

**DATE** January 5, 2016**PROJECT No.** 1543540**TO** Mr. Bertho Caron, Ing., Engineering Manager  
Greenstone Gold Mines**FROM** Reza Moghaddam and Ken Bocking**EMAIL** Ken\_Bocking@golder.com**A PEER REVIEW REGARDING THE DESIGN OF TAILINGS MANAGEMENT FACILITY FOR THE  
HARDROCK PROJECT IN GERALDTON, ONTARIO.****1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) was retained by Greenstone Gold Mines to complete a peer review for the Hardrock Project in Geraldton, Ontario.

AMEC Foster Wheeler Environment & Infrastructure (AMEC) was responsible to provide feasibility level geotechnical and hydrologic design of the tailings management facility (TMF) and waste rock areas (WRA) for the Hardrock Project. Mining planning, site infrastructure, cost estimating and the overall feasibility study were the responsibility of G-Mining Services Ltd. (G-Mining). TBT Engineering (TBT) was responsible for the design of the Highway 11 realignment for the Hardrock Project.

Review was required with respect to the three following aspects of the project:

- 1- Review of TMF design report provided by AMEC (2015a),
- 2- Review of long term stability of WRA 'A' (AMEC, 2015b), and
- 3- Review of the stability aspects of the portion of the Highway 11 realignment (TBT, 2015) that has to be built over MacLeod High Tailings (MHT).

The intention was to review the approach and design concepts for the three aspects in a "high level" scale and to identify any questions or concerns for further response by the Consultants (AMEC and TBT).

**2.0 REVIEW**

Golder received and reviewed relevant documents on the three aspects in November 2015. The documents received (AMEC, 2015a-h) are listed in the References section below.

On November 10, 2015, Golder (Ken Bocking) attended a briefing session by AMEC regarding the first two aspects of the review. On November 24, 2015, Mr. Bocking also attended a meeting at the Greenstone Gold Mines office, which focused on the third aspect. The latter meeting was attended by representatives of Greenstone, AMEC and TBT.



This technical memorandum only addresses the first aspect of the project (i.e., TMF design report) with respect to the concerns discussed during the briefing session. The two other aspects of the project were addressed in a separate document (Golder, 2016).

### **3.0 SUMMARY OF ASSESSMENTS**

The proposed TMF dams were designed to meet design criteria specified in the Lakes and River Improvement Act (MNR, 2011) and the Canadian Dam Association Guidelines (CDA, 2007).

In AMEC (2015d), three potential cross-sections were considered for the dams:

- 1) A centreline raise with a central till core,
- 2) A downstream raise with an upstream liner, and
- 3) A downstream raise with an upstream till core.

The third cross-section was selected for all perimeter dams. (For geometric reasons, the Inner Dam will use a centreline raise.)

The cross-section selected for the dams incorporates a relatively low permeability core along with filters and transition zones upstream of the main shell, which will be constructed of mine rock. The core was proposed to be constructed contiguously with cut offs to intercept potential seepage through sandy foundation soils. Foundation filters were designed under the rockfill to prevent piping of fines out of the foundation soils.

Consolidation grouting of the upper fractured bedrock would be carried out where outcropping or shallow bedrock is encountered under the North Dam and the East Dam. Construction of a deep cut-off (i.e., a bentonite slurry cut-off wall keyed 1 m into till) along the Southwest Dam was recommended in the feasibility study (AMEC, 2015a). For the Southeast Dam and the West Dam, the cut-off trenches would penetrate through shallow sand silt and interbedded silts to tie into underlying low permeability till. In the case of the West Dam, the cut-off would extend to bedrock after removal of shallow overburden soils. The cut-off trenches would be backfilled with compacted till.

The Hardrock TMF dams were classified under the 'Very High' failure consequence category. In accordance with the CDA Guidelines, the Peak Ground Acceleration (PGA) corresponding to the 1 in 10,000 year return period earthquake design ground motion (EDGM) was considered for the TMF dams. The 2010 National Building Code of Canada (NBCC) seismic hazard calculator was used to calculate interpolated seismic hazard values up to the 1:2475 year return period for the Geraldton area. The 1:10,000 year return period seismic event and corresponding PGA of 0.065 g were extrapolated from this retrieved data.

Static and pseudo-static stability analyses were carried in support of the feasibility design of the TMF. Two dimensional (2-D) limit equilibrium stability analyses were carried out using the computer software "SLOPE/W". General limit equilibrium modelling by the "Morgenstern Price" method was used in the analysis. Various failure surfaces such as circular, composite and wedge shaped failures were examined. The results showed that the calculated factors of safety for the TMF dams met or exceeded the minimum criteria.

The geotechnical investigations have indicated the presence of a relatively thin layer of "interbedded silt" under the East Dam, the Southeast Dam and the West Dam. This layer, which was interpreted as being an "associated glacio-lacustrine deposit", was encountered in three boreholes as well as in several test pits. It is noted as having thin layers, including clay. Grain size testing indicates that clay contents of about 25% are

typical. There was no indication that shear strength testing or consolidation testing had been carried out on this material.

Table 9 in AMEC (2105a) indicates that the TMF will be raised in three main stages. It also indicates that each stage will be equipped with an emergency spillway with an invert level 1.5 m below the dam crest elevation. It is understood that the staged development of the TMF allows for ample storage of water at all stages. At the end of the development, water will be able to flow northwards through a lowered spillway. Dam design criteria included maintaining storage to contain the Environmental Design Flood (EDF), a 100-year return hydrologic event (24-hour storm or freshet), with no discharge through the spillway. The emergency spillways will be designed to safely pass the Inflow Design Flood (IDF) consisting of a routed Probable Maximum Flood (PMF).

## **4.0 DISCUSSION**

### **4.1 General**

Golder agrees with general approaches and procedures carried out in the study. However, some recommendations are summarized in the following sub-sections to improve the quality of the assessments.

The TMF design report at the feasibility level of study included: a tailings deposition plan, water balance modeling, hydrologic and hydraulic design, dam and seepage collection design and operational and closure consideration. Among these, the closure scenario needs to be elaborated.

With respect to geotechnical design, it was properly demonstrated that the TMF dams are stable in the static and pseudo-static stability analyses. Some additional recommendations are summarized in the following subsections.

### **4.2 Earthquake Design Criteria and Liquefaction Assessment**

The selection of the 'Very High' hazard classification of the Hardrock TMF dams is considered to be conservative. It could be argued that a lower category such as 'High' could be justified by reassessment of the hazard classification.

The extrapolation of PGA value based on the NBCC is not acceptable for large structures such as TMF dams in accordance with the Natural Resources Canada (NRC) website. For the seismic events with a return period more than 2,475 years, no PGA values are provided by the NBCC. In this case, a site specific hazard calculation is required.

Based on the current design criteria, a 2.5 m thick, very loose stratum of outwash sand to sand and silt at surface in the Southwest Dam footprint is potentially liquefiable (marginally) under the design earthquake. To better evaluate the susceptibility of the marginally liquefiable layer under the current design earthquake (i.e., 'Very High'), a CPT-based liquefaction analysis is recommended for this area. The CPT approach may well indicate that the layer has higher cyclic resistance than the SPTs indicate.

### **4.3 TMF Water Management**

The decision to provide emergency spillways at each of the three stages of the TMF development is appropriate. The spillways will passively prevent overtopping of the dams even if inappropriate decisions are made about water management during operations. This is considered to be very important given the potential consequences of overtopping failures.

#### 4.4 Dam Construction

AMEC (2015d) indicates that the life of mine cost for the cross-section selected for the perimeter dams (i.e., the section using the upstream till core) will be higher than that for the section with the centreline till core. Nonetheless, it is argued that the former section will be simpler to construct and that construction scheduling will be less critical. This makes sense because it will be possible to place the large downstream rock fill shell probably on a year round basis using mine equipment and then to raise the upstream core with contractor equipment in the summer season,

The filters on the downstream side of the upstream core need to be filter compatible with the adjacent waste rock in the shell. When rock fill is placed by dumping from large mining trucks, it is common for very large rocks to accumulate at the toe of the fill, resulting in incompatibility with the filters. (This was identified as one of the causes of the failure of the tailings dam at Omai Mine.) This potential problem can be avoided by requiring special placement in thin horizontal lifts in the rock fill zone immediately behind the filters. It may also be appropriate to specify a smaller maximum size for fill in the special placement zone. AMEC indicated that this was the intent; however it is important that this be incorporated into the cross-sections and specifications at the detailed design stage.

Gradation specifications for filter and transition zones should be developed at an early stage to demonstrate filter compatibility throughout the cross-section. Borrow sources and/or rock processing requirements to produce the filter and transition zones should be identified before construction is tendered.

Given the high permeability of the glacio-fluvial deposits that underlie much of the TMF area, it is important to achieve a good seepage cut-off under all of the perimeter dams. The need for consolidation grouting of pervious bedrock under the North Dam and the East Dam has been noted. Consideration should be given to carrying out a test grouting program in these areas in advance of the main construction and providing the results to bidders. This would provide more certainty in the costing of the production grouting. There may be some difficulty in keying the proposed bentonite slurry trench under the Southwest Dam into the dense till because of imbedded boulders and cobbles. It is recommended that more geotechnical investigation be carried out in this area to better define the conditions at the top of the till. In addition, a study should be undertaken to define the best excavation technique to build the cut-off trench.

#### 4.5 Characterization of the Interbedded Silt

The interbedded silt is a glacio-lacustrine deposit which contains clay varves. In the slope stability analyses, this material was characterized simply as a cohesionless material with an angle of internal friction,  $\phi'$ , of 30 degrees. This characterization may be unconservative. The clay varves could have a lower  $\phi'$  value of perhaps 25 degrees. While the SPT "N" values clearly indicate that the layer is overconsolidated, it is possible that the layer could generate excess porewater pressure and exhibit undrained behaviour under the high loads that will exist in the future under the dam fills. It is recommended that additional geotechnical testing be carried out on this layer to better characterize its shear strength and porewater response characteristics and to confirm the current stability assessments. This would require obtaining undisturbed samples and carrying out laboratory triaxial shear testing.

#### 5.0 RECOMMENDATIONS

- A site specific seismic hazard analysis should be undertaken to determine the seismic design parameters corresponding to the 'Very High' hazard category (i.e., return period of 10000 years) of the TMF dams. The

hazard analysis should include the de-aggregation analysis to determine the magnitude-distance of the design earthquake for the liquefaction assessment.

- A special placement rock fill zone should be shown at the upstream edge of the downstream shell on the design cross-sections of the TMF dams. The specifications should indicate that, within this zone, rock fill is to be spread in thin lifts to prevent segregation. Also, a reduced maximum size should be specified for this zone.
- Gradation specifications for the core, filter and transition zones should be prepared in the near future to demonstrate the filter compatibility of the zones and the adjacent rock fill.
- Borrow sources should be identified and tested and rock fill processing requirements should be identified to demonstrate how the filter and transition zones can be produced before construction is tendered.
- The closure scenario for the TMF should be detailed.
- A CPT investigation is recommended in the area of the Southwest Dam where potentially liquefiable loose sands were noted on surface.
- Consideration should be given to carrying out a test grouting program prior to construction tendering in areas of pervious rock under the North Dam and the East Dam.
- More geotechnical investigation should be carried out in the area of the Southwest Dam where a bentonite slurry cutoff wall is contemplated in order to better define the conditions at the top of the till. In addition, a study should be undertaken to define the best excavation technique to build the cut-off trench.
- Additional geotechnical testing should be carried out on the interbedded silt layer to better characterize its shear strength and to confirm the current stability assessments. This should include obtaining undisturbed samples and carrying out laboratory triaxial shear testing.

## 6.0 CLOSURE

We trust that this document provides the information that is currently required. If you have questions do not hesitate to contact us.

*Original signed by:*

Reza Moghaddam, Ph.D., P.Eng.  
Geotechnical Engineer

RM/KAB/jl

*Original signed by:*

Ken Bocking, M.Sc., P.Eng.  
Principal

n:\active\2015\3 proj\1543540 greenstone\_peer review\_hardrock\technical memo\1543540 tech memo 2016jan05 hardrock mine peer review 1 tmf.docx

## References

AMEC Foster Wheeler, 2015a. Greenstone Gold Mines Tailings Management Facility Design, Hardrock Feasibility Study, Geraldton, ONTARIO. Report (Final), TC140307. September 2015. CAHR-RE-15-10-09-AMECFW.

AMEC Foster Wheeler, 2015b. Hardrock Tailings Disposal Feasibility Study, Waste Rock Areas Stability Assessment – WRA A (West and Central), Technical Memo (Draft), June 22, 2015. CAHR-TM-15-06-22-AMECFW.

AMEC Foster Wheeler, 2015c. Hardrock Mine Feasibility Study, Geraldton, Ontario – Geotechnical Investigations for Tailings Management Facility and Waste Rock Areas. Final report submitted to Premier Gold Mines Limited, April 1, 2015. CAHR-RE-15-04-01-AMECFW.

AMEC Foster Wheeler, 2015d. Hardrock Feasibility Study, Tailings Management Facility – Impoundment Dam Section Alternatives. Technical Memorandum (Draft), TC140307. March 13, 2015. CAHR-RE-15-10-09-AMECFW.

AMEC Foster Wheeler, 2015e. Greenstone Gold Mines Tailings Management Facility Design, Hardrock Feasibility Study, Geraldton, ONTARIO. Report (Draft), TC140307. July 2015. CAHR-RE-15-07-24-AMECFW.

AMEC Foster Wheeler, 2015f. Hardrock Tailings Disposal Feasibility Study, Geraldton – Tailings Management Facility (TMF) Site Selection Considerations. Final memo submitted to Premier Gold Mines Limited, January 28, 2015. CAHR-TM-28-01-05-AMECFW.

AMEC Foster Wheeler, 2015g. Hardrock Tailings Disposal Feasibility Study, Goldfield Creek Diversion Options, Premier Gold Mines Limited, Technical Memo (Final), April 03, 2015. CAHR-TM-15-04-03-AMECFW.

AMEC Foster Wheeler, 2015h. Hardrock Feasibility Study - Construction Material Quantities Estimates – TMF (Revised), Technical Memo (Draft), October 22, 2015. CAHR-TM-15-10-22-AMECFW.

CDA, 2007. Technical Bulletin – Geotechnical Considerations for Dam Safety. Canadian Dam Association.

Golder Associated Ltd., 2016. A Peer Review Regarding the Design of Waste Rock Area and the Highway 11 Realignment for the Hardrock Project in Geraldton, Ontario.

MNR, 2011. Lakes and Rivers Improvement Act – Technical Guidelines. Ontario Ministry of Natural Resources.

TBT Engineering Limited, 2015. Preliminary Design Report, Highway 11 Realignment, June 11, 2015.