APPENDIX B2

SITE INVESTIGATION REPORTS COMPLETED SINCE CLOSURE AND RECLAMATION PLAN – BENCH SCALE TESTING OF SHALLOW HEAVILY IMPACTED SOIL NEAR FORMER ROASTER COMPLEX, GIANT MINE REMEDIATION PROJECT, NT

GOLDER

TECHNICAL MEMORANDUM

DATE 17 November 2020 **Reference No.** 1314260010-456-TM-Rev0-46000

TO Rene Hawkes, P.Eng.
PSPC - Giant Mine Remediation Project

CC Cathy Corrigan, AECOM Canada
Hugh Carter, Golder Associates Ltd.

FROM Ryan Preston and Arthur Cole **EMAIL** Ryan_Preston@golder.com; Arthur_Cole@golder.com

FINAL RESULTS –
BENCH SCALE TESTING OF SHALLOW HEAVILY IMPACTED SOIL NEAR FORMER ROASTER COMPLEX GIANT MINE REMEDIATION PROJECT, NT

The Giant Mine Remediation Project (GMRP) is currently in the regulatory, remedial design and closure planning stages and is in the care, custody, and control of Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) and the Government of the Northwest Territories (GNWT). The GMRP design team is led by CIRNAC and supported by GNWT. CIRNAC funds this project and has engaged Public Services and Procurement Canada (PSPC) to provide project management and contract oversight services. PSPC has retained AECOM Canada and Golder Associates Ltd. (the Consultants) to provide remedial engineering design support. PSPC has recently also selected Parsons Inc. as the GMRP main construction manager (MCM).

Approximately 50,000 m^3 of heavily impacted surficial soils are present in the vicinity of the former Roaster Complex. These shallow soils have been affected by Roaster emissions, and the concentration of total arsenic in these coarse materials has been typically greater than 4500 mg/kg. These materials have been deemed unsuitable for disposal with contaminated granular fill in either the A1 open pit or the unfrozen zone of the B1 open pit or the designated tailings containment areas (TCAs). The disposal of these materials within the frozen zone of the B1 Pit was therefore identified as the preferred location.

Through the B1 Pit closure design process, the costs associated with the placement and freezing of the heavily impacted soil in the B1 Pit was identified by CIRNAC/PSPC as significant. Furthermore, the risks associated with identifying larger volumes of material (greater than 50,000m^3) also represented significant technical risks, as the B1 Pit has specific volume limitations.

The potential application of soil processing was originally identified by AECOM/Golder in 2017 as a strategy to potentially reduce the volume of materials requiring long term freeze stabilization in the B1 Pit. Based on a desk top review, it was concluded that the processing of these heavily impacted shallow soils may achieve a significant reduction in the volume of material requiring freeze stabilization in the B1 Pit. However, field testing was necessary to evaluate this potential strategy further.

In September 2018, CIRNAC/PSPC requested that Golder coordinate the completion of a bench scale testing program. The purpose of the testing program was to determine whether soil processing is technically feasible, and to estimate an approximate cost per m^3 to process heavily impacted soil. CIRNAC/PSPC issued a Request for Information (RFI) in early 2019, and subsequently pre-qualified four remediation contractors in May 2019. These remediation contractors were selected based on their experience with respect to remediation of granular material. PSPC/CIRNAC pre-qualified the following four contractors to complete bench scale testing: (i) Clean Earth Technologies; (ii) EnGlobe; (iii) Milestone Environmental Contracting; and (iv) Nelson Environmental Remediation (referred to as “Contractor” or “the Contractors”).

A site visit was completed on 22 August 2019. Each Contractor was provided with site characterization data (provided by Golder/AECOM) as well as a brief technical presentation and site tour. Following the site tour, each Contractor was provided with a sealed 20L plastic container of contaminated material. Each Contractor was responsible for transporting the contaminated material to their testing facility, completing bench scale testing and reporting results.

PSPC/CIRNAC specifically requested pre-qualified Contractors to consider applicable ex-situ remedial “soil processing” methods. It was anticipated that the Contractors would likely propose a mechanical separation technique in combination with water, however the specific “soil processing” method was to be independently proposed by the Contractors.

The Contractors were requested to provide bench scale test information in the format requested by CIRNAC/PSPC. The template response form was intended to ensure the Contractors provided CIRNAC/PSPC with the information needed to evaluate applicability of soil processing, and to allow comparison of results between Contractors. The Contractors were generally requested to limit their submission to the provision of factual data. CIRNAC/PSPC also requested the Contractors (if possible) to provide brief descriptions/additional information on several topics. Contractors were also requested to refrain from providing proprietary methods/information as part of the results.

The purpose of this memorandum is to summarize the results of the bench-scale testing. This report is divided into two main sections: (i) data interpretation and (ii) summary of results. The data interpretation section provides a brief comparison of the test results for the four Contractors. Section 2 presents a summary of the bench scale testing program.

Should soil processing ultimately proceed to full scale remediation, PSPC through the MCM will proceed with an open bid process. It is understood that the results of bench scale testing will be disclosed to all participants in the open bid process.

1.0 DATA INTERPRETATION

1.1 Overview

The requested information from bench scale testing was subdivided into five main test components: (i) pre-processing sample characterization; (ii) general test information; (iii) processed material; (iv) residual material; and (v) potential full-scale operations. The results of the testing are compiled and compared in Tables 1 to 5 below. The Contractors were instructed to provide “not applicable” responses where appropriate.

For the purposes of this report, the comparison of the bench test results between the four Contractors are qualitatively evaluated as follows:

- inconclusive result – no consistent result or opinion
- majority result - three of four Contractors provide similar results or opinions
- unanimous result - all Contractors agree

The four Contractors generally reported either "majority" or "unanimous" results within each of the five testing components (defined above), with occasionally conflicting conclusions. The following sections provide our interpretation and comparison of the results.

1.2 Pre-processing Sample Characterization

The soil samples were obtained from several shallow test pits in the Roaster area. The soil was placed in plastic 20L containers and sealed for shipping prior to the Contractor site visit and each bucket received a roughly equal amount of soil from each test pit. Although each sample was gently mixed, it was recognised that there would be some heterogeneity within each sample and between the samples. The results of pre-processing sample characterization are summarized below.

Table 1: Pre-processing Test Results

	Clean Earth		EnGlobe		Milestone		Nelson	
Sample No.	UT-1/ UT-2		9		-		-	
What is the total arsenic concentration of the unprocessed soil?	2,540/ 8,460	mg/kg	5,600	mg/kg	2,100	mg/kg	3,150 (avg.) 12,403 (max)	mg/kg
What is the mass of the unprocessed soil?	12.5	kg	3.2	kg	20	kg	12	kg
What is the grain size distribution of the unprocessed soil?	70/39[a]	% gravel sized;	40	% gravel sized;	50	% gravel sized;	43.1	% gravel sized;
	14/28	% sand sized;	35	% sand sized;	40	% sand sized;	41.2	% sand sized;
	16/33	% silt/clay sized	25	% silt/clay sized	10	% silt/clay sized	15.7	% silt/clay sized
What is the estimated percentage of cobbles and boulders in the unprocessed soil (based on observations made during the site visit)?	20–40	%	20–40	%	20	%	20–40	%
Was demolition debris observed in the unprocessed soil sample?	☐ Yes ☒ No		☐ Yes ☒ No		☐ Yes ☒ No		☐ Yes ☒ No	
What is the unprocessed soil description (Unified Soil Classification System [USCS])?	GW-GC Well graded/ fine to coarse gravel to clayey gravel		Silty sand		SW Well graded sand/ fine to coarse sand		GM-GC Silty gravel to clayey gravel	

(a) Clean Earth providing grain size distribution data for two samples.

The total arsenic concentrations within the unprocessed soil ranged widely from 2,100 mg/kg (Milestone) to 12,403 mg/kg (Nelson). These analytical results were generally consistent with historical soil quality investigations in the former Roaster area and reflect the heterogenic nature of the distribution of arsenic in shallow soil.

The mass of sample used in the bench scale testing ranged from 3.2 kg (EnGlobe) to 20 kg (Milestone). None of the Contractors identified the presence of demolition debris in the unprocessed materials.

The grain size distributions of the unprocessed materials were generally consistent, with each Contractor classifying the sample material as coarse grained soil ranging from a silty sand to a clayey gravel; with 20 to 40% cobbles and boulders. These gradational results are also generally consistent with historical investigation data in the former Roaster area and also reflect the grain size variability of the shallow fill materials.

1.3 General Test Information

The Contractors were requested to respond to several general questions concerning pre-processing; the use of chemical agents and disposal of wastewater. A summary of the reported information with respect to these issues is provided below.

Table 2: Summary of General Test Information

	Clean Earth		EnGlobe		Milestone		Nelson	
Briefly describe test method / standards followed or referenced (ASTM / CSA), if applicable.	EPA[a] SW646		In-house testing		TCLP[b]		EPA SW 846 6020A/	
Does the unprocessed soil require blending/ homogenization prior to processing?	☐ Yes ☒ No		☐ Yes ☒ No		☐ Yes ☒ No		☒ Yes ☐ No	
Will the unprocessed soil require the addition of chemicals as part of processing? If yes, please provide SDS/MSDS of proposed chemicals. All chemicals must be pre-approved by the MVLWB prior to use on site.	☐ Yes ☒ No		☐ Yes ☒ No		☒ Yes ☐ No (SDS not provided – proprietary chemical)		☒ Yes ☐ No (SDS not provided – proprietary chemical)	
What is the total arsenic concentration of process wastewater planned for disposal either on-site or off-site?	-	mg/L	25	mg/L	-	mg/L	-	mg/L
	☒ Not Applicable		☐ Not Applicable		☒ Not Applicable		☒ Not Applicable	

(a) EPA = Environmental Protection Agency.

(b) TCLP = Toxicity Characteristic Leaching Procedure.

The Contractors referenced test methods used for chemical analysis and defining the grain size distribution. No standard method for soil processing testing was identified.

The majority of Contractors agreed that the unprocessed soils will not require blending or homogenization prior to processing. Nelson suggested that pre-processing of the soil would be preferred.

The majority of Contractors agreed that the disposal of treated wastewater would not be required. EnGlobe indicated that the wastewater was expected to have a total arsenic concentration of 25mg/L.

1.4 Processed Material

The Contractors were requested provide information with respect to the processed material. This information may be used to assess potential suitability of these materials for either disposal or re-use on site. A summary of the reported information is provided below.

Table 3: Processed Material

	Clean Earth		EnGlobe		Milestone		Nelson	
1) What is the ratio of processed to unprocessed soil?	53–78	%	42	%	92.5	%	80–88	%
2) What is the grainsize distribution of the processed soil?	90	% gravel sized;	100	% gravel sized;	-	% gravel sized;	55	% gravel sized;
	10	% sand sized;	0	% sand sized;	-	% sand sized;	45	% sand sized;
	0	% silt/clay sized	0	% silt/clay sized	-	% silt/clay sized	0	% silt/clay sized
3) What is the total arsenic concentration of the processed soil?	66–185	mg/kg	127	mg/kg	1070	mg/kg	1169–1683	mg/kg
4) What is the total leachable (TCLP) arsenic concentration of the processed soil?	0.03–0.04	mg/L	0.49	mg/L	0.4	mg/L	0.185–0.4825	mg/L

The majority of Contractors reported the processed/unprocessed soil ratio ranging from about 78 to 92.5%. This result indicates that the processing of heavily contaminated materials will result in the production of a large volume of “processed material”. These processed materials will be suitable for either: (i) re-use on site; or (ii) on site disposal. The results from EnGlobe were significantly lower (42%), compared to the other three contractors. This information was used to estimate the overall volume reduction of heavily impacted soils.

The majority of Contractors agreed that the grain size distribution of the processed soils would be comprised of gravel and sand sized particles with some cobbles and boulders. EnGlobe indicated that the processed material will consist of gravel-sized material with some cobbles and boulders.

The Contractors were inconclusive with respect to the total arsenic concentration within the processed material. Total arsenic concentration ranges between 66-185 mg/kg were recorded by two Contractors; and two Contractors reported ranges from 1070-1683 mg/kg. The Contractors unanimously agreed that the total leachable (TCLP) arsenic concentration of the processed soil was less than 0.5 mg/L.

1.5 Residual Material

This information may be used to assess potential disposal alternatives for these materials. It is possible that the residual materials may be either frozen in the B1 Pit or further processed for underground disposal within a frozen area, as paste. A summary of the reported information with respect to residual soil bench scale testing is shown below.

Table 4: Residual Material

	Clean Earth		EnGlobe		Milestone		Nelson	
1) What form will the full-scale residual material be produced as? If available, please provide photographs.	☐ Liquid ☒ Solid ☐ Paste		☐ Liquid ☒ Solid ☐ Paste		☐ Liquid ☒ Solid ☐ Paste		☐ Liquid ☒ Solid ☐ Paste	
2) What is the ratio of residual material to unprocessed soil?	47–22	%	58	%	7.5	%	12–20	%
3) What is the grainsize distribution of the residual material?	0	% gravel	0	% gravel	-	% gravel	0	% gravel
	29	% sand	70	% sand	-	% sand	0	% sand
	71	% silt/clay	30	% silt/clay	-	% silt/clay	100	% silt/clay
4) What is the total arsenic concentration of the residual material?	819–9770	mg/kg	5826	mg/kg	8000	mg/kg	7151	mg/kg
5) What is the total leachable (TCLP) arsenic concentration of the residual material?	3.05–23.0	mg/L	22.5	mg/L	10	mg/L	11	mg/L
6) What is the soil description of the residual material?	Low plastic clay		Silty sand		Silty sand		Silt	

The Contractors unanimously agreed that the residual materials produced at full-scale would be a solid material.

The majority of Contractors reported the ratio of residual/unprocessed soil ranged from 7.5 to 22%. EnGlobe results were the outlier; with a reported 58% mass of residual soil. This information will be used to estimate the overall volume residual material produced.

The Contractors were inconclusive with respect to grain size distribution of the processed residual soil. Nelson reported that the residuals would be composed of 100% silt and clay sized particles. Two Contractors reported that the residuals would be composed of proportions of sand and silt/clay sized particles.

The Contractors unanimously reported high concentrations of total arsenic in the processed residual soil. These total arsenic concentrations typically ranged from 5800 to 9800 mg/kg. The Contractors also reported leachable arsenic concentrations (TCLP method) of the residual material in the range of 10 to 23 mg/L.

1.6 Potential Full-scale Operation

Based on the results of the bench scale testing, the Contractors were requested to provide information with respect to the potential implementation of a full-scale soil processing facility. This information may be used to assess the performance of soil processing; potential efficiencies and constraints. A summary of the reported information with respect to full scale operation is shown below.

Table 5: Full Scale Operation

		Clean Earth		EnGlobe		Milestone		Nelson	
1)	Can the system achieve the total arsenic concentration reduction goal for the processed soil of less than 340 mg/kg?	☒ Yes ☐ No		☒ Yes ☐ No		☐ Yes ☒ No Arsenic mineralization in processed material is a constraint.		☒ Yes ☐ No More work required	
■	If no, what total arsenic concentration for processed soil can you achieve?	-	mg/kg	-	mg/kg	1070	mg/kg	-	mg/kg
■	If yes, on a scale of 1 to 10, how confident are you in the above answer?	10		-		10		6, more work required	
2)	Estimate the daily through put at full scale	☒ Less than 1000m3/day ☐ Greater than 1000m3/day		☐ Less than 1000m3/day ☒ Greater than 1000m3/day		☒ Less than 1000m3/day ☐ Greater than 1000m3/day		☒ Less than 1000m3/day ☐ Greater than 1000m3/day	
3)	Estimate the ratio of processed soil (excluding residual) and unprocessed soil achieved at full scale remedial operation.	63–81	%	45–50	%	92.5	%	85	%
4)	What is the consumptive volume of process water estimated at full scale?	25	m^3/day	40	m^3/day	-	m^3/day	-	m^3/day
5)	Is water re-cycling a component of the process?	☒ Yes ☐ No		☒ Yes ☐ No		☒ Yes ☐ No		☒ Yes ☐ No	
6)	Will water discharge be necessary?	☐ Yes ☒ No		☐ Yes ☒ No		☐ Yes ☒ No		☒ Yes ☐ No Periodically	
■	If yes, what is the daily disposal quantity at full scale?		m^3/day	-	m^3/day		m^3/day	N/A water to be treated	m^3/day
7)	Dust generation is a concern during operation. Can this be effectively managed?	☒ Yes ☐ No		☒ Yes ☐ No		☐ Yes ☒ No		☒ Yes ☐ No	
8)	Are you recommending the use of additives/ solvents to extract contaminants? If yes, please provide SDS sheets.	☐ Yes ☒ No		☐ Yes ☒ No		☒ Yes ☐ No		☒ Yes ☐ No	

The majority of Contractors agree that soil processing will achieve the total arsenic concentration reduction goal of less than 340 mg/kg. Milestone indicated that the arsenic mineralization in processed material will represent a constraint. Verification of processed material quality will be required prior to evaluating re-use. This issue was not a criterion with respect to the evaluation of the feasibility of soil processing.

The majority of Contractors agree that the daily through put at full scale will be less than 1000 m^3/day. EnGlobe indicated that the daily throughput will be greater than 1000 m^3/day.

The majority of Contractors agreed that soil processing would significantly reduce the volume of heavily impacted soil. The ratio of processed to unprocessed soil achieved at full scale remediation ranged from 63 to 92%. EnGlobe was the single outlier; and estimated a volume reduction of 45 to 50%.

The majority of Contractors agreed that dust generation could be effectively managed. Milestone was not confident that dust could be effectively managed.

The Contractors were inconclusive with respect to whether the addition of a chemical agent would be beneficial. Both Nelson and Milestone supported the use of chemical agents to improve processing performance. Details concerning the type of chemical to be used was considered proprietary information and therefore SDS/MSDS was not provided at this time.

2.0 SUMMARY OF RESULTS

All four selected Contractors completed the bench scale testing program in general accordance with the requirements specified by CIRNAC/PSPC. The heterogeneity of the bench scale soil samples resulted in variability of physical and chemical results. Several Contractors noted material variability within individual samples, and therefore elected to run multiple trials. Responses provided by several Contractors are therefore presented as a range of values. The majority of Contractors requested additional test materials and additional time to complete further testing. This request was not approved by CIRNAC/PSPC due to schedule constraints.

The following points summarize the key findings of the bench scale testing program.

- The Contractors unanimously agreed that soil processing was technically feasible. The Contractors unanimously agreed that hydro-processing in conjunction with mechanical/physical agitation was the preferred remedial method. The Contractors were inconclusive with respect to whether the addition of a chemical agent would be beneficial.
- Soil processing will transform the heavily impacted Roaster soils into: (i) processed materials (70 to 90% of total volume); and (ii) residual material (10-30% of total volume). The estimated volume reduction from the majority of Contractors therefore ranged from 70 to 90%. EnGlobe was the single outlier; and estimated a volume reduction of 50%.
- Processed material typically consists of sand and gravel; with some cobbles and boulders. The Contractors were inconclusive with respect to the total arsenic concentrations within the processed material. Total arsenic concentration range from 66 to 85 mg/kg was reported by two Contractors; and two Contractors reported a range from 1070 to 1683 mg/kg.

Milestone indicated that the "intrinsic" concentrations of arsenic in the processed material will likely result in total arsenic concentrations above 340 mg/kg. The potential presence of natural arsenopyrite (and other arsenic bearing minerals) within the granular material may pose an unacceptable long-term environmental risk post closure. Although the re-use of processed material has been identified by Milestone as a potential concern due to the presence of natural arsenic, this issue will be assessed during the project implementation phase. A material re-use/management strategy will be developed, and the quality of the processed material will be confirmed in the field.

Nelson indicates that with the application of low-cost chemical conditioners, further reductions in total arsenic concentrations (below 340 mg/kg) may be possible. The implementation of a field verification testing program would be required to confirm the re-use of processed material as construction material on site.

Based on the results of the bench scale testing, it should therefore be assumed that processed material will be disposed in either TCAs or A1 open pit or the unfrozen zone of the B1 open pit as contaminated granular fill. Further testing will be required to determine if the re-use of processed materials on site is acceptable.

- Residual material typically consists of silt and clay sized particles. The Contractors unanimously agreed that the total arsenic concentrations in the residual material would typically range from about 5800 to 9700 mg/kg. This material will likely therefore require disposal in the frozen zone of the B1 Pit. Alternatively, these materials may potentially be incorporated into a cemented paste and potentially disposed underground within one of the arsenic remediation areas that will be frozen. Additional testing would be required to verify the suitability of this approach. The cost for cemented paste production is not included in the cost estimate.
- The Contractors generally agreed that water recycling will be incorporated into the process. The consumptive use of water was estimated to range from 25 to 40m^3/day by two Contractors. The majority of Contractors agreed that water disposal would not be necessary. Nelson indicated that periodic disposal of wash water will be required.
- The majority of Contractors agreed that further testing work would be required prior to proceeding with full scale production.

The bench scale testing program successfully confirmed that soil processing is technically feasible.

The following points summarize our recommendations:

- The Arsenic Waste Disposal design team should complete a trade off analysis to compare soil processing with the disposal of these materials within the frozen zone of the B1 Pit. The soil processing option should assume: (i) 80% volume reduction of heavily impacted soil and; (ii) placement of residual material in the B1 Pit frozen zone. Alternative disposal options may be considered for both the management of the residual material and disposal of the processed material.
- Should the results of the trade off analysis indicate that soil processing is preferred:
  - CIRNAC/PSPC should consider incorporating the processed materials into the site wide material balance as contaminated granular fill. It is possible the processed materials may be disposed as contaminated granular fill in the B1 Pit.
  - CIRNAC/PSPC should evaluate whether additional research into chemical conditioners is necessary to achieve a total arsenic concentration of less than 340 mg/kg in the processed materials.

3.0 CLOSURE

Please contact the undersigned should you require additional information or clarification.

Golder Associates Ltd.

REGISTERED PROFESSIONAL ENGINEER
A. W. COLE
LICENSEE
NWT/NU

17 Nov 2020

Ryan Preston
Mine Stability West Group

Arthur Cole, P.Eng.
Principal, Senior Geological Engineer

RP/AC/cmm/et

https://golderassociates.sharepoint.com/sites/14381g/07 deliverables/03 wp use only/1314260010-456-tm-rev0-46000/1314260010-456-tm-rev0-46000-benchscale testing heavily impacts roaster soils 17nov_20.docx

PERMIT TO PRACTICE
GOLDER ASSOCIATES LTD.
Signature
Date Nov. 17, 2020
PERMIT NUMBER: P 049
NT/NU Association of Professional Engineers and Geoscientists