ENHANCED "NATURAL" INCREMENTAL REMEDIATION APPROACH FOR A FINE-GRAINED BORROW PIT IN THE NORTH

Jim Cassie[1], P.Eng. and Geoff Claypool, P.Eng.
BGC Engineering Inc., Calgary, AB

Giselle Cotta, P.Eng.
Public Works and Government Services Canada, Edmonton, AB

Bob Johnson, P.Eng.
Aboriginal Engineering Ltd., Yellowknife, NT

and

Emma Pike
Indian and Northern Affairs Canada, Yellowknife, NT

ABSTRACT

As part of the closure work at Discovery Mine in the NWT, a borrow pit was developed within some fine-grained, ice-rich material proximal to a nearby lake. Following excavation of the required material, the borrow pit filled with local run-off so that a pond was formed. Due to permafrost thaw and localized erosion, the pond water was high in suspended solids, which discharged into the nearby lake. Hence, in order to prevent further discharges, it was necessary to come up with a management plan for the non-compliant water and for the disturbed borrow pit. Six different options were formulated for the remediation of the pit. An incremental approach using low-key natural elements, in combination with on-going water treatment and pumping was selected as the desired option. The approach consisted of the placement of a erosion-control mat (coco-mat), seeds, and fertilizer along with the planting of willow shoots, reducing overhanging slopes near the shoreline and minor buttressing of erosional gullies. In addition, water was treated and pumped so that the natural measures could take hold and to prevent any further discharges of non-compliant water. This approach permitted small scale work to be undertaken by a small workforce at the remote site, reducing capital costs for the government, providing work for northerners and allowing for flexibility as conditions changed.

1.0 INTRODUCTION

Discovery Mine is located north of the City of Yellowknife, on the western shore of Giauque Lake. Underground mining at this mine produced over 1 million ounces of gold between 1949 and 1969 (UMA 2001). Approximately 1.1 million tonnes of tailings solids were produced during this time. Initially, these tailings were disposed on-land, immediately south of the mine site. The aerial extent of tailings coverage reached as far as, and into, Round Lake. However, in the final years of operation, the tailings also flowed into nearby Giauque Lake, as illustrated on Figure 1.

[1] Corresponding author; BGC Engineering Inc., #1605, 840 – 7 Avenue SW, Calgary, AB, T2P 3G2,
Phone (403) 250-5185, jcassie@bgcengineering.ca.

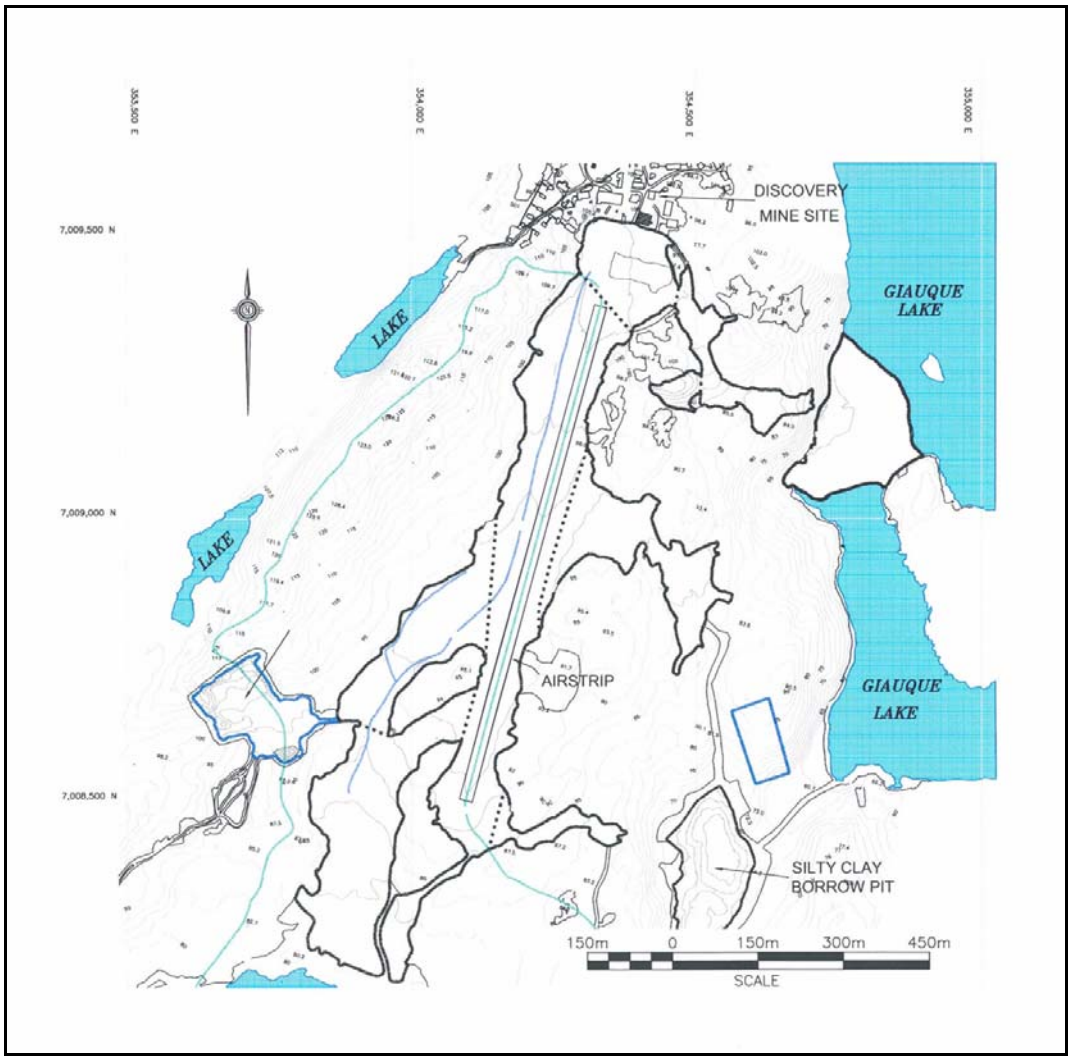

Figure 1: Site Location Map

Between 1998 and 2000, the Federal Government undertook the remediation of these tailings by constructing a cover of natural materials. The cover layer material requirements for over 140,000 m³ of silty clay necessitated the excavation of a borrow pit, approximately 400 m long, 80 m wide and 6 to 8 m deep. As shown on Figure 1, the borrow pit is located approximately 400 m east of the Discovery Mine airstrip and approximately 200 m from Giauque Lake.

Following construction, the borrow pit filled with surface runoff water within a period of two years and began to overflow at the low point in the crest of the borrow pit. The overflow water discharged into nearby Giauque Lake along a 200 m long natural drainage path between the borrow pit and the lake. The resultant discharge of the pit water into Giauque Lake did not meet the Canadian Council of the Ministers of the Environment (CCME) water quality guidelines for the protection of freshwater aquatic life for Total Suspended Solids (TSS) and turbidity. Indian

and Northern Affairs Canada (INAC), who currently manages the site, was then directed by the Water Resources Inspector in the summer of 2001 to address the stability of the borrow pit.

As a result, INAC through Public Works and Government Services Canada (PWGSC), initiated an assessment, design and implementation program. The objective of the program was to both prevent any further non-compliant water discharges and to prepare a remediation approach for this borrow pit. The following paper outlines the highlights of the assessment program and documents the progress of the finally selected remediation approach. Rather than a capital intensive, highly structured and detailed engineering design approach, the selected approach consisted of natural and human-enhanced re-vegetation measures. In combination with low key erosion control measures and the pumping and management of pond water, the re-vegetation measures were implemented in an incremental and adaptive manner.

2.0 BACKGROUND INFORMATION

2.1 Location and Topography

The Discovery Mine is located approximately 85 km north of Yellowknife and access is only possible by plane or winter road (when constructed). The site topography is relatively rugged, controlled mainly by the north-easterly trending structures in the bedrock.

The borrow pit, as previously noted, is located just west of Giauque Lake, at an elevation higher than the lake but lower than the main tailings cover. The borrow pit location corresponded to the location of a previously existing ephemeral surface drainage. Before pit development occurred, the area was a small wetland area with peat and organic soil cover.

The borrow pit consists of a north pit and a south pit that are separated from each other by a soil ridge. This division of the borrow pit is related to excavation of the pit which was conducted in two stages with the north half being excavated in 1999 and the south half being excavated in 2000. The elevation of the bottom of the borrow pit ranges from 267 m in the north pit to 270 m in the south pit. The crest elevation of the borrow pit ranges from a low of 272 m near the northeast corner of the borrow pit to approximately 279 m near the south end of the borrow pit.

2.2 Geology

The mine is located within the Yellowknife Greenstone Belt in the south-western part of the Slave Structural Province. The most prominent geologic feature at the mine site is the Discovery Shear Zone which gives rise to the north-northeast trending topography. Bedrock types within the shear zone include amphibolite, quartzite and metaturbidites.

Surficial deposits of peat, till, glaciofluvial and glaciolacustrine sediments have been observed in the region. Till deposits are described as loosely compacted, stony, matrix-supported diamicton, with a matrix ranging from coarse to fine sand with minor amounts of silt. Glaciofluvial deposits consist of fine sand to cobbles in the form of eskers, kames and subaqueous outwash.

Glaciolacustrine deposits consist of poorly to moderately sorted, coarse to fine sand, silt and clay estimated to be up to 20 m thick, with varied amounts of pebbles, cobbles and boulders. These materials occur preferentially in topographic lows (Kerr et al. 2001).

After the initial disturbance of the pit occurred, a terrain assessment of the surficial geology was undertaken. The silty clay borrow pit was developed in a low-lying area located south-southwest of Giauque Lake. The area was once occupied by a glacial lake that deposited a blanket of glaciolacustrine silt and clay. Evidence of a veneer of till is visible overlying bedrock outcrops located along the north, east and west sides of the borrow pit. The presence of bedrock outcrops and thin glacial till deposits to the north, east and west of the borrow pit are expected to limit possible thaw degradation advancing from the borrow pit in these directions.

Where they are covered by organics and shaded by vegetation, glaciolacustrine deposits in wet, low-lying areas are expected to contain ice-rich permafrost that is sensitive to disturbance to the vegetation and organic cover. Based on the terrain analysis, it appears that such deposits extend north-northeast and south of the borrow pit. These sensitive areas, therefore, need to be protected from any additional disturbances.

2.3 Climate and Permafrost

No site-specific climate data is available for Discovery Mine. Considering the proximity of the mine to Yellowknife, the climate data from the Yellowknife Airport was reviewed to characterize the climatic conditions at Discovery Mine.

Climate normals for Yellowknife indicate a mean annual air temperature of -4.6°C, with an air thawing index of 1835°C-days and an air freezing index of 3473°C-days. The average annual precipitation in Yellowknife is approximately 280 mm.

The Discovery Mine is located within the region of extensive discontinuous permafrost. The local distribution of permafrost is controlled by the following:

- the presence of lakes,
- the type and density of vegetative cover;
- the presence and thickness of peat, organic and mineral soils;
- slope aspect; and,
- other factors.

Kilgour (1969) reported that permafrost was approximately 75 m thick when mining commenced. As noted earlier, fine-grained soils under peat cover are expected to contain ice and hence, be thaw-unstable.

3.0 BORROW PIT PROBLEMS

In addition to pit water high in TSS and turbidity, several areas around the borrow pit exhibited indications of permafrost degradation. Observations of tension cracks, settlement troughs, collapsing vegetation covers and slumping of pit walls indicated that permafrost degradation has occurred. Several significant erosional gullies at the south and west sides had formed, providing sediment load to the pond. Figure 2 provides an aerial view of the borrow pit before any remediation works were initiated.

Figure 2: Aerial view looking north of borrow pit before remediation (Summer 2001).

The poor water quality was attributed to the following root causes, as outlined in AMEC (2002) and BGC (2003):

- Degradation of ice-rich permafrost around the pit due to loss of insulating cover;
- Degradation of ice-rich permafrost around and beneath the pit as collected runoff water acted as a heat source;
- Excess pore pressure generation due to the melting of ground-ice leading to instability of the slopes (slumping) towards and into the pit;
- Gully development, sheet and rill erosion and resultant transport of eroded soils into the pit by surface drainage; and,
- Shoreline erosion and re-suspension of the fine bottom sediments from near-shore shallow areas by waves.

As a result, any proposed remediation measures for the borrow pit needed to address these main root causes.

4.0 OPTIONS ASSESSMENT

Six different approaches were developed for the remediation of the borrow pit, as follows:

1. Manage pond water for potentially ten years and let re-vegetation attempts (both natural and human enhanced) take effect to stabilize slopes and gully areas.
2. Raise pond level by several metres using a dam at the current overflow location.
3. Line borrow pit slopes and bottom with geotextile and 1 m thickness of rip rap cover.
4. Construct a "wet weir" at the pit separation area. The weir would separate the south pit where much of the sediments originate and north pit where the water discharges. The weir would also act as a wave break.
5. Detailed engineering approach comprised of covering pit walls above high water line with a combination of wood chips for insulation and rip rap and gully armouring at erosion areas and along the shoreline.
6. Excavate a spillway notch at the current overflow location with a base elevation of 270 m. Line a channel through the pit with rip rap and allow water to discharge through the spillway notch and down to Giauque Lake.

In order to rank the options, several major ranking criteria were selected and these included the following:

1. Technical certainty and the estimated probability of success. Ranked subjectively from low to high with an estimated value of probability of success.
2. Cost based on estimated quantities and unit rates, based on experience. Cost values do not include any allowances for investigation, design, permitting and/or contingency.
3. Estimated amount of reduction in environmental risk, again based on subjective ranking from low to high.
4. Stakeholder acceptance in terms of local communities, first nation groups and regulatory acceptance, based on subjective ranking from low to high.
5. Health and safety issues during implementation, based on subjective ranking from low to high.
6. Risk cost is the sum of the probability of failure (1 – probability of success) times the cost plus the cost. The lowest risk cost is the most desirable value.
7. Rating score is the sum of the three subjective ranking criteria (environmental risk, stakeholder acceptance and health and safety during implementation) where a low ranking equals three points, a medium ranking get two points and a high ranking gets one point. The lowest rating score is the most desirable value.

A final ranking parameter was based on the product of multiplying the risk cost by the rating score, hence combining the results of the subjective rankings with the semi-qualitative ranking of the risk costs.

Based on the risk cost (combination of technical certainty and project cost), the top-ranked approaches were #5 (detailed engineering approach), #4 (wet weir) and #3 (entire rockfill cover). Based on the summary rating score of the three other subjective criteria, the top-ranked approaches are #3 (entire rockfill cover), #4 (wet weir) and #1 (water management and re-vegetation). Finally, when using the product of the risk cost to the rating score, the overall rankings of the six approaches were as follows:

1. #3 entire rockfill cover.
2. #4 wet weir.
3. #1 water management and enhanced re-vegetation.
4. #5 detailed engineering approach.
5. #6 overflow notch and flow-through.
6. #2 raise pond by 4 m with overflow area dam.

Hence, Approach #3 was selected as the top ranked Approach but approaches #4 and #1 were also considered top-ranked. In fact, it was felt that some form of wet weir would be complementary to Approach #1 using the re-vegetation. Given that INAC wished to reduce its initial capital investment into the remediation project, the incremental re-vegetation approach, along with pond water management, was selected as the first choice for implementation. It was felt that Approach #3 with the entire rockfill cover could be implemented as a contingency plan, if so required after a trial period with the re-vegetation approach. These options and technical recommendations were presented to INAC and their First Nations partners, including the North Slave Metis Alliance and the Yellowknives Dene First Nation, for final selection. These stakeholders were very supportive of a more naturally enhanced approach, rather than a detailed engineered approach.

5.0 NATURAL APPROACH DETAILS AND PROGRESS

5.1 Elements of the Approach

The enhanced "natural" re-vegetation and water management concept was an extension of the following aspects and observations:

- Water treatment and pumping was a necessity in the short term to prevent any non-compliant water discharges.
- Numerous borrow pits in the north (for highway projects) had naturally re-vegetated within a period of approximately ten years.
- Observations from the Norman Wells pipeline indicated that re-vegetation also occurred within the right-of-way within a ten year time period, as well.

Since work forces would be on-site for several years potentially managing water, it was advantageous to propose a remediation plan that could be phased in appropriate increments. In addition, only plane access was possible during summer months and no construction equipment was left at site. Hence, all borrow pit remediation measures had to be undertaken with small-scale equipment that could be flown into site or by hand. So rather than adopting a capital and

equipment intensive approach (perhaps suited to larger specialized contractors), INAC chose to try a phased incremental approach to the remediation that could be undertaken by northerners.

Further details on the re-vegetation enhancement program are provided in Johnson and Lamoureux (2005).

5.2 Activities Undertaken Since 2002

Beginning in 2002 and continuing into 2003, numerous activities were undertaken to manage the water and initiate remediation of the borrow pit, including the following:

- Pumping of a total of 127,000 m^3 of pit water into Giauque (from under the ice) and Round Lakes (treated) in April and September 2002, respectively;
- A trial re-vegetation plot was undertaken in 2002 and the results were encouraging;
- A vegetation enhancement program (transplanting of local willows, placement of northern cat tails, grass seed application and fertilization) was started in 2003 along the shoreline area of the borrow pit;
- Flattening of oversteepened slopes of the pit walls by water monitoring (and later re-vegetated);
- Applying erosion protection to the shoreline area in the form of coco-mat (biodegradable erosion-control matting) to assist with soil protection and seed retention; and,
- Attempting erosion control by placement of coco-nut matting, woody debris and rip rap in selected erosion gullies.

The transplanted willows did not grow well due to the dry climatic conditions experienced at site throughout that summer.

Efforts to reclaim the borrow pit area and improve the quality of in-pit water continued in 2004, and included the following:

- Treatment (flocculant and lime) of pond water and pumping of 45,000 m^3 of water from the borrow pit to Round Lake;
- Continuation of the re-vegetation program along the shoreline area of the borrow pit;
- Re-sloping some of the erosional gullies including grade flattening and coco-mat application; and
- Applying erosion protection to the shoreline area in the form of coco-mat.

5.3 Progress and Water Quality Changes

Visual inspections of the borrow pit are conducted each summer to observe the physical conditions and read installed instruments. During the inspections made in 2004, the following main observations were made:

- Re-vegetation around the pit appears to be developing well. The majority of the previously disturbed ground surface is now re-vegetated, as shown on Figure 3.

- Previously noted areas of permafrost disturbance and cracking (except for the following noted area) have appeared to stabilize. Grasses and vegetation are catching on in previously noted cracks and slumped areas.
- Some additional permafrost thawing, slumping and cracking has occurred in the northeast corner of the pit, proximal to the overflow area.
- Some previously noted gullies are still ravelling and soil debris is falling over some minor vegetation.
- The significant south gulley appears stable currently with the work done to it but additional erosion will occur later under large precipitation events and during spring run-off.
- With the low water level, it was almost possible to see the bottom of the entire some pond. Some suspended solids were observed in the north pond.

Figure 3: Comparison of vegetation along borrow pit shoreline prior to vegetation enhancement (August 2002, left) and after vegetation enhancement (August 2003, right).

In summary, the previous rehabilitation work, coupled with dry conditions this year, have progressed the remediation condition of the borrow pit. Figure 4 provides an aerial view of the borrow pit showing the progress of the re-vegetation efforts. The dry weather, however, has also led to decreased seed germination rates for the seed spread in 2004. The advancing thaw front has caused additional thaw settlement at the northeast corner of the pit.

Figure 4 Oblique aerial photo of the borrow pit, looking north (August 23, 2004).

Despite the thawing that has occurred around the borrow pit, ice rich permafrost still remains below the active layer. Considering the warming trend observed in the monitoring data and the continued surficial indications of continued permafrost degradation (i.e. melting in northeast corner of pit observed in 2004), some additional permafrost degradation may still occur in the future.

Water quality testing is undertaken at the borrow pit as per the requirements in the Surveillance Network Program (SNP) issued for the site in the Water License. The SNP requires that sampling of water from the borrow pit be undertaken a minimum of twice during periods of open water (spring and fall) and once during periods of ice cover. The samples are tested for Total Suspended Solids (TSS), turbidity, nutrients, pH and aluminium. When treatment and pumping of pit water were undertaken, the TSS and turbidity levels were much lower than the discharge limits at the outflow of Round Lake. Recorded TSS values within the pit are also generally below both the maximum grab sample concentration (50 mg/L) and the maximum limit for average sample (25 mg/L). During times of monitoring (no treatment or discharge), turbidity values have been observed to exceed maximum grab sample concentration (30 NTU) and the maximum limit for average sample (15 NTU). Based on the long term monitoring data, however, both TSS and turbidity have improved since 2002. No water quality concerns have emerged with respect to the use of fertilizer proximal to the pond.

6.0 FUTURE WORK

Work undertaken to-date appears to have made significant improvements to both pit water quality and to the remediation of the disturbed area. But the work is not complete and some work items are proposed for 2005 and possibly for future years, as noted below:

- Two small rockfill dikes were installed into the pond bottom in March 2005. The purpose of these dikes is to break wave energy in the pond and prevent the re-suspension of fine sediment from the pit bottom. The dikes may also be partially effective in retaining some sediment that may enter the pond from erosional gullies.
- Some grading was undertaken in March 2005 at the significant erosional gulley at the south end. After flattening of the grade, and the removal of minor debris, some rip rap was placed to protect the native soil.
- On-going stabilization of minor erosional gullies will be undertaken by the placement of coco-nut matting, rip rap and seeding, as appropriate.
- Further re-vegetation work, including matting placement, seeding, willow transplantation and fertilizer application will continue until a continuous vegetation mat has been applied to the bare soil slopes.
- Pumping and management of pond water will be required until the pond water meets appropriate discharge criteria.

It is hoped that this program of active management will only be necessary for the next two or three years. At that time, any accumulated pond water would be allowed to discharge naturally over the overflow location and then down into Giauque Lake.

In addition to the noted works, a program of on-going permafrost, pit stability and water quality monitoring will be undertaken to ensure that the proposed objectives of the remediation plan are met.

7.0 CLOSURE

The excavation of a borrow pit in ice-rich fine-grained soils lead to the creation of unstable and erodible slopes, along with a pond high in TSS and turbidity. Six possible remediation approaches were formulated and ranked according to important criteria for INAC and related stakeholders. In the end, an incremental approach, stressing enhanced "natural " re-vegetation, was selected. Several low-key re-vegetation activities and erosion control measures have been undertaken over a period of three years, in combination with water management. The remediation work has provided opportunities and training for aboriginal people and northerners, based on their traditional knowledge and values. The progress to-date has been positive with both remediation measures taking hold and the pit water quality improving. Wildlife are also beginning to return to the area.

8.0 ACKNOWLEDGEMENTS

Both INAC and PWGSC are acknowledged for permission to prepare and present this paper. Aboriginal Engineering Ltd. and BGC Engineering Inc. acted as specialist contractor and consultant, respectively on this project. All parties involved are to be thanked for their ongoing efforts to ensure project success.

REFERENCES

AMEC Earth & Environmental Ltd. 2002. Discovery Mine Borrow Pit, Long Term Remediation Plan, Preliminary Design – Draft Report. Report submitted to PWGSC, November 2002.

BGC Engineering Inc. 2003. Review of Draft Report by AMEC Earth and Environmental Limited on Discovery Mine Borrow Pit Reclamation Plan. Letter report to PWGSC, February 7, 2003.

Kerr, D.E., Knight, R.D., Smith, D., and Nickerson, D. 2001. Drift-Prospecting Investigations in the Yellowknife Greenstone Belt, Northwest Territories. Geological Survey of Canada, Current Research 2001-C1.

Kilgour, R.J. 1969. Mining Experience with Permafrost. Proceedings of the 3rd Canadian Conference on Permafrost, National Research Council of Canada Associate Committee on Geotechnical Research, Technical Memorandum No. 96, September 1969.

Johnson, B. and Lamoureux, S. 2005. Natural Remediation Through the Use of Re-vegetation at Abandoned Northern Mining Properties. Paper in preparation for ARCSACC, Edmonton, May 2005.

UMA Engineering Ltd. 2001. Discovery Mine, NWT, Remediation of Mine Tailings, Summary Construction Report. Report prepared with Public Works and Government Services Canada for Indian and Northern Affairs Canada, April 2001.