Giant Mine

Remediation Project

Determination and Practical Use of Geochemical Acceptance Criteria for Coarse-Grained Borrow at the Giant Mine Remediation Project

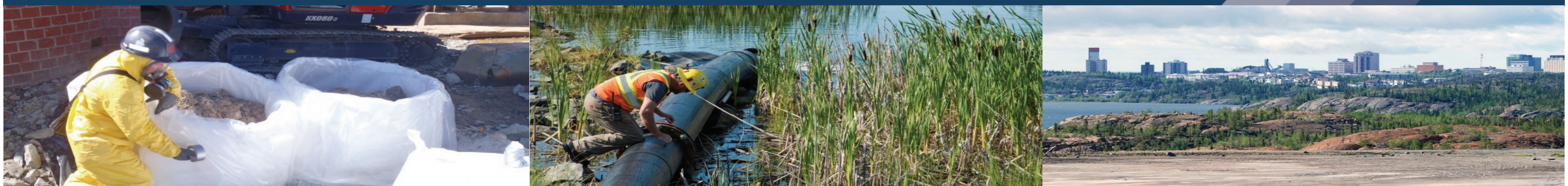
AECOM Contributors:
Mehrnoush Javadi
Cheibany Ould Elemine
Michael Steed
Rebecca Hurtubise

WSP Contributors:
Nico Bezuidenhout
Evelyn Tennant

Acknowledgement: AECOM and WSP are thankful to PSPC and CIRNAC for the permission to present this work

Government of Northwest Territories / Gouvernement des Territoires du Nord-Ouest

Canada



Presentation Outline

- Overview of Giant Mine Remediation Project (GMRP)
- Design and implementation of the characterization program
- Approach to the development of Project Specific Geochemical Acceptance Criteria (GAC)
- From Characterization to Implementation: Lessons learned from Water Treatment Plant (WTP) construction

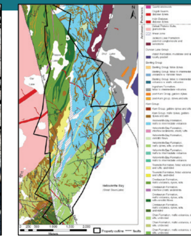
Giant Mine Remediation Project

- Located 5 km north of Yellowknife, NWT
- Abandoned open pit and underground gold mine
- In production over 5 decades, produced 220 tonnes of Au
- Has a large footprint of 1,600 hectares
- Includes 8 open pits, 4 tailings ponds behind 12 dams, extensive underground workings, over 1M m^3 of contaminated soils and 100 buildings
- Challenge: geogenic and anthropogenic As
- 237,000 tonnes of As trioxide dust stored in 14 chambers and stopes
- Crown Indigenous Relations and Northern Affairs Canada (CIRNAC) received water license and land-use permit in 2020 to proceed with implementation of closure and reclamation plan

Reference: "Project Planning for the Closure of the Legacy Giant Mine" paper by Chris MacInnis1, Brad Thompson2, and Michael Nahir3 1Crown Indigenous Relations and Northern Affairs Canada, Ottawa, ON. 2Public Services and Procurement Canada, Edmonton, AB, Canada, 3Parsons Inc., Chelsea, QC, Canada, Proceedings of ICARD 2024

Giant Mine Remediation Project

- Closure and reclamation required fine and <u>coarse</u> grain borrow
- Borrow is processed bedrock material
- Purpose: identify potential borrow sources for closure and reclamation works
- Majority of forecasted need could get generated from site closure activities
- Utilize borrow which are not source of environmental contamination and are appropriate for remedial use



CRP: closure and reclamation plan

The large volume requirement planned to be sourced from on site and off site borrow sources

On-site coarse-grained material will be sourced from bedrock quarries or from other remediation activities, where material is a ‘by-product’ (such as blasting rock to make a new channel for Baker Creek).

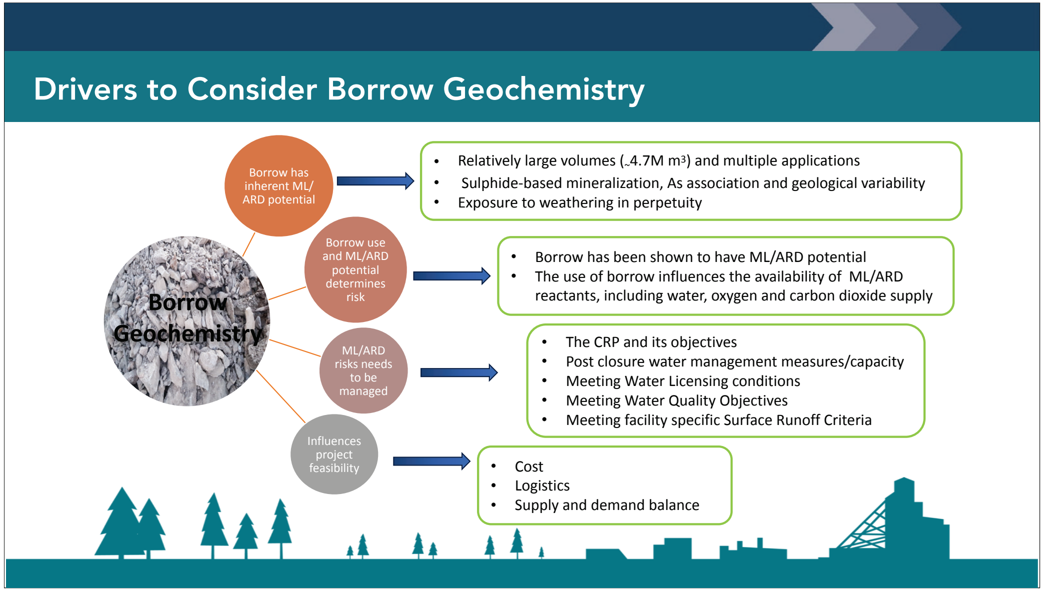
This presentation focuses on on-site coarse-grained borrow sourced from bedrock

Borrow use in GMRP is similar to mine waste and has the potential to undergo ARD/ML
ARD/ ML potential is determined by both borrow geochemistry and borrow use
ARD/ML from borrow is required to be managed in the context of:

- The CRP and its objectives
- The design of borrow use
- Post closure water management measures/capacity
- <u>Meeting complex/strict Water Licencing conditions</u>

To define the geochemical characteristics of borrow material that is required for a specific use to not exceed downstream water quality criteria

Add a comment on the deposit type and mineralization and geological variability on surface and potentially in depth



Mention CRP and SRC in full and define the acronyms

Summarize statements

Add approximate before 4.7M m3

For consideration:

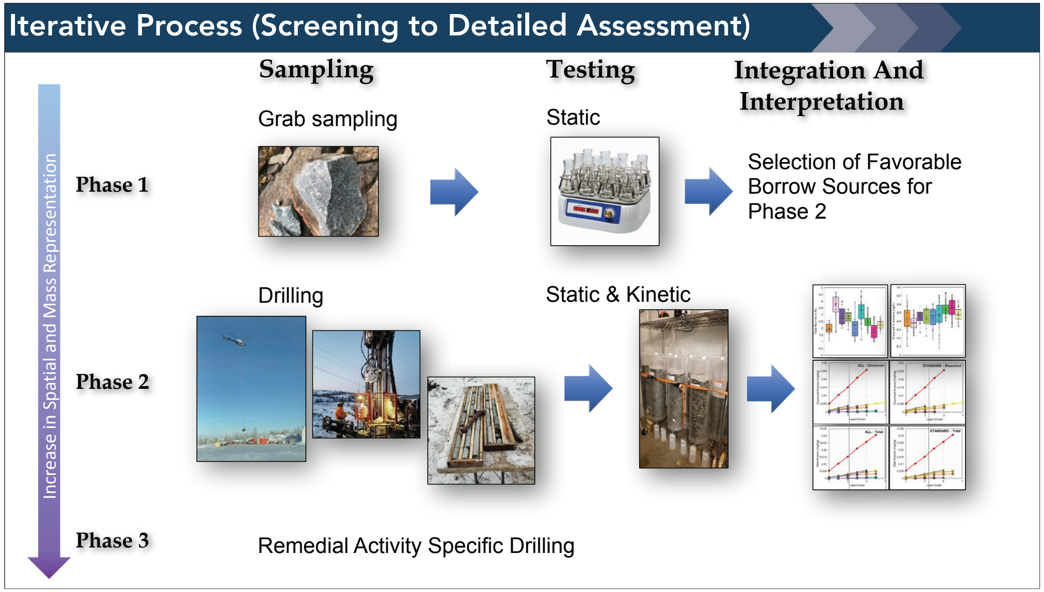
This is an important reminder of why borrow geochemistry is important and the headlines are that the geology at Giant is known to contain sulphide (and in particular arsenopyrite associated) mineralization reasonable to expect ARD/ML risks. Also large volumes etc

There is also As associated with roaster outfall that is highly mobile species (As^{5+})

Not only does the ARD/ML potential of borrow materials determine the ARD/ML risks but also the uses. If the use is such that it will allow for weathering and drainage to environment is far worse than where the borrow is used as fill under a cover.

There are environmental protection goals and regulatory compliance drivers in considering ARD/ML of borrow with the approved CRP outlines closure objectives and closure criteria that will apply once remediation is complete.

Then there are the project considerations…all good reasons to consider borrow quality



•Phased approach

•Iterative Process
(Screening to Detailed Assessment)
•Review background information and formulate key project questions
•Identify geology and potential borrow sources
•Determine mass of borrow sources, develop sampling strategy and collect representative samples
•Conduct and interpret static and kinetic geochemical tests
•Evaluate data sufficiency in context of project questions

For consideration:

There is an ongoing multi-year geochemical characterization program that was started for (coarse) borrow in 2018. At that stage we knew we were going to produce and use large masses of borrow, that some of the uses of borrow will be exposed to weathering in perpetuity and produce drainage and drainage chemistry that will have to be managed to meet project specific SRC and water quality objectives. More specifically the MVLWB directed the project to develop and refine more specific, lower criteria, for runoff from engineered structures.

This geochemical characterization program was initiated since the Board did not accept water license application that included numbers for surface runoff criteria that were in line with the federal Metal and Diamond Mining and Effluent Regulations or MDMER and directed the project to work *<u>to develop refine more site specific, lower criteria for runoff from engineered structures.</u>*

<u>Mackenzie Valley Land and Water Board (MVLWB) – regulatory authority</u>

The geochemical characterization program follows typical steps in a geochemical characterization programs in this case aimed at characterizing the borrow materials, prioritizing the best quality borrow and to provide specific data to answer project questions.

<u>Go from left to right ----</u>test that borrow to support the development of site specific lower, runoff criteria from engineered structures and geochemical criteria for materials to meet this SRC.

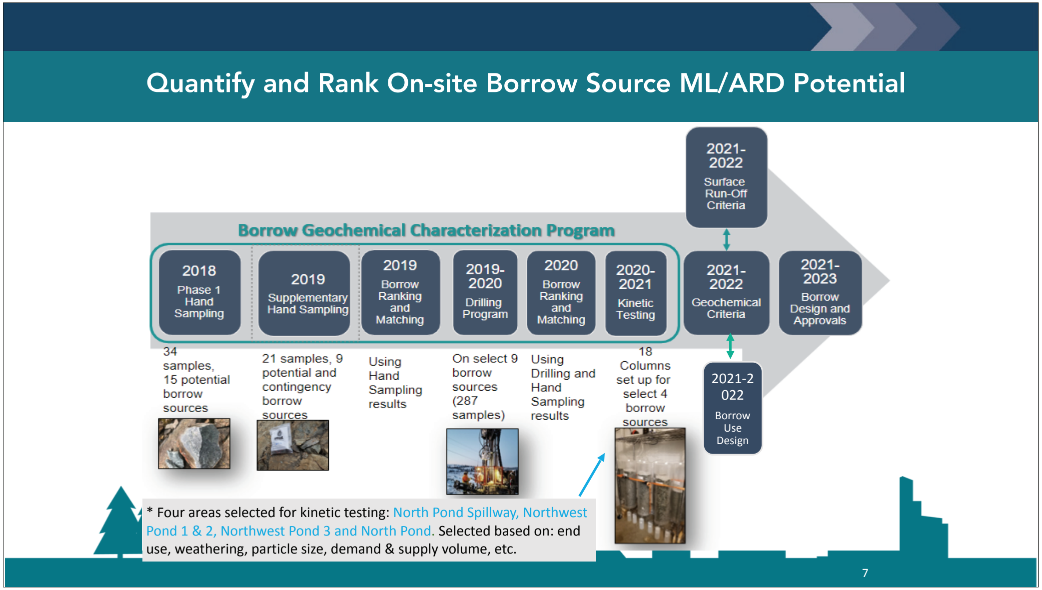
This diagram provides an overview of the geochemical characterization program which started in 2018 with broad based sampling of borrow sources, progressing to more detailed and invasive (drilling) characterization and continued prioritization of borrow sources for kinetic testing. Eventually, we chose 4 best borrow sources for kinetic testing which has been ongoing for over a year now. We are using this data for the SRC process, the development of geochemical acceptance criteria and the material balance (matching the demand of best quality borrow with the uses that require best quality borrow).

•Hand sampling Phase 1 – 38 samples, planned and contingency borrow sources, collected from surface, static testing.
•Supplementary hand sampling – 23 samples, planned, contingency and potential borrow sources, collected from surface, static testing
•Drilling Phase 2, 9 borrow sources screened from hand sampling programs, 36 boreholes, sampled every 3m , 300 samples, static and kinetic testing

•The Geochem and Geotech characterization drove the further characterization program, to understand the spatial variability in subsurface.
•We took advantage of this program to get as much as information we can get from the core to collect enough samples to provide large coverage

Phase 3:

Areas targeted specific geological structures. Not captured in the previous phases.
There was actually a third phase which is the remedial activity specific drilling (Phase 3 drilling) that targeted specific geological structures and delineation of geology/borrow quality using GAC.



It is for specific for aggregate products

Mentioning standard practices, GARD guide, MEND etc.

A multi-year geochemical characterization program of coarse-grained borrow was commenced in 2018.
The objectives of the geochemical characterization program were to: (1) characterize the ARD/ML potential of various coarse-grained, on-site, borrow resources; (2) prioritize the coarse-grained borrow resources based on their ARD/ML potential; and (3) develop material-specific geochemical data that can be used in the estimation of drainage chemistry from the use of the coarse-grained borrow.

Relative ranking of borrow sources

Matching borrow sources to applications (Tailings Cover, Landfill Cover, Construction, Pit Fill, Near-shore and Fore-shore)

Numerical modeling (PHREEQC) for run-off quality from tailing covers

Development of geochemical criteria

Used in Goldsim model for development of run-off quality criteria

Overview of Kinetic Program

Column Size, Type, PSD and Sample Characterization (18 columns, including 4 duplicates)

Column Type	Quantity		Borrow Source and Sub-Type	Diameter (m)	Approx. Height of Solids (m)	PSD
	Main	Dup.				
Standard	4	1	NPSW and NWP 3 For Base and Upper Composition	0.2	0.5	< 20 mm
	4	1	NWP1/2 and NP For Base and Upper Composition	0.2	0.5	< 10 mm (reject from TCA covers)
TCA Cover	4	1	NPW1/2 and NP For Base and Upper Composition	0.2	0.7	10 mm -20 mm
Subaqueous	2	1	NP For Base and Upper Composition	0.2	0.5	< 20 mm

Trickle/Leaching Rates:

- Sub-aerial– 100 mL/day (approx. 11 day cycle)
- Sub-aqueous – 1 L/2weeks

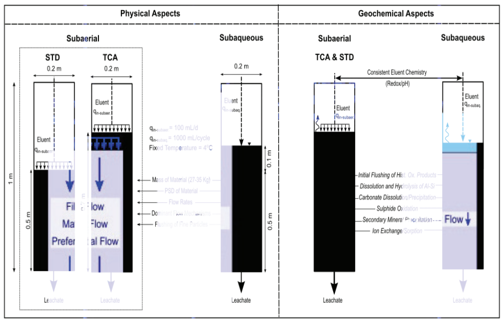
Columns maintained at 4°C (ave. T of site)

Pre- and Post-Column Geochemical Tests:

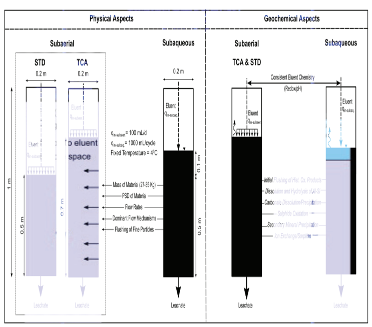
- Total Metals (Aqua Regia – ICP MS)
- Dissolved Metals (SFE)
- Acid Based Accounting (ABA)
- Mineralogy
- Particle Size Distribution (PSD)

Overview of Kinetic Program

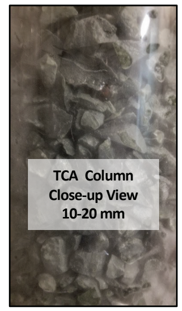
Physical Aspects

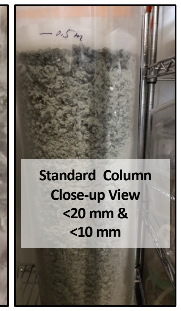


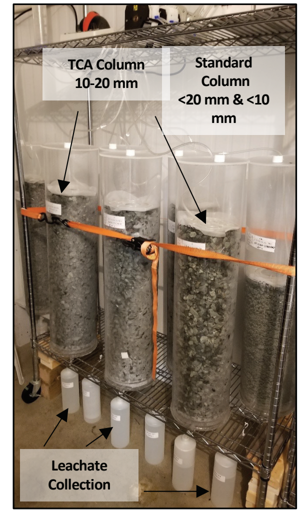
Geochemical Aspects

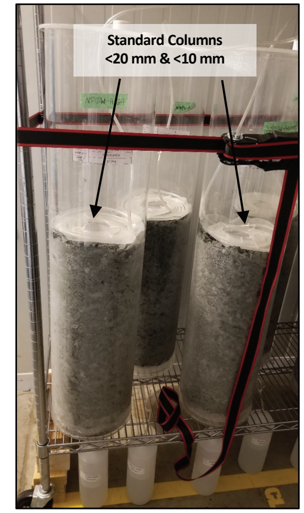


Subaerial Columns

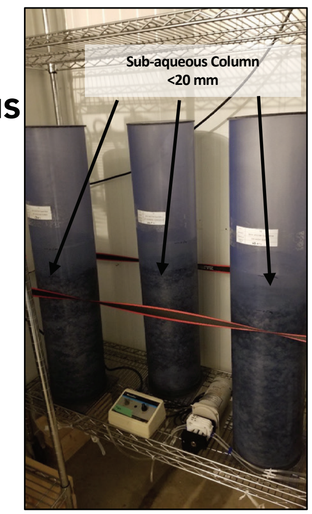


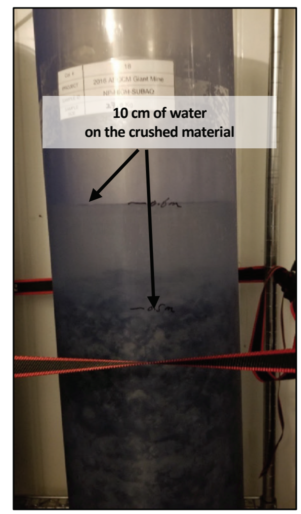






Sub-aqueous Columns





Summary of Key Findings

Good news

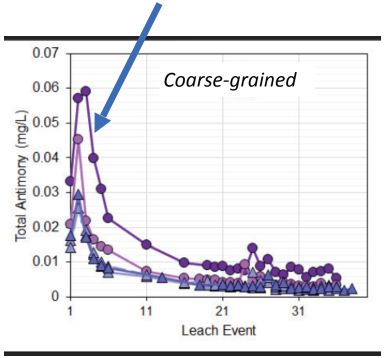
- No acidic drainage expected
- Not potentially acid generating
- Good quality material borrow found on Site with "natural" metal leaching

Other key results

- Pattern is higher concentrations during first flush, then drops
- Varies by area on Site

*Results used as an input to determine water quality in long term

'First flush' is high, then drops in longer term



For consideration:

The results of the kinetic test program indicate that the cover materials for the coarse grained covers will not be acidic confirming that the material does not have an acid drainage potential in otherwords a good quality runoff and that the material has low metal contents (particularly As) and metal leaching is similar to metal leaching that will take place for natural geology under natural weathering of these materials under site conditions.

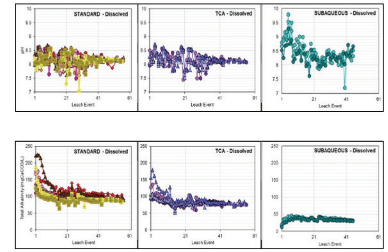
The graph on the right shows you a typical results from the column, in this case Antimony. Explain the graph axis. There is an initial high concentration as fines and fresh surfaces react with the water which then decreases over time to more representative longer-term qualities. We refer to these trends as ordered rate kinetic and results in a typical declining water quality as the columns testing progresses.

These trends are obviously specific to the type of material (its main mineralogy) and each element.

These results are used in the calculation of long-term runoff water qualities.

Summary of Key Findings

- Long-term trends: most elements continued to display temporal decreasing or stable trends
- Elemental liberation rates
- Refinement of conceptual model: trend analyses of most elements indicated sufficient congruence with the conceptual models
- Identification of key flow and geochemical processes
- Data used for development of geochemical source-terms
- Source-terms were used in development of site-specific surface run-off criteria



Key message: the design included scaling factors, results indicated all the geochemical concepts that we conceptualized and the test was designed for development of source terms

We use this for …

Column Leachate Trends

- **Most measured elements in subaerial and subaqueous column leachates continued to display temporal decreasing or stable trends in concentration, supporting the conceptual model that most weathering reactions follow order rate kinetics. Ongoing decreasing and or stable trends also indicate progression towards longer-term elemental liberation rates.**
- Leachate chemistry for the different types of columns and chemistries (high-case, average-case) are consistent with experimental design (e.g., inclusion of finer PSD results in greater leachate concentrations, high-case columns [those with higher sulphide content] generally have higher arsenic concentrations in leachate).
- **Trend analyses of most elements, including key parameters of interest pH, total suspended solids, nitrate, total ammonia, total aluminum, antimony, arsenic, cobalt, copper, iron, lead, and selenium, indicate sufficient congruence with the conceptual models of key flow and geochemical processes determining column leachate qualities. Combined with the geochemical data set and recorded leachate data, sufficient temporal/kinetic data exists to approximate the future leaching behavior of these elements in the context of the program objectives.**

- ***Refined Conceptual Models:***
- Key processes expected to control elemental liberation rates from the borrow materials include: (1) initial flushing of fine particles and historic weathering products, (2) migration of fine particles in the column profile, (3) carbonate dissolution and precipitation, (4) sulphide oxidation, (5) hydrolysis and dissolution of primary rock forming aluminosilicate minerals, (6) secondary mineral precipitation and dissolution, and (7) ion exchange and sorption/desorption. The magnitude of influence of these processes differs between subaerial (standard and TCA) and subaqueous columns.

Conclusions

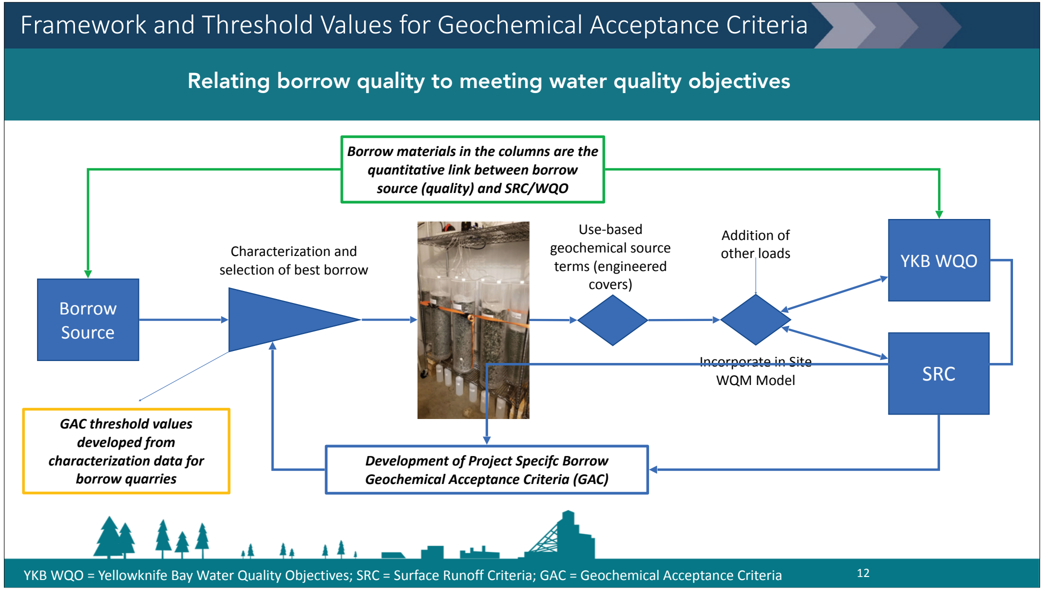
The GMRP borrow kinetic test program has achieved its objective of measuring elemental liberation rates from selected coarse-grained borrow under laboratory test conditions. The kinetic test program also met its data quality objectives and provides leaching data that supports the understanding of key geochemical and flow processes determining the quality and temporal variation of elemental liberation rates from the selected coarse-grained borrow under controlled laboratory conditions.

Long-term elemental liberation rates are indicated/inferred for most elements and interpretation of the results using conceptual models of the key geochemical and flow processes indicate that long-term weathering rates of the borrow in the columns are determined by geochemical processes that will also be present under site conditions. These geochemical processes are similar to weathering of naturally exposed mafic volcanic rocks at the site and are expected to take place over geological time frames.

The post-kinetic test results and analyses are consistent with data trends observed in the 2021 analyses and provides further confidence and refinement of the conceptual models developed to describe the column elemental liberation rates and leachate quality evolution. Post-kinetic test results and analyses also indicates that the previous reliance on column test data in support of other GMRP work (e.g., geochemical acceptance criteria, surface runoff criteria) was conservative.

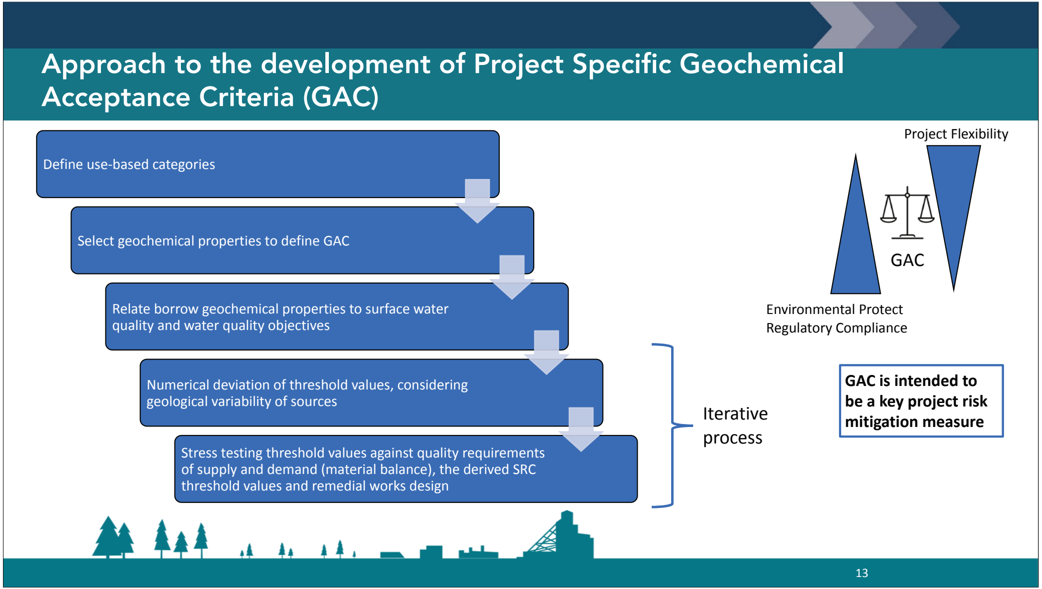
Key processes:

1. initial flushing
2. migration of fine particles
3. carbonate dissolution and precipitation
4. sulphide oxidation
5. hydrolysis and dissolution of aluminosilicate minerals
6. secondary mineral precipitation/dissolution
7. ion exchange and sorption/desorption



This is an important slide and we need to spend a bit of time on it:

- This was the original blue print of the development of the GAC and indicates a quantitative relationship between borrow quality, use and outcomes.
- Going from the left to the we the quality of borrow sources ……Kinetic tests at the centre
- Going back from right to left we derived GAC based on the best borrow sources
- So the column material is the key connection between left and right. Given that we have analytical descriptive data for things in the column we can correlate/relate it back to the quality of borrow and how it is connected to water quality effects



Slide summarizes the process we followed in the development of GAC…..

Important to remember that GAC aims to find a balance between ……and does not allow perfect project flexibility to ensure sufficient Env protection

Project Specific ARD/ML Paramaters and Threshold Values

Note these are Project Specific criteria and subject to Adaptive Management

Geochemical Property	Parameter	Rational	GAC for General Construction Uses	GAC for Specialized Construction Uses
Acid Generation Potential	ABA, including Total S and NPR (NP/AP)	Standard indicators for ARD/ML potential (defines PAG vs NPAG).	NPR ≥ 3 Total S ≤ 0.5	NPR ≥ 10 Total S ≤ 0.25
Near-total Metals of Concern	Near-Total Arsenic (aqua regia)	Key indicator for mineralization. Unique site parameter. Site has base loading of As and sensitivity to soluble As.	Tot As ≤ 60 ppm	Tot As ≤ 30 ppm
Mass of Readily Soluble Constituents	Selected readily soluble constituents (SFE)	Specific to "Specialized Construction" category (metal leaching) where there is a requirement to meet SRC.	Not applicable	Element specific mg/L (SFE) (Al, Sb, As, Co, Cu, Fe, Pb and Se)

GAC = Geochemical Acceptance Criteria

Ok this slide gives you a perspective on the types of use categories and parameters chosen and current threshold values.

Two important aspects to consider.
1) Note these are project/site specific GAC and threshold values that were stress tested
<u>Not intended as industry guidelines + they are subject to change through adaptive management process</u>

2) We defined tow categories of borrow use – Specialized …these are all applications of borrow where the runoff will be subject to SRC – large applications all TCA and pit covers

3) In terms of parameters - focused on smallest number of geochemistry related parameters that captures/covers the main risks, which are ARD and ML. ARD risks are more discrete (associated with geological structures and mineralization) whereas the ML risks are more distributed.
These criteria can be generated by standard tests.

- Our reasoning was as follows – although not expecting PAG, want to confirm by a total S (conservative) and NPR (standard industry approach) criteria
- Near total As – chose this as a proxy for metal leaching (specifically As and Sb) but also because it is highly sensitive to mineralization and an indicator for mineralization zones
- The above two are for general construction material only
- In the case of the specialized construction criteria, we felt the need to include criteria specific to ML using standard short-term leaching. As and some other metals leachability is not linear to total metals content, so felt a need for leachable fraction criteria. Given the SRC work indicting the most sensitive elements from a drainage perspective, we included those elements into the SFE criteria.

Not restrictive to the project when using on site borrow because there is great resource of high quality borrow on site but have some port quality borrow associated with remedial works near the shear zone.
You can see ARD is not the issue, plenty NP, ML is the issue, in particular As and some selected elements when we are talking SRC compliance

From Characterization to Implementation

Lessons learned from WTP construction (1)

Orders of magnitude increase in "reactive surface areas" of materials created through blasting, processing and use of aggregate

Although there has been urgent remedial activities taking place at site for multiple years, the large infrastructure related remedial activities started last year with the construction of the WTP. The WTP needed approx. 100K m3 of borrow and was the first time we implemented the GAC.

Although it was all GC uses, it was complicated since borrow source was not developed yet and there was a requirement to use borrow from blast rock produced from remedial activities.

Ok, on to some learnings when we applied this GAC for the first time to a remedial activity which is the construction of the WTP. I am happy to share some lessens learned which I hope will be useful for the audience.

A good visual for us/others involved in project to understand the potential impact of the blasting and processing of outcrops

- Creates increased surface area on both a surficial perspective (more spread out over the surface), and an individual grain perspective (in that there is now reactive surface area exposed on each grain); leads to increase in reactive surface area by orders of magnitude, ie stresses the importance of geochem

- Don't underestimate this increase in reactive surface area and make sure you conservatively take account of it in ST derivations (knowing that it is difficult to scale these things).

From Characterization to Implementation

Lessons learned from WTP construction (2)

Consulting/Study time pressures are very different to Operational time pressures (costs for equipment standing times are significant)

- Operations are driven by metrics where geochemical quality is a small part, they have significant financial implications and focus of contractors to make money.

- Need to be practical in all QA/QC and to be responsive and available for QA activities without having permanent people on site.
- Contractors need training on some of the specialized work….

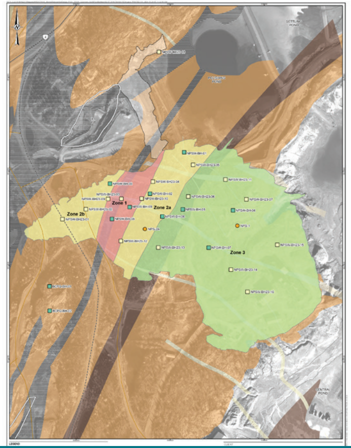
From Characterization to Implementation

Lessons learned from WTP construction (3a)

The system of geochemical characterization → pre-blast assessment → verification for general construction material is robust (1)

Upfront geochemical characterization is critical for design support:

- Contributes to the GMRP "supply" estimates of the borrow material balance
- Allows for more detailed specification of borrow quality in the Remedial Designs
- Increases operational efficiency



Our overall takeaway from the WTP program is that the overarching system, from a geochemical quality perspective, was robust, and resulted in the production and placement of material that was: general construction use-based, generated on an as-needed approach, that was generated from closure by-product material, generated through remedial works.

Here is an example of a geochemistry quality map of one of the remedial areas at the site indicating three types of materials that can be used for borrow.

From Characterization to Implementation:

Lessons learned from WTP construction (3b)

The system of geochemical characterization → pre-blast assessment → verification for general construction material is robust (2)

Pre-blast assessments provides robust data on geochemical variability and reduces material handling risks

- **Solidified pXRF testing procedure and communications**
- **pXRF provides reliable data for the in-field demarcation of material quality risk**
- **Building up database to understand field bias of arsenic pXRF measurements in**

pXRF = portable XRF instrument

Part of the QA?QC system is the use of pXRF to measure tot S and As in drill cuttings on drilling grid.

pXRF is in tandem to the QC verification

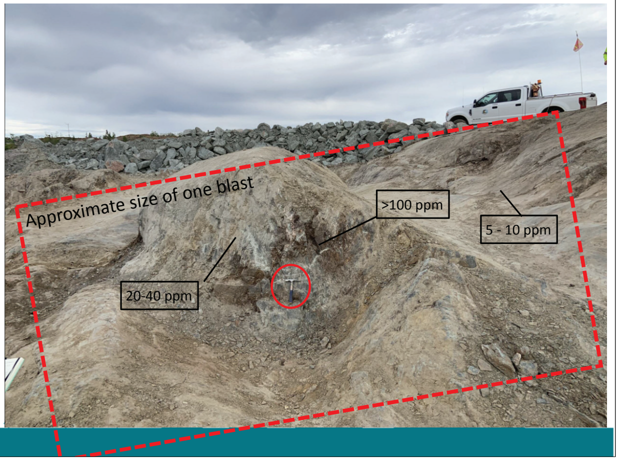
This provided really good data on spatial variability, verification of the original characterization and building a data set for the site.
It's been shown to be instrumental in making risk based decision in a consistent manner for managing borrow quality.

From Characterization to Implementation:

Lessons learned from WTP construction (4)

Assessing, predicting and dealing with geochemical variability is highly complex and technically challenging

- **Scale of variability is important:**
  - Confident at geological scale
  - Difficult at blasting scale
- **Limited correlation between visual aspects and high As content material**
- **Affects verification frequencies**



Additionally, we obtained valuable learnings regarding the scale of geological variability at WTP, a well as the forms and mobility of arsenic

Focus on just scale of variability

Showing a photo of blast area 2, which was observed to have higher variability in arsenic, as indicated through characterization and field assessments. We can see here some surficial features with very high ppm arsenic, which was generated as a result of mobilized anthropogenic arsenic, and/or weathering of geogenic (in – place) arsenic phases. Seen to be more prominent in rock with higher arsenic content, and often localized in fractures/preferential flow paths

From Characterization to Implementation:

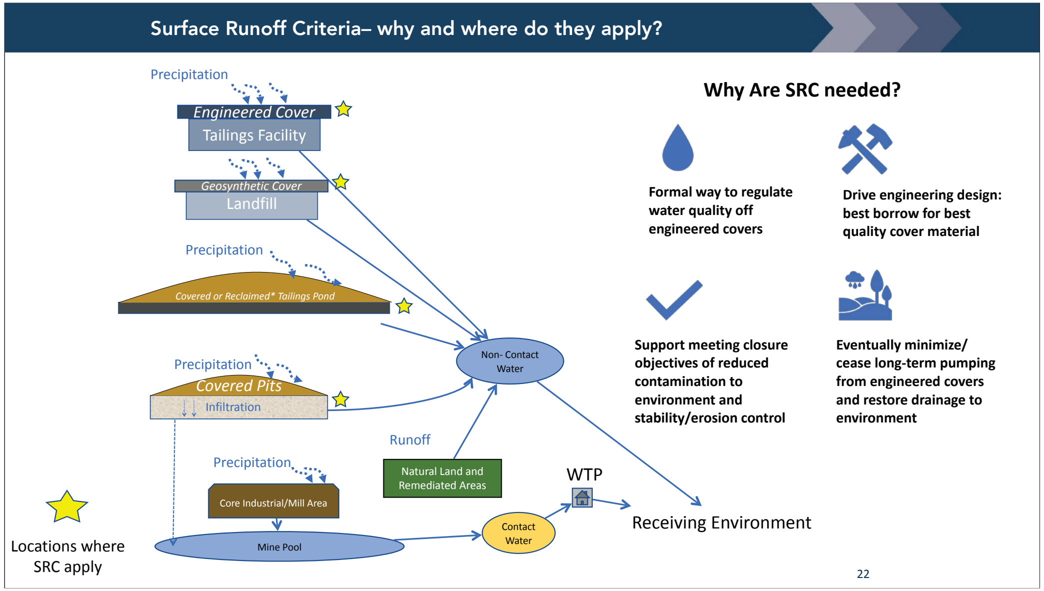
Conclusions

- Closure of the Giant Mine site is complex and are required to meet strict stakeholder and regulatory requirements
- Project specific use-based Geochemical Acceptance Criteria (GAC) were developed for all borrow use based on extensive characterization and modelling programs
- The GAC and associated verification program was successfully applied (with lessons learned!) in the construction of the WTP

Questions?

Mehrnoush Javadi
Geochemist-Hydrogeologist
AECOM
Mehrnoush.Javadi@aecom.com

Nico Bezuidenhout
Senior Technical Director - Geochemistry
WSP Canada
Nico.Bezuidenhout@wsp.com



I mentioned SRC and its important to understand where these will apply and why the borrow behind it needs to be of a certain quality.

Essentially, the water license says that SRC will apply to all large uses of borrow, including covers form the tCAs, pits and landfills. There are other contact and no-contact water on site, that will ultimately have to comply with WQO End of mixing zone.

What is different is that not as much volume as waste rock, however, it is spread thin over large areas.

These are all major surface area where borrow is spread relatively thinly over the area as opposed to piled in a stockpile.
Let's take a closer look at where these apply. This is a very conceptual figure of where the surface runoff criteria apply.

Yellow stars indicate the engineered covers where the criteria apply:

- Pits (7) major area
- Tailings containment areas (2) major area
- Settling pond/polishing pond (1)
- Landfill (1)
- South Pond (1)

There are four main reasons why we need surface runoff criteria. We've already mentioned that the criteria provide a formal way to regulate water quality off engineered covers, but there are a few other reasons. They can drive engineering design by encouraging the best quality material is used for covers, and that blasting practices are optimized. Design teams and on-site contractors must keep the runoff criteria in mind as the remediation progresses. They can also support meeting the closure objectives by limiting contamination to the receiving environment and promoting erosion control. Ultimately, the goal is to minimize or eliminate the need to manage the water from the covers into the very long-term. Natural drainage from covers to the receiving environment is preferred but there needs to be a set of number to provide confidence that it's ok.