. **Limitations:** Construction costs; challenging installation. **Comments:** Moderate O&M	Seasonal constraints, and not applicable due to potential destruction to environment.
Deep Well Injection	**Advantages:** Limited effectiveness for PHC remediation. **Limitations:** Pilot-scale testing would be highly recommended. Regulatory approvals will be complicated and lengthy. **Comments:** Not likely practical for Site	Limited effectiveness for PHC remediation.