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REPORT

GEOTECHNICAL ENGINEERING SERVICES FOR AFTON TAILINGS STORAGE FACILITY

Phase 1: Review Possibility of Mount Polley Mine Conditions at Afton TSF site

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EXECUTIVE SUMMARY

The Afton Mine is located between Highway 5 and Highway 1, approximately 5 km to the west of their junction and 12 km to the southwest of the City of Kamloops. The Afton Tailings Storage Facility (TSF) was designed to store tailings and water from mining operations. The Afton TSF construction began with East and West Starter Dam construction in 1976 and 1977. The Afton TSF dams were raised to their current approximate crest elevation of 706 m during operation from 1977 until 1997. Since 1997, the Afton TSF has been under care and maintenance. The Afton TSF is located next to the New Afton Mine which is operational and owned by New Gold Inc. (New Gold). KGHM Ajax Mining Inc. (KGHM) is the current owner of the Afton TSF.

The Afton TSF consists of two larger earthfill/rockfill dams (the West Dam and East Dam) to provide containment for the Afton TSF and four smaller dams (two seepage collection dams and two diversion dams on Alkali Creek). The West and East Dams were originally designed as conventional water storage dams based on the assumption of zero water reclaim. The rockfill dams were designed with an upstream low hydraulic conductivity till zone with fine and coarse filters separating the till from the rockfill. Between the low hydraulic conductivity till zone and the downstream rockfill there are two filter layers (fine and coarse filters). The East Dam is buttressed by a mine rock storage facility at the toe and there is no stability concern for a failure of the East Dam.

In a letter after the review of the incident at Mount Polley, the Ministry of Energy and Mines of British Columbia (MEM) requested KGHM to confirm that the conditions that led to the incident at Mount Polley are not present at the Afton TSF. KGHM commissioned Golder Associates Ltd. to review the Afton TSF for the specific conditions that led to the failure of the Mount Polley tailings dam. This report provides a summary of the findings during this review to address the specific questions from the MEM related to (i) undrained shear failure of foundation soils, (ii) water balance inadequacy; and (iii) filter inadequacy.

The Undrained Shear Failure of Silt and Clay Foundations Review:

a) Including a determination with respect to whether or not similar foundation conditions exist below the dams on your site

The Afton TSF was built on the historical Hughes Lake and the previous path of Alkali Creek. The borehole data show that clay and silt (clay/silt) deposits exist in some locations beneath the West and East Dams. Although parts of the clay/silt deposits were removed from the foundation during dam construction, some of these deposits may still exist beneath the downstream portion of the West Dam. We also estimate that the clay/silt deposits may be susceptible to undrained shear failure if the rate of new additional loading is sufficiently fast. Fast loading conditions may happen during raising of the existing dam or seismic activity. New additional loading such as raising of the existing dam is not contemplated by KGHM.

b) Whether or not sufficient site investigation (drill holes, etc.) has been completed to have confidence in this determination

Although it appears that a significant portion of the clay/silt deposits under the starter dams may have been removed during the cut-off construction, it is possible that clay/silt deposits still exist under the downstream portion of the West Dam. Based on the investigation information available to date, a definitive and reliable assessment of the potential extent of the clay/silt deposit under the dam was not possible. In order to assess if additional definition of the extent of these deposits under the West Dam is needed, Golder carried out a stability analysis to examine the impact of these deposits, for undrained shear failure conditions, existing under the current configuration of the West Dam. The primary finding of the analysis is stated below in the response to another question, and presented and discussed in this report.

Should the owner contemplate raising the dam, an investigation program should be designed and executed to understand the potential extents of clay/silt material within the foundation footprint of the West Dam.

c) If present, whether or not the dam design properly accounts for these materials

The stability analyses performed by the designers of the existing dams did not consider the possibility of normally consolidated clay/silt deposits in the foundation of the dams. Golder evaluated he stability, for undrained shear failure conditions, of the existing West Dam for estimated extents and properties of the clay/silt deposits in the downstream foundation of the West Dam. The results show that the Dam Safety Guidelines (CDA 2007 and 2013), in terms of calculated minimum factors of safety, are satisfied when undrained shear failure of the clay/silt is considered in the analysis for the static condition and post-earthquake condition. However, depending on the assumed extent of the clay/silt despots under the downstream portion of the dam, the calculated minimum factor of safety from pseudo-static analysis can be slightly less than the CDA specified value.

It is noted that the dams have not been built to their design final elevation. The performance of the existing dams is reported to be satisfactory. The implication of undrained shear failure is more relevant should the West Dam be raised beyond its current configuration; however, this is not allowed under the current permit, nor contemplated by KGHM. If the seismic stability of the West Dam is a concern for closure, consideration should be given to carrying out a detailed study on the seismic effects on the performance of the West Dam.

d) If any gaps have been identified, a plan and schedule for additional subsurface investigation

For the current dam configurations and plans of KGHM, gaps in information do not exist. However, should the West Dam be raised, consideration should be given to drilling and sampling at least three boreholes in the area within 20 m distance from the downstream toe of the West Starter Dam to confirm the estimated extent of clay/silt deposits under the West Dam. A review of the stability for a higher dam is required if the results of this investigation show that the extent of the clay/silt is more than what is used in the stability analysis in this report.

The water balance adequacy review:

a) Including the total volume of surplus mine site water (if any) stored in the tailings storage facility

The TSF is not used for water impoundment as it is currently a non-operational facility. There is minimal water collected in the TSF, most of which is direct precipitation and the local TSF catchment runoff (runoff contributing drainage area of less than 2.5 km^2). During an average hydrologic year, there is a net loss of about 30,000 m^3 annually due to annual evaporation losses exceeding annual precipitation over the drainage area, resulting in a quasi-equilibrium water elevation of about 700 m in the TSF. Because of this net water loss the TSF is functioning essentially as a “dry closure” pond.

b) The volume of surplus mine water that has been added to the facility over each of the past five years

The TSF pond has essentially reached a quasi-equilibrium water elevation of about 700 m and is functioning as a “dry closure” pond before 2014. It is noted that approximately 245,000 m^3 of water was allowed to flow into the TSF in 2014 during construction of the Alkali Creek diversion channel construction raising the water level. This water was pumped from the TSF between December 2014 and April 2015 lowering the water level to its current elevation. The dewatering was carried by KGHM at the historic Afton TSF to address recommendations made in the Mount Polly Investigation and Report by limiting water storage within the TSF. Currently the TSF is practically dry.

There were records of relatively small unusual water level changes when in 2011 New Gold pumped water out of the Afton open pit into the Afton TSF to facilitate underground mine development and into their new tailings impoundment for start-up. Estimates of the volumes are not available but were likely small. As mentioned above, in the spring of 2014, Alkali Creek was diverted into the TSF during construction and repair of the Alkali Creek Diversion Channel. The inflow volumes are reported to have been approximately 245,000 m^3 during the three-month construction period.

c) Any plans that are in place or that are under development to release surplus mine water to the environment

No such plans are envisioned at this time.

d) Recommended beach width(s), and the ability of the mine to maintain these widths

The minimum beach width is about 250 m at the sections of the dams where the toe is lowest. A large percentage of the beach has been reclaimed. The beach length is expected to remain within this range because there is no plan for additional tailings and water deposition into the Afton TSF. If the pond rose to the spillway level during possible future flooding, the pond would be about 70 m away from the West Dam and will start flowing through the spillway in the East Dam. These beach lengths are sufficient to maintain adequate distance between the pond and the dams to keep the gradient within the dams and their foundation within acceptable level.

e) The ability of the TSF embankments to undergo deformation without the release of water (i.e. the adequacy of the recommended beach width)

The settlement measurements on the West Dam and the East Dam show that most of the settlement in the dams happened during active dyke raises. Since 1997, very little settlement has occurred in the West Dam and East Dam.

The normal freeboard is more than 6 m and the freeboard during flood (spillway elevation is 704 m) is about 1.5 m. Therefore the observed settlement does not compromise the ability of the TSF to contain water.

f) Provisions and contingencies that are in place to account for wet years

The available storage volume in the TSF up to the invert of the East Dam Spillway is adequate to safely contain the net inflow during a 100-year wet year, assuming that the diversion structures on Alkali Creek do not fail. The Alkali Creek diversion channel was recently improved to increase its capacity to handle a design flow of 4.4 m^3/s from the 200-year, 24-hour storm event.

g) If any gaps have been identified, a plan and schedule for addressing these issues.

Although the current rate of settlement is not an issue for the East and West Dams, the effect of the Afton Pit operation on the East Dam needs to be investigated and observed. The issue is currently under a joint investigation by KGHM and New Gold Inc.

The filter adequacy review:

a) Including the beach width and filter specifications necessary to prevent potential piping

The fine and coarse filters meet standard filter design requirements. Despite some small deviation from the filter criterion for coarse filter in term of the 'permeability' criterion, the filters are adequate to meet the intent of the filter design for the West and East Dams. The beach is also wide enough to enhance satisfactory performance of the filters as the applied hydraulic gradients are within acceptable level.

b) Whether or not the filter has been constructed in accordance with the design

The as-built filter gradations are generally within the design limits and are expected to perform satisfactorily. The small deviations in the filter specifications are not expected to be an issue for the dam integrity based on our assessment. The filters were constructed wider than the design and this is a positive change.

c) If any gaps have been identified, a plan and schedule for addressing these issues

No gap in information is identified in connection with the filters.

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1.0 INTRODUCTION

1.1 Background

The Afton Mine is located between Highway 5 and Highway 1, approximately 5 km to the west of their junction and 12 km to the southwest of the City of Kamloops (Figure 1). The Afton Tailings Storage Facility (TSF) was designed by Klohn Leonof Consultants Ltd. (KL 1976) to store tailings and water from mining operation. The Afton TSF construction began with East and West Starter Dam construction in 1976 and 1977. The Afton TSF dams have risen to their current approximate crest elevation of 706 m during operation from 1977 until 1997, with a temporary halt in operation from 1991 to 1994 (Klohn-Crippen Consultants Ltd. (KCC) 1998). Since 1997, the Afton TSF has been under care and maintenance.

The Afton TSF was originally operated by Teck Resources Ltd. (Teck). KGHM Ajax Mining Inc. (KGHM) is the current owner of the Afton TSF. The Afton TSF is located next to the New Afton Mine which is operational and owned by New Gold Inc. (New Gold).

The Afton TSF comprises the following components, as shown on Figure 2:

- Two zoned earthfill/rockfill dams with engineered filters. The two dams are referred to as the West and East Dams. The TSF dams were constructed to an approximate crest elevation of 706 m. The maximum height of the West Dam, the larger of the two dams, is approximately 70 m.
- An overflow spillway is located at the north end of the East Dam with invert elevation of 704 m.
- Two seepage collection dams referred to as the Northwest and Southwest Seepage Pond Dams are located downstream of the West Dam.
- The Alkali Creek Diversion includes the East Diversion Dam, West Diversion Dam, and Alkali Creek Diversion Channel. The diversion structures divert Alkali Creek (with an upstream catchment of 53 square kilometres (km^2)) to Cherry Creek around the south side of the TSF.

The West and East Dams were originally designed as conventional water storage dams based on zero water reclaim. The rockfill dams were designed with an upstream low hydraulic conductivity till zone with fine and coarse filters separating the till from the rockfill.

As a result of the Mount Polley tailings dam breach in 2014, the Ministry of Energy and Mines of British Columbia (MEM) requested KGHM to confirm that the conditions that led to the incident at Mount Polley are not present at the Afton TSF (MEM 2015). KGHM commissioned Golder Associates Ltd. (Golder) to perform a review of the Afton TSF for the specific conditions that led to the failure of the Mount Polley tailings dam. This report provides a summary of the findings from this review.

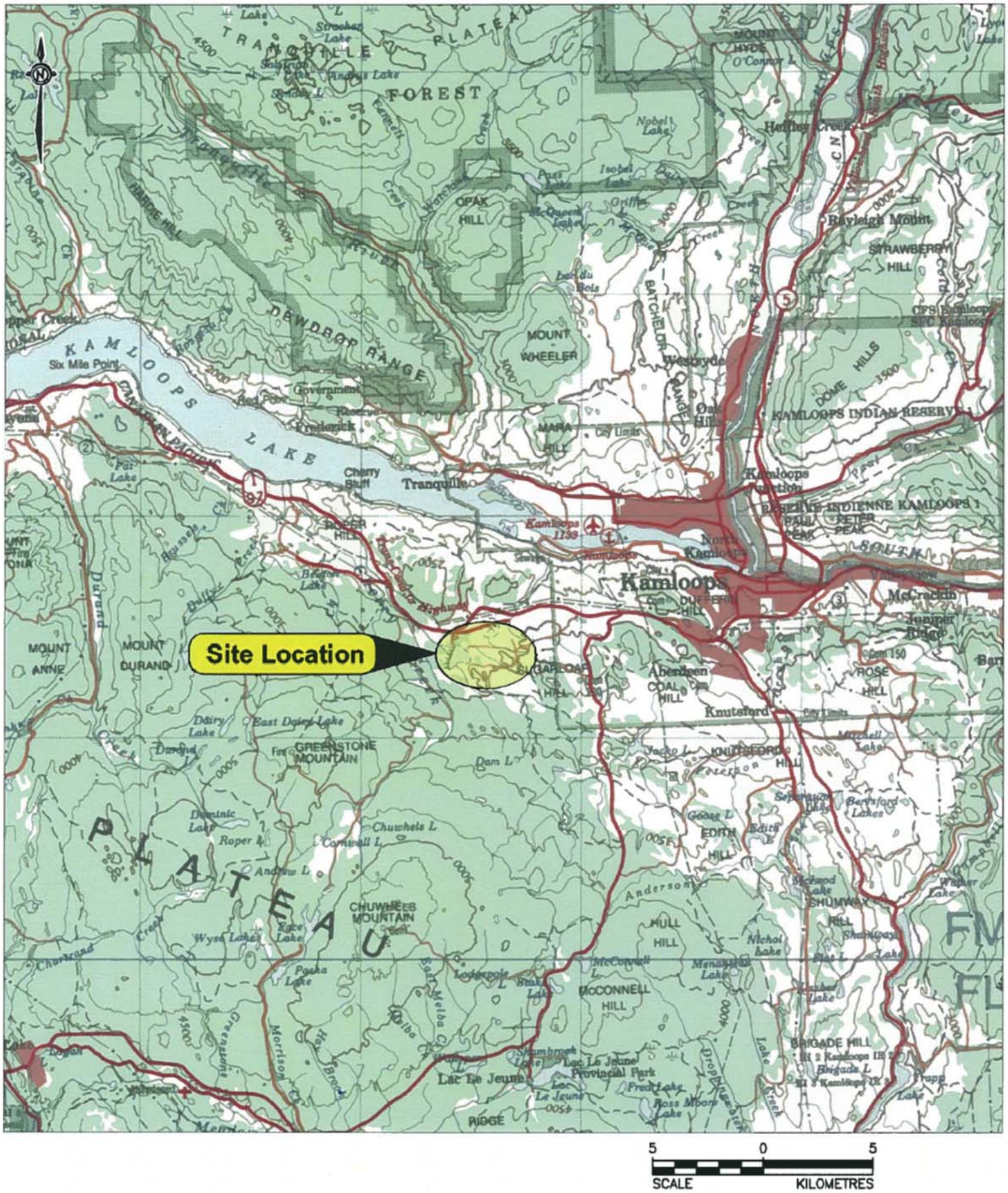

Figure 1: Afton Mine Operation Location Plan

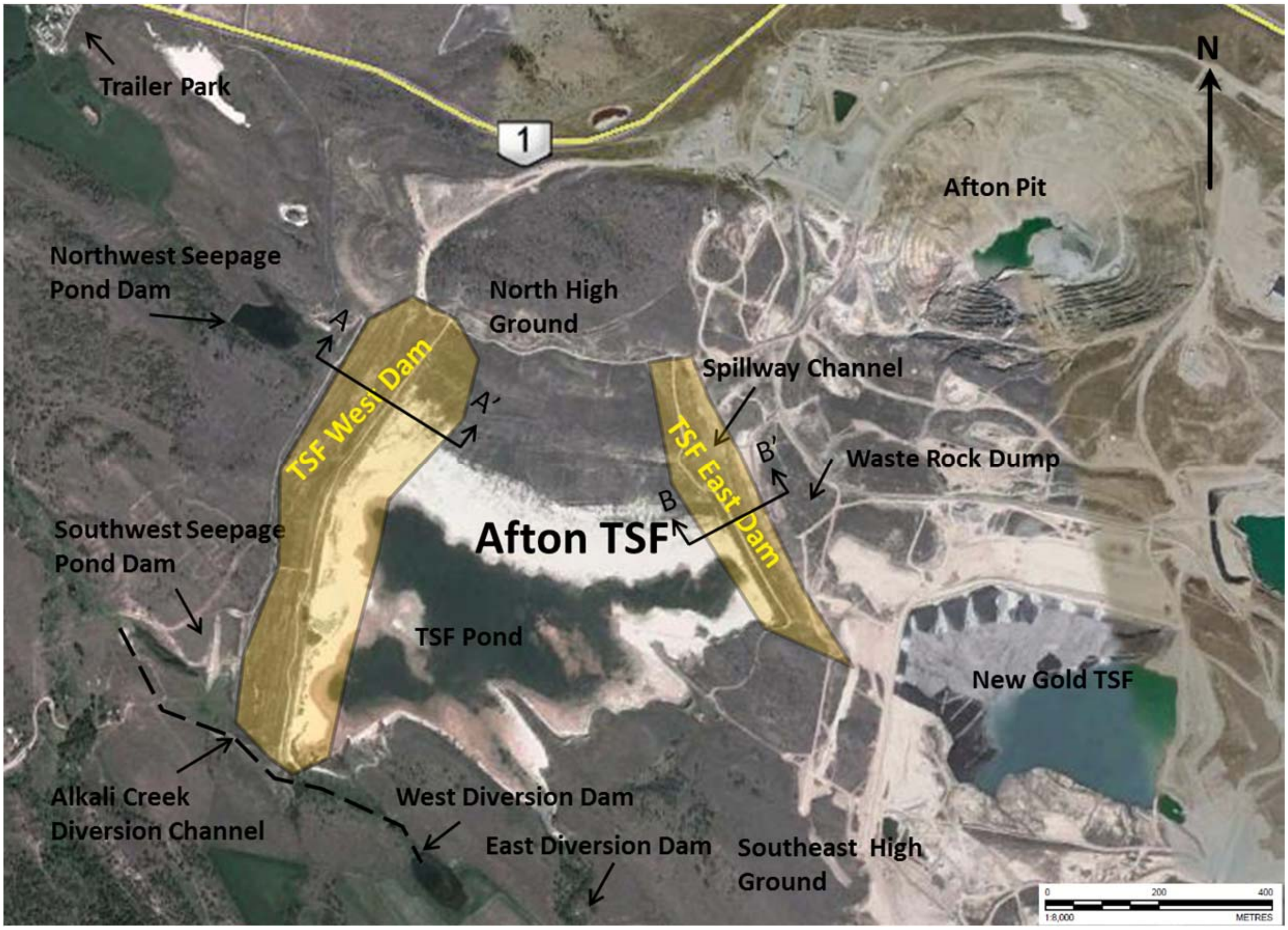

Figure 2: Afton TSF General Arrangement

1.2 Scope of the Report

The scope of the geotechnical engineering services for the review of the Afton TSF was established by KGHM in their Request for Proposal # KA39-KGHM-PRP-000058 (KGHM 2015). The work scope includes four main tasks, which Golder proposed to perform in four phases. This report specifically deals with Task A (Phase 1) of the geotechnical engineering services scope listed in the RFP document.

The scope for Phase 1 of this project includes a geotechnical assessment based on historical construction records, original site investigation reports, recent instrumentation installation logs, and other reports to evaluate if the dams associated with the Afton TSF may be at risk due to:

- undrained shear failure of foundation soils;
- water balance inadequacy; and,
- filter inadequacy.

The Phase 1 scope does not include a site visit. However, a site visit by Golder senior engineers is currently scheduled for summer 2015 in later phases of the project.

1.3 Reference Documents

The following documents were provided by KGHM to support the Afton TSF condition assessment for Phase 1.

- Design Reports:
  - Report on Tailings Dams (KL 1976) (this is the original design report)
  - Afton Tailings Impoundment, Seismic Hazard and Seismic Stability Assessment (Klohn Crippen Berger Ltd (KCB) 2011)
  - Construction Monitoring of 1996 Dam Raises (KCC 1995)
  - Closure Tailings Dam Stability Review (KCC 1998)
- Dam Breach Inundation Study:
  - Dam Breach Study - Afton Tailings Storage Facility (Knight Piésold Consulting Ltd. (Knight Piésold) 2014c)
- Field Data and Construction Data and Review Reports:
  - Fine Filter – Quality Control (KL 1979a)
  - Review of Tailings Dam Facilities (KL 1979b)
  - Piezometers and Monitoring Wells - West Dam Revised Alignment (KL 1980a)
  - Tailings Dam Construction Reports for 1980 (Afton Mine Ltd. (Afton Mine) 1981)
  - Tailings Dam Construction Reports 1981, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, and 1991 operation years (Afton Operation Corporation (AOC) 1982, 1984, 1985, 1986, 1987, 1988, 1989, 1990a, 1990b, 1992)
  - Results of Laboratory and Field Tests on Filter Materials for Tailings Dams (KL 1981c)
  - Review of 1981 Tailings Dam Progress Report (KL 1982)
  - Annual Review of Tailings Dams for 1986, 1988, 1989, 1990, 1991 (KL 1987, 1989, 1990, 1991, 1992)
  - 1994 Tailings Pond Status Report (AOC 1995)
  - Review of Afton's 1994 Tailings Pond Status Report (KL 1995)
  - 1995 Tailings Pond Status Report (AOC 1996)
- Site Visit and Dam Inspection Reports:
  - Tailings Dam Inspection Visit – October, 1980 (KL 1980b)
  - Site Visit – April 9, 1981 (KL 1981a)
  - Record of Site Visit, October 14, 1981 (KL 1981b)

- Summary of Site Visit on September 21, 1995 (KCC, 1996)
- Annual Dam Inspection (Golder Associates Ltd. (Golder) 2011)
- 2014 Annual Inspection Report (Knight Piésold 2014b)
- Review of the Afton Tailings Storage Facility - 2014 Annual Inspection Report (Tetra Tech EBA (EBA) 2014)

- Dam Safety Review Reports:
  - 2004 Dam Safety Review - East and West Dams (BGC 2004)
  - 2009 Dam Safety Review - East and West Dams, Afton Mine (BGC 2009), (Knight Piésold 2015b)
  - Proposal for Design of Diversion Facilities for the Re-located West Dam (KL 1979c)
  - Memorandum Order from Ministry of Energy and Mines – Mines and Mineral Resources Division, to review Mount Polley condition at Afton TSF site (MEM 2015)
  - TSF Monitoring Program – Preliminary results (presentation) (NewGold 2015)

2.0 SITE CONDITIONS

2.1 Physical Setting

The Afton TSF is located at latitude 5,614,000N and longitude 674,500E (coordinate system NAD 1983 UTM Zone 10N). The mine is accessed by Highway 1, approximately 12 km west of Kamloops and the Afton TSF access is by internal mine roads west of the former mine office.

The Afton TSF is located in the Greenstone midlands of the Thompson Plateau (Interior Plateau), an area of moderate relief. Local relief varies between El. 347 m at Kamloops Lake approximately 10 km north of the site, to over El. 1,790 m at Greenstone Mountain approximately 10 km south of the site.

At the Afton TSF site, two topographical highs are located at the north and southeast boundaries of site at approximate elevations of 760 m and 780 m respectively (Figure 2). Prior to the TSF construction, the Afton TSF footprint was partially occupied by Hughes Lake, an east-west trending lake approximately 880 m long and 160 m wide with approximate water level of 645 m (KL 1976). Hughes Lake was drained prior to construction and the West Dam and East Dam were constructed at the low points at the west and east sides of the lake to provide containment storage for the tailings.

Alkali Creek previously drained into Hughes Lake from the southwest, and was diverted in 1976 to allow for TSF dam construction. Alkali Creek currently discharges into Cherry Creek around the south side of the TSF (Kala Geosciences Ltd. 2010).

The Afton TSF was originally designed with a crest elevation of 731.5 m. However, the dams were only constructed to an approximate elevation of 706 m before the end of operation in 1997. The East Dam is buttressed by the mine rock storage area at the downstream toe. The low areas at the downstream toe of the West Dam is occupied by the Southwest Seepage Pond at approximate water level of 635 m and the Southeast Seepage pond at approximate water level of 675 m.

2.2 Geology

The area was subjected to several glaciations during the Pleistocene, resulting in massive erosion and the subsequent deposition of glacial and lacustrine sediments. The physiography of the site is the product of late Triassic geological events that were significantly modified during Pleistocene.

On the Surficial Geology Map of the Kamloops Lake area (Geological Survey of Canada 1963), the surficial geology of the area is defined as:

- Drift (unit 2a on the map): primarily till covered by 0.3 m to 1.5 m of colluvial material and may include areas of younger deposits.
- Rock (unit R on the map), moraine gravel.
- Till (unit 3a on the map): mixture of gravel, sand and fines with boulders.

At the TSF location, the foundation consists of till on bedrock. The till layer has silt layers up to 3.3 m thick close to Hughes Lake (KL 1976).

2.3 Climate

The area has a semi-arid climate. Average winter temperatures are commonly below 0°C, with lows falling below -20°C. The dry summers have temperatures upwards of 30°C. Total precipitation averages approximately 300 mm/year (Kala Geosciences Ltd. 2010).

The mean annual lake evaporation rate as given in the Kala (1997) report is about 561 mm. A review of Environment Canada's map of mean annual lake evaporation rate suggests an annual rate of 600 mm.

2.4 Seismicity

The site is located in a low seismic hazard zone. Adams and Halchuk (2003) presents the 1 in 475 year and 1 in 2,450 year return period peak ground acceleration (PGA) values as 0.07 g and 0.14 g, respectively for this area. BGC (2004) estimated a 1 in 10,000 year peak ground acceleration of 0.25 g for the Kamloops area using the Adams and Halchuk (2003) maps. The upper bound earthquake for southeast British Columbia is magnitude 7.3, based on the H model parameter table in Appendix C3 of Adams and Halchuk (2003).

Klohn Crippen Berger Ltd. (KCBL) performed a site-specific seismic hazard assessment for the Afton TSF area in 2011 to establish seismic ground motion parameters for the Afton TSF (KCBL 2011). KCBL indicates that the PGA is the appropriate earthquake design ground motion for analysis at this site. The PGA depends on the ground stiffness of the foundation and also the assumed return period of earthquake (and therefore indirectly to the dam classification as per the Canadian Dam Association (CDA) Dam Safety Guidelines (2007, 2013)). Table 1 presents the various estimated PGA values for different return periods and site class as presented in KCBL 2011.

Table 1: Afton Site PGA versus Site Class and Return Period

Site Class	Foundation Condition (average within the upper 30 m)	Return Period	
		10,000 year return period	2,475 year return period
B/C	Rock (760 m/s < Vs < 1,500 m/s) to very dense soil and soft rock (360 m/s < Vs < 760 m/s or with either N_{60} > 50 or Su > 100 kPa)	0.29	0.16
C/D	Very dense soil and soft rock (360 m/s < Vs < 760 m/s or with either N_{60} > 50 or Su > 100 kPa) to stiff soil (180 m/s < Vs < 360 m/s or with either 15 < N_{60} < 50 or 50 kPa < Su < 100 kPa)	0.34	0.2

Note:

1. Vs: average shear wave velocity
2. N_{60}: average Standard Penetration Resistance
3. S_u: average undrained shear strength

Based on a review of the borehole and Standard Penetration Test (SPT) results for the site, KCBL (2011) concludes that the till foundation of the Afton tailings impoundment belongs to the reference National Earthquake Hazards Reduction Program (NEHRP) Site Class C (very dense soil and soft rock) to Site Class D (stiff soil). KCBL (2011) uses earthquake design ground motion values equal to peak ground accelerations of 0.20g for the East Dam (high consequence failure dam with design earthquake return period of 1 in 2475 year) and 0.34g for the West Dam (extreme failure consequence dam with design earthquake return period of 1 in 10000 year). They also indicate that a design earthquake magnitude of 7.3 is appropriate for the 2,475 and 10,000 year events.

Golder reviewed the 12 boreholes with SPT data presented in the KCBL 2011 report. Most of the SPT data are collected at a depth shallower than 30 m, with average depth of 18 m. The average SPT N value of each borehole is between 43 and 110 blows per 300 mm penetration, with an overall average of 65 blows per 300 mm penetration. Among the 12 boreholes, only three had average SPT N value less than 50 blows per 300 mm penetration. The boreholes indicate that the foundation consists of silt up to 3.3 m thick overlaying very dense till.

Based on the information and data, Golder concludes that the previous site class assumption (KCBL 2011) might be too conservative for the as-built and existing conditions of the dams. It may be more appropriate to consider that the till foundation of the Afton tailings impoundment belongs to the reference NEHRP Site Class B (Rock) to Site Class C (very dense soil and soft rock). Therefore Golder used earthquake design ground motion values equal to peak ground accelerations of 0.22g for the East Dam (very high consequence failure dam) and 0.29g for the West Dam (extreme failure consequence dam).

3.0 CONSTRUCTION AND OPERATION

The original design was based on zero water reclaim and the dams were designed as conventional water storage dams (KL 1976). However, the design of the Afton dams evolved during the construction and operation period. In later stages of operation tailings beach separated the pond from the dams.

3.1 Site Preparation and Starter Dam Construction

The preconstruction field investigation in and around the Afton TSF footprint consisted of six boreholes and 44 test pits. Of those, five test pits and four boreholes were located in the West Dam area and two boreholes and 10 test pits in the East Dam area. These original site investigation results indicate that the foundation of the West and East Dams consist of silt close to the ground surface underlain by till or bedrock (KL 1976).

Two starter dams were constructed at the west and east side of the drained Hughes Lake. The starter dams were constructed using compacted till (KL 1976, AOC 1981). The starter dams were designed with a cut-off trench to undisturbed till or intact bedrock (KL 1976). If properly constructed, this design would remove the loose silt layers beneath the starter dam cut-off trench. The design also required extension of the fine filter under the starter dams beyond the cut-off trench) and part of the rockfill. The design required stripping to firm undisturbed soil beneath the fine filter area. The foundation of the rest of the dam required clear and grub beneath the rockfill portions and ground stripping as required by the Engineer (KL1976).

As-built sections of the starter dams presented in construction reports (e.g. the 1981 construction report (AOC 1981)) show the approximate extent of the fine filter on the foundation, corresponding to the extent of the original ground stripping. The as-built sections also show that the fine filter extends about 150 m downstream from the upstream toe of the starter dam (AOC 1981).

3.2 Dam Raises

During the periodic dam raises from 1977 to 1997, some modifications to the original design were made. The main changes to the original design are:

- In 1979 Afton Mines began reclaiming up to 50% of the tailings water. This resulted in greater proportion of tailings to water than the original design during operation (KL 1981). Therefore wider beaches started to develop between the pond and the dams.
- The gradation limits for the fine and coarse filters were widened from the original design.
- The coarse filter was overbuilt (possibly due to construction equipment limitations).

The West and East Dams were raised to an approximate elevation of 706 m by end of operation in 1997. Settlement gauge data suggest that there was up to 0.6 m of settlement of the dams from 1987 to 1995 (AOC 1995). Most of the settlement happened during active raising of the dams. This suggests that the compression of the foundation soils is the primary source of dam settlement (KCL 1995) and that settlement is relatively quick, suggesting reasonably high hydraulic conductivity and coefficient of consolidation of the foundation soils.

3.3 Current Condition

Since the end of operation in 1997, the West and East Dams have maintained approximate crest elevations of 706 m. This is about 25 m lower than the original design crest elevation of 731.5 m. As a result, the crest of both dams is more than 100 m wide instead of the design final crest width of 15 m. Figures 3 and 4 compare the inferred as-built sections to the design sections for the West Dam and East Dam, respectively.

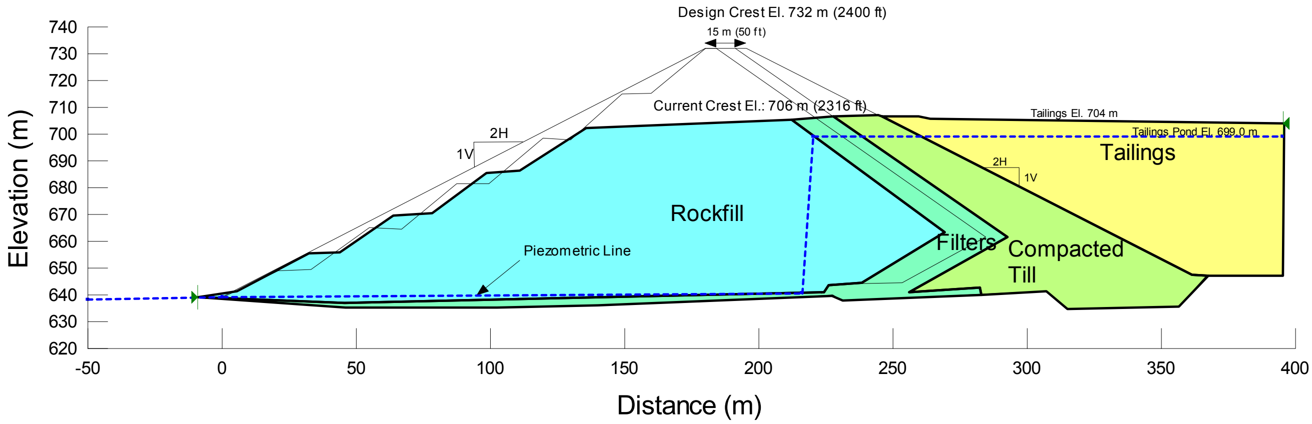

Figure 3: West Dam Inferred As-built Section (Section A-A', Figure 2)

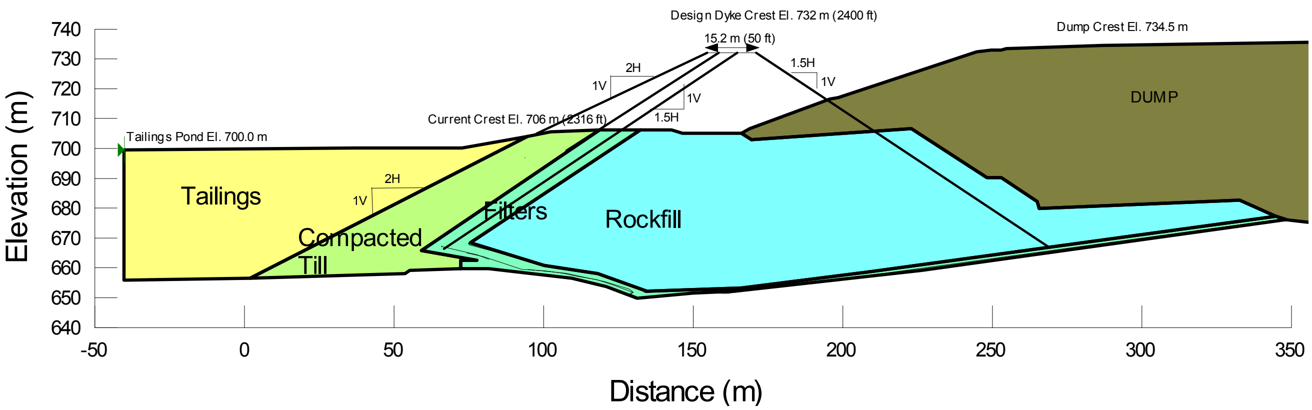

Figure 4: East Dam Inferred Estimated As-built Section (Section B-B', Figure 2)

As of 2014, the pond level within the Afton TSF was recorded at 699.5 m. In December 2014 and April 2015 KGHM completed a dewatering program at the Afton TSF. This pumping program was initiated due to recommendations made in the Mount Polly Investigation and Report to limit water stored within the TSF.

From December 20, 2014 to January 2, 2015 KGHM pumped approximately 330,000 m^3 from beneath an ice cover on the pond. Once the ice melted pumping was initiated again on April 10, 2015. From April 10 to April 19 an additional 150,000 m^3 was transferred out of the TSF. As of June 2015, the TSF is practically dry despite recent heavy rainfall (Rob Maciak, email dated June 15, 2015).

The dam classification defines the design parameters for the inflow design flood (IDF) and the earthquake design ground motion. A dam breach inundation study performed in 2014 identified the flood inundation area due to hypothetical failure events in the dams (Knight Piésold 2014c). Based on this study and the CDA Dam Safety Guidelines (CDA 2007 and 2013), the West Dam has an extreme consequence classification, and the East Dam has a very high consequence classification (Knight Piésold 2014e).

The West Dam was given a higher classification due to the presence of a trailer park downstream of the dam that may be impacted by a hypothetical failure of the West Dam (Knight Piésold 2014c). The dam breach inundation study maps show that a dam breach in the West Dam may inundate the trailer park. The trailer park has approximately 50 dwellings and is located about 1.4 km downstream of the West Dam (BGC 2009). Therefore a breach of the West Dam may result in a relatively large number of fatalities and results in an extreme consequence classification based on the loss of life category.

The previous classification of the East Dam considered that a breach in the East Dam may result in flooding of the Afton pit but with no permanent population at risk. They also considered the possibility of water and/or debris reaching Highway 1 in the event of dam breach. New Gold is currently engaging in underground, block caving mining activities with the portal and decline located near the bottom of the Afton pit; therefore, some workers may be at risk (Knight Piésold 2014c). A recent review of the findings resulted in the estimation of very high consequence classification for the East Dam (Knight Piésold 2014e). Raising the East Dam consequence level from high to very high is based on assumptions that workers can be underground and the cave breakthrough to the Afton pit creating a conduit to underground should there ever be a breach.

Recent pumping from the Afton TSF pond reduced the water level to lower than 699 m. With the beach slope observed, the beach length to the sections of the dams with lowest toe is estimated to be about 250 m. This can result to an average hydraulic gradient of about 0.1 under the dam.

4.0 TSF FOUNDATION CONDITIONS

4.1 Introduction

The Ministry of Energy and Mines (MEM) requires confirmation that the conditions that led to the incident at Mount Polley are not present at other mines in British Columbia. More specifically, KGHM is required to undertake an assessment to evaluate if the West Dam and East Dam may be at risk due to undrained shear failure of foundation soils. A review of the West and East Dam foundation conditions is presented in this section to:

- Assess if the original site investigation carried out has identified silt and clay deposits in the dam foundations that may be susceptible to undrained shear failure under loading.
- Assess whether sufficient site investigation has been completed to have confidence that foundation soils potentially susceptible to undrained shear failure under loading are not present.
- Assess if the design and construction of the West and East Dams can accommodate the potential presence of foundation soils susceptible to undrained shear failure under loading.
- Identify possible information gaps in the investigation data, design, and construction.
- If required, propose a plan and schedule for additional subsurface investigation and design refinements that are necessary to satisfactorily address the presence and effect of dam foundation soils that may be susceptible to undrained shear failure under loading.

4.2 Available Information

Previous site investigation boreholes, test pits, and cone penetration tests (CPT) were reviewed by Golder to evaluate the foundation conditions at the West and East Dams. Table 2 presents a summary of the information used by Golder. Table 2 only lists the boreholes that were advanced through the dam and tailings of the TSF and reached the TSF foundation.

The test pits and boreholes in 1973 and 1974 were performed before the start of Afton TSF construction. The later boreholes and CPT were performed after start of dam construction. Some of these boreholes were drilled from the dam or tailings beach/pond surface and did not reach the foundation.

A series of CPTs was also pushed and reported by Knight Piésold in 2014 within the TSF pond area and those data were available to Golder for review (Knight Piésold, 2014). The 2014 CPT targeted the tailings material at the inner part of TSF and in most cases their penetration into the foundation soils was limited. Therefore, they are not listed in Table 2 as information used to assess the West Dam and East Dam foundation.

Table 2: Summary of Available Foundation Site Investigation at the West and East Dams

Type of Investigation	Investigation Year	Number	Reference	Comments
Borehole	1974	6	KL (1976)	Drilled at the lower areas around Hughes Lake Depth between 22 m and 34 m Three boreholes ended in bedrock at depth between 20.7 m and 32.0 m
	1980	5	KL (1980)	-
	2014	12	Knight Piésold (2015a, 2015b)	-
Test Pit	1973	18	KL (1976)	Maximum depth 4.6 m 3 test pits ended in bedrock at a depth between 0.3 m and 3.6 m
	1974	25	KL (1976)	Maximum depth 3.6 m 5 test pits ended in bedrock at a depth between 0.3 m and 2.1 m
Sonic Boreholes	2014	12	Knight Piésold (2014)	-

4.3 Clay/Silt Deposits in Foundation

4.3.1 Clay/Silt Extent

Based on the information available to Golder (Table 2), the TSF foundation is mainly till on top of bedrock. Bedrock at the lower ground surface elevations in the previous Hughes Lake area is more than 30 m deep, but bedrock is at a much shallower depth at higher ground surface elevations. Prior to construction, the foundation was covered by a topsoil layer up 0.6 m of mostly silt, sand with organic content and roots. Based on the construction procedures and as-built sections (Section 3.1) this top layer was removed from beneath the West Dam and East Dam.

The pre-construction extent of the clay/silt deposits was estimated based on the boreholes drilled before construction. At the low ground (original ground below El. 655 m (2150 ft.)) in the previous Hughes Lake area, deposits of clay/silt were found in the boreholes between the topsoil and the till. Clay/silt deposits were also observed along the creeks in the TSF footprint at higher ground surface elevations. These deposits were occasionally more gravelly and sandy, but due to their vicinity to the previous lake and creeks they are of fluvial and lacustrine nature and of different origin than the till and topsoil. Figure 5 presents a plan view of the TSF area showing the boreholes which penetrated into the foundation soils and the estimated extent of the clay/silt deposits before the TSF construction.

The clay/silt deposits under the footprint of the dams may be potentially susceptible to undrained shear failure under fast increase in loading conditions and, as such, may affect the stability of the dams. The existing permits from MEM are for care and maintenance, and do not allow for raising of the dams. Fast increased load conditions can happen during a seismic event.

Part of the clay/silt deposits beneath the dams was removed during the dam construction. The existing condition beneath the dams can be divided into three areas as follow:

- Area under the starter dams: The as-built sections of the dams show that a cut-off trench was constructed under the starter dams with specifications to excavate to undisturbed till or intact bedrock (KL 1976). Also in the rest of the starter dam foundation, the as-built sections show a deeper excavation and thicker fill. Boreholes DH14-1, SD-14-47 and DH14-2 drilled after dam construction in this area show no signs of clay/silt deposits. Therefore it is concluded that the clay/silt in this area was most likely removed from the dam's foundation during construction.
- Area under the fine filter on the foundation: The design required extension of the fine filter under the starter dams and part of the rockfill downstream of the starter dams with stripping to firm undisturbed soil. The as-built sections of the East and West Dams show the excavation in this area is shallower than the cut-off trench area. Based on these as-built sections and design specifications, Golder considers that the clay/silt layer is also most likely removed from the foundation of the dams in this area.
- Area from the downstream extent of fine filter on the foundation to the toe of the dams. Based on boreholes/test pits TH1002, TH1003 and TP410 in this area under the West Dam and borehole/test pits TH1006 and TP404 under the East Dam, the clay/silt deposit in this area was lower than the average depth of 0.6 m under both dams. The average thickness of the clay/silt deposits is 0.9 m and 2.5 m under the West and East Dams, respectively, before construction. The construction specifications for foundation preparation required clearing and grubbing beneath the rockfill portions, and ground stripping as required by the Engineer (KL1976). Golder considers that it is likely that the clearing and grubbing operation was not deep enough to remove the clay/silt layer in this area.

The original design of the West Dam was to extend the fine filter on the foundation to about 80 m downstream from the West Starter Dam toe. The as-built section shows the extent of the fine filter on the foundation only to about 30 m downstream of the West Starter Dam. From the construction records it is not clear what foundation preparation was followed within this 50 m zone difference between the design and as-built extent of the fine filter. A borehole drilled in 2014 (DH14-5) drilled after the West Dam construction did not identify a clay/silt deposit under this area at the West Dam downstream foundation. The ground surface of this borehole is at Elevation 648 m, which is slightly higher than the Hughes Lake level before construction. The DH14-5 drill method was most likely designed considering the rockfill on top of the foundation and not necessarily would capture the detail of a soft soil layer beneath the rockfill. Also the borehole is close to the edge of the estimated extents of the clay/silt deposits (Figure 5). The thicker clay/silt deposits at this area in the middle of valley at the lower ground surface elevation area may still be in place. This area is shown on Figure 5 as an area where clay/silt removal is uncertain (i.e., the red-hatched area).

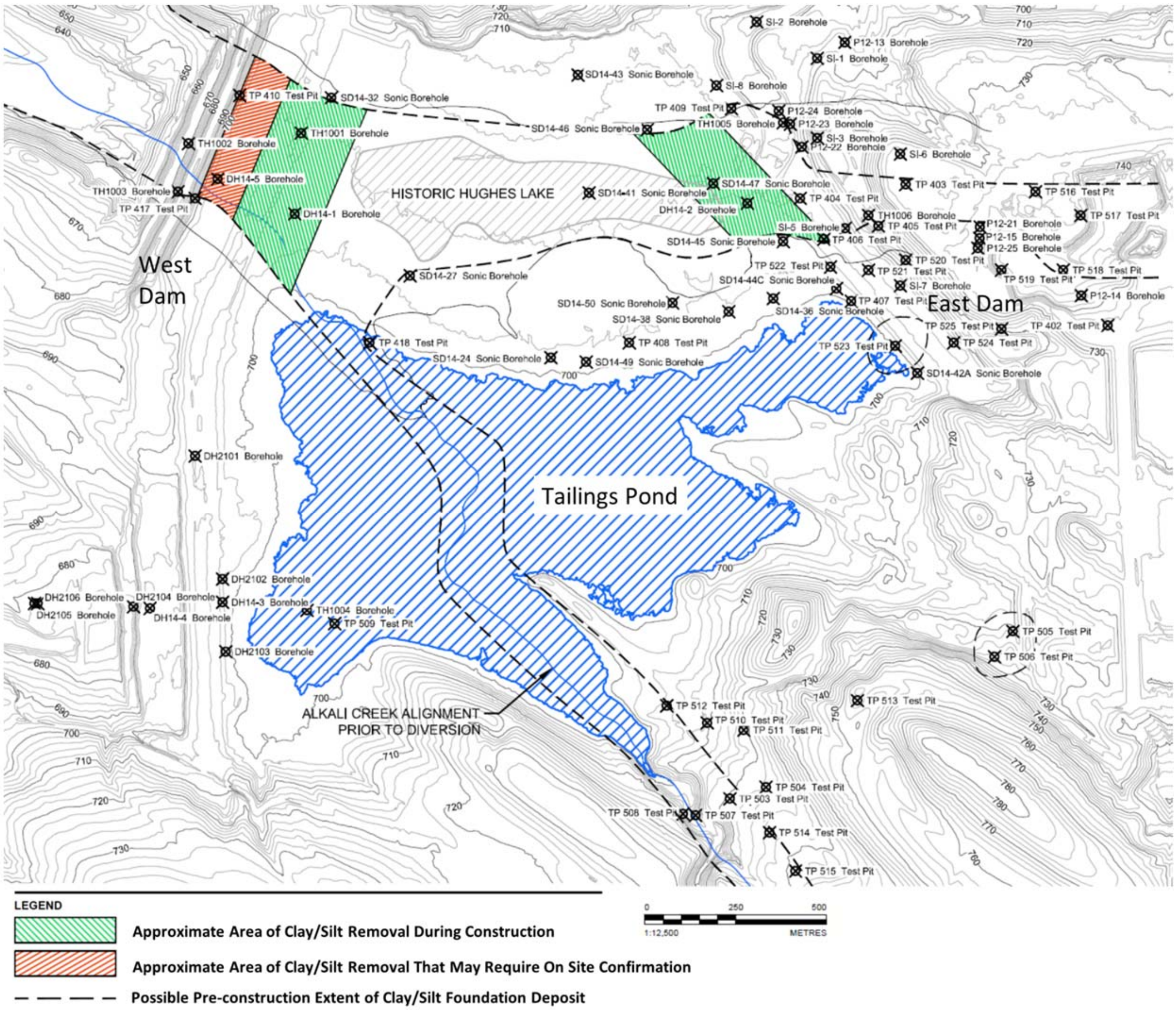

Figure 5: TSF Plan Showing the Boreholes in the Foundation and Estimated Extent of Clay/Silt Deposits

4.3.2 Clay/Silt Properties

The lacustrine and fluvial clay/silt deposits in the TSF area is described in the borehole records in most cases as silt, gravelly silt, sandy silt, and silt with some sand. It is described as ranging from "soft to stiff" in the borehole records. In a limited number of boreholes, the deposits are shown as clay with some sand (for example in Borehole TH 1003, (KL 1976). The measured SPT N-value for this material varies between 13 and 40 blows per 300 mm penetration (KL 1976). This suggests that the material is "stiff to hard" (or compact to very dense). No shear test was performed on this material.

The clay/silt has most likely been deposited in a fluvial or lacustrine environment associated with Hughes Lake or Alkali Creek, and is relatively recent (of young age) in comparison to the till. Therefore, it is not as over consolidated as the till.

Although no Atterberg Limits tests have been reported for the clay/silt samples beneath the dams, three tests were conducted on samples from this deposit from boreholes closer to the Hughes Lake (Knight Piésold Ltd. 2014f). Golder considers that the clay/silt under the dams are from the same origin and similar to these samples from around the Hughes Lake. These tests show that the clay/silt deposit is classified as CL to CH with an average water content of 32% (between 24% and 42%). One water content test was performed on a sample from a “clay” layer in Borehole TH 1003 in the West Dam foundation area that shows a water content of 45%. The sampler was relatively thick walled and therefore this water content may not be representative.

The silt layer in the Mount Polley tailings dam’s foundation was also classified as CL to CH with an average water content of 32% (range between 19% and 53%). The CPT tip resistance was between 2 MPa and 4 MPa with a clay consistency of stiff to very stiff. Therefore, the undrained shear strength ratio of the clay/silt in the Afton TSF is estimated to be 0.27, similar to the silt at Mount Polley. The undrained shear strength of a stiff to very stiff silt and clay material is in the range of 50 kPa to 200 kPa. Golder has estimated the minimum undrained shear strength (S_u) of the clay/silt to be around 100 kPa. Therefore, the maximum vertical effective stress on the material is estimated to be about 370 kPa, or equivalent to an approximate fill height of 20 m (assuming unit weight of 21 kN/m^3 and groundwater surface slightly higher than the original ground surface). The current maximum height of the West Dam and East Dam is about 70 m and 50 m, respectively. Therefore, the loading from these dams results in a normally consolidated condition in the clay/silt portions of the TSF foundation. An undrained shear failure condition may be possible if the loading changes sufficiently rapidly in the clay/silt foundation.

The seepage dams are smaller with an estimated height less than 10 m. Therefore, it is considered that the clay/silt portions of the foundation beneath these dams would still be in an over consolidated state and geotechnical stability would not be an issue.

4.4 Dam Stability

The stability analysis for the West Dam was previously modelled with the assumption that the West Dam was constructed directly on the till (KCBL 2011). Based on Golder’s assessment of potential foundation conditions, clay/silt deposits that may be susceptible to undrained shear failure may exist beneath the downstream slope of the dam with the approximate extent shown in Figure 5.

The stability analysis of the existing West Dam was reviewed to assess the effect of the foundation clay/silt deposits on the West Dam stability. Different potential failure surfaces and loading conditions were considered in the analysis. The loading cases are:

- Static loading: in this condition static loading with static strength parameters are used in analysis.
- Earthquake loading: a pseudo-static limit equilibrium analysis was performed to model the seismic loading on the structure.
- Post-earthquake loading condition: Earthquake loading may soften the clay/silt and reduce the undrained shear strength of this layer due to cyclic loading. Static analysis is done using post-earthquake parameters for the clay/silt and liquefied tailings.

Material properties similar to those used in previous stability analyses were used in the modelling performed by Golder, except for the clay/silt material. For the post-earthquake loading condition, the shear strength of clay/silt is estimated to be reduced by 20% (a factor of 0.8) as suggested by Boulanger and Idriss (2007). Table 3 presents a summary of material properties used in the stability analysis.

Table 3: Material Properties Used in Stability Analysis

Material		Unit Weight (kN/m^3)	Effective Friction Angle (degrees)	Undrained Shear Strength Ratio
Tailings		17.5	30	$S_u/\sigma_v' = 0.15$
Compacted Till		22.0	32	-
Foundation Till		22.0	30	-
Filters		19.5	32	-
Rockfill		19.5	37	-
Foundation Clay/silt	Static and Seismic case	19	-	$S_u/\sigma_v' = 0.27$ (minimum S_u of 100 kPa)
	Post-Earthquake	19	-	$S_u/\sigma_v' = 0.22$ (minimum S_u of 80 kPa)

S_u: undrained shear strength

σ_v' : vertical effective stress

Stability analysis was considered for failure surfaces that may result in release of the tailings material and water from the West Dam. Golder estimates that such failure surfaces may start from the upstream crest of the dam to the downstream toe (Figure 6).

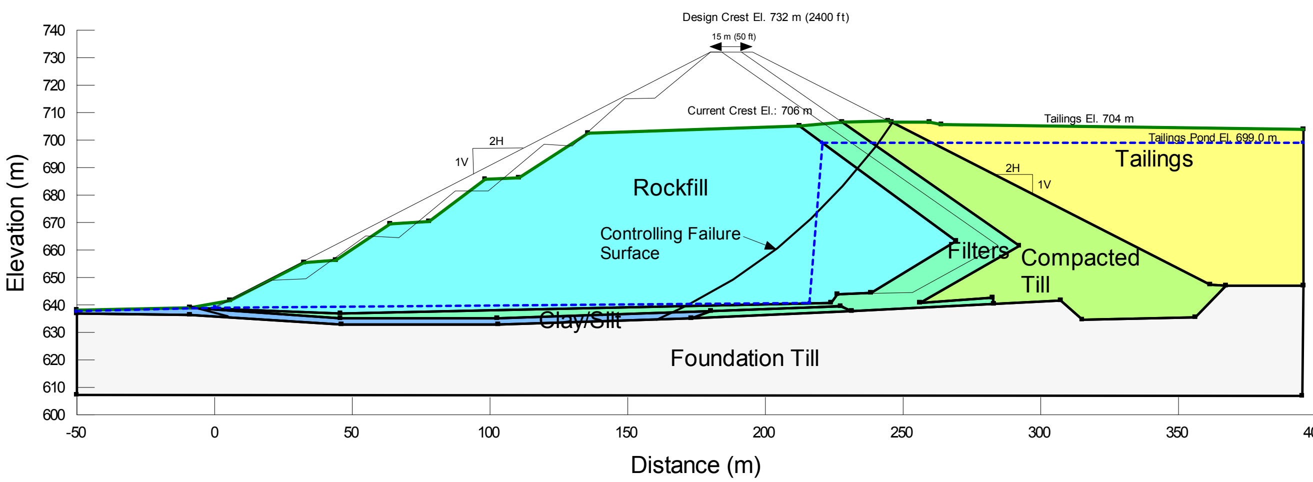

Figure 6: West Dam Stability Analysis Section, Controlling Failure Surfaces

The results of stability analysis show that the Dam Safety Guidelines (CDA 2007 and 2013), in terms of calculated minimum factors of safety, are satisfied when undrained shear failure of the clay/silt is considered in the analysis for the static condition and post-earthquake condition. However, depending on the assumed extent of the clay/silt despots under the downstream portion of the dam, the calculated minimum factor of safety from pseudo-static analysis can be slightly less than the CDA specified value.

5.0 WATER BALANCE

5.1 Introduction

The Ministry of Energy and Mines (MEM) requested KGHM to undertake a water balance assessment to assess if the Afton TSF dams are at risk of failure during extreme rainfall or flood inflow events. Several items are included under the "Water Balance Adequacy" section in MEM's letter dated February 3, 2015 and these are addressed herein in the same order as presented in the letter.

Most of the items were addressed through a review of existing information available in reports prepared by various consultants to Afton. Where data were available, high-level analyses were made to check flow magnitudes or hydrologic conditions described in the existing reports that formed the basis of this water balance adequacy.

5.2 Water Balance Adequacy

5.2.1 Background Information

The most recent documents that provide background information on the water balance at the Afton TSF site are:

- Knight Piésold Consulting Ltd (Knight Piésold) prepared a Dam Safety Review (DSR) report (2013 DSR) on the Afton TSF during 2013 and 2014 (Knight Piésold 2014a). Hydrotechnical considerations for an extreme consequence rated facility include that the facility be designed to store and/or safely pass the Probable Maximum Flood (PMF). Knight Piésold noted that the spillway design met those requirements at time of construction in 1997; however, they recommended the spillway design be reassessed based on updated hydrology information and incorporating changes that may impact the spillway including new infrastructure (New Gold's TSF and roadways) and potential future settlement of the dams.
- Knight Piésold carried out an annual inspection of the TSF on June 13, 2014 (Knight Piésold 2014b). The inspection report was reviewed by Tetra Tech EBA Inc. (EBA 2014). EBA noted that a review of the provided documentation indicates that the 2014 Afton TSF inspection was undertaken in general accordance with the requirements of the CDA Dam Safety Guidelines (2013) and the BC MEM Guidelines for Annual Dam Safety Inspection Reports (2013). In addition, the dam consequence classification undertaken as part of the Dam Safety Inspection (DSI) adequately reflects the potential impacts associated with a dam failure.

5.2.2 Adequacy of TSF to Pass the PMF

One of the recommendations from the 2009 DSR (BGC 2009) was to upgrade the Alkali Creek diversion system at the south end of the TSF to pass flows of 5 m^3/s, or review the pond elevation during routing of the Inflow Design Flood (IDF) assuming the diversion system is not able to fully pass 5 m^3/s. The IDF was estimated to be 182 m^3/s, and the design TSF spillway outflow capacity was 177 m^3/s. The Alkali Creek diversion channel was recently improved to increase its capacity to handle a peak flow of 4.4 m^3/s generated during a 200-year, 24-hour storm event.

The TSF has a spillway located at the East Dam north crest. The objective of the spillway is to provide a controlled release of stormwater from the TSF to prevent overtopping of the dams. Stormwater flows passing through the spillway would discharge onto the New Gold property. The spillway was designed to pass the PMF flow, which was estimated at 182 m^3/s. Knight Piésold reviewed the PMF value during the 2013 DSR and indicated that the estimate of 182 m^3/s was generally appropriate for the size of the upstream catchment area (about 56 km^2).

Knight Piésold stated in the 2013 DSR report that it is standard engineering practice to assume the failure of upstream diversion systems during extreme storm events when sizing critical dam safety components, such as emergency overflow spillways. The design of the spillway should have considered flows from the entire upstream catchment, estimated at 182 m^3/s. The key to this evaluation is the level of accuracy in defining PMF volumes and peak flows through the system. Estimated flood values are likely accurate to within 10% to 20%. The addition of 5 m^3/s from the Alkali Creek diversion system is therefore within the level of accuracy of the PMF estimate and spillway outflow capacity.

Knight Piésold (2014a) notes that the TSF has an upslope catchment area of 55.6 km^2 and 3.4 million m^3 of normally available storage capacity, from a pond level of 699.5 m up to the spillway outlet level at 704.1 m. This will be exceeded by the PMF inflow volume and the attenuation capacity of the reservoir will be small; therefore, the water level in the TSF at the time when the PMF occurs will have little impact on the peak spillway outflows.

The rationale provided by Knight Piésold to indicate that the TSF would be able to pass the estimated PMF of 182 m^3/s is reasonable. A check on the reasonableness of the PMF estimate of 182 m^3/s was made by Golder as part of this assessment and the findings are presented below:

- Abrahamson and Pentland (2010) developed regional regression-based empirical equations for estimating the magnitude of the Probable Maximum Flood (PMF) from watersheds in British Columbia. The Afton TSF site is located in Hydrologic Region 12B (Southern Interior), which suggests that the PMF equation for Zone 12 B would be applicable. The "best-fit" and "upper envelope" equations for estimating PMFs are:
  - PMF(best-fit) = $2.1086(DA)^{0.9240}$, where DA is the watershed area in km^2
  - PMF(upper-envelope) = $4.1768(DA)^{0.9240}$, where DA is the watershed area in km^2
- Application of these two equations result in best-fit and upper envelope PMF estimates of 87 m^3/s and 172 m^3/s, respectively.
- The estimate of 182 m^3/s for the PMF is reasonable and likely conservative. Hence, the East Dam spillway, with a reported capacity of 177 m^3/s, should be able to safely pass the PMF.

The ability of the TSF facility to contain a Probable Maximum Precipitation (PMP) event centred over the TSF pond (assuming the diversion structures on Alkali Creek perform as designed) was assessed by Golder as a second check. Referencing a study done for BC Hydro, Abrahamson and Pentland (2010) suggests that 24-hr PMPs for 16 BC Hydro watersheds in southwestern British Columbia varied from 260 mm to over 500 mm.

The Hershfield method was used to estimate an approximate PMP for the Afton TSF site using the following standard equation:

$P_m = P_{mean} + k_m * Stdv$

Where P_m is the Probable Maximum Precipitation at the site of interest, P_{mean} and *Stdv* are the mean and standard deviation of maximum annual rainfall at that site, and k_m is a frequency factor, which varies between 5 and 20. The k_m value of 20 is used in this study to be conservative for the estimation of PMP.

The closest Environment Canada climate station with the appropriate data to use the Hershfield approach is Kamloops Airport. The short duration rainfall intensity-duration-frequency (IDF) data compiled by Environment Canada at Kamloops A were used for the estimation of the PMP. The 24-hr mean maximum annual rainfall amount is 21.3 mm and the standard deviation of the 24-hr maximum annual rainfall amount series is 8.9 mm. Using Hershfield's equation results in a point PMP of about 200 mm.

Assuming a contributing runoff area of about 2.5 km^2 to the TSF (Knight Piésold 2014c), a starting pond water surface area of about 35 hectares (ha) at an elevation of 700.4 m (Kala 1997) and a runoff coefficient of 0.5, the PMP event results in a total runoff inflow volume of about 320,000 m^3. The available storage volume in the TSF pond between elevation 700.4 m and the invert of the spillway at 704.1 m (Kala 1997) is about 3.4 million m^3 (Knight Piésold 2014a). Hence, the TSF pond can safely contain a local PMP event assuming that the diversion structures on Alkali Creek do not fail.

Our review of the available background information and high-level checks suggests that as long as the TSF is not used for water impoundment, it is capable of passing the IDF (PMF) or a local PMP event.

5.2.3 MEM Identified Items for Water Balance Adequacy

The MEM has identified several items that need to be addressed under this section. These are addressed as follows.

a) Total volume of surplus mine site water (if any) stored in the tailings storage facility

The TSF is not used for water impoundment as it is currently a non-operational facility. There is minimal water collected in the TSF, most of which is direct precipitation and the local TSF catchment runoff (runoff contributing drainage area of less than 2.5 km^2). The tailings pond has not historically had a staff gauge or other precise means of determining the water level.

The 2013 DSR visual inspection of the dams showed that the tailings pond elevation was approximately 699.5 m on July 9, 2013 or approximately 6 m below the crest of the dams. The area of the TSF was approximately 15 ha.

Knight Piésold carried out a DSI of the TSF on June 13, 2014. The tailings pond elevation was estimated to be slightly below 700 m at the time of the inspection, with an estimated pond area of 55 ha. At this level there is over 4 m of freeboard to the spillway outlet (704.1 m). The pond level was estimated to be approximately 0.5 m higher than it was one year earlier during the 2013 DSR site visit. The water level increase can be attributed to the Alkali Creek inflow that was diverted to the TSF for approximately three months during repair of the Alkali Creek Diversion Channel from late March to late June 2014.

The Kala water balance report (Kala 1997) indicates that the spillway was constructed with an invert elevation of 704.1 m. Knight Piésold, in its 2014 annual inspection report (Knight Piésold 2014b), indicates that based on LiDAR data provided to them, the lowest contour within the TSF area was 699.5 m, implying that the tailings pond was between Elevations 699.0 m and 699.5 m at the time of the LiDAR survey. The ponded volume and bathymetry of the pond below the 699.5 m contour is not known; however based on estimated beach slopes, the pond is expected to be quite shallow. Less than 0.5 million m^3 of water storage below the 699.5 m contour is expected in 2014. The surface area corresponding to the 699.5 m contour is approximately 40 ha. A depth-area-capacity relationship developed for the tailings beach area between 699.5 m and the spillway channel invert shows that, in addition to the water below the 699.5 m contour, roughly 3.4 million m^3 of water storage is available, and the full pond would cover an area of 100 ha. There is approximately 1.9 m of freeboard from the base of the Spillway Channel to the East Dam crest.

In December 2014 and April 2015 KGHM completed a dewatering program at the historic Afton TSF. This pumping program was initiated due to recommendations made in the Mount Polly Investigation and Report to limit water stored within the TSF.

From December 20, 2014 to January 2, 2015 KGHM pumped approximately 330,000 m^3 from beneath an ice cover on the pond. Once the ice melted pumping was initiated again on April 10, 2015. From April 10 to April 19 and an additional 150,000 m^3 was transferred out of the TSF. As of June 2015 the TSF is practically dry, despite recent heavy rainfall (Rob Maciak, email dated June 15, 2015).

b) Volume of surplus mine water that has been added to the facility over each of the past five years

In 1997, water levels in the surface water pond were reported to range between 702.6 m and 704.0 m (Kala 2010). Based on the 1997 water balance, it was estimated that a 'dry' closure would naturally occur, with depletion of the pond occurring over a period of seven years (Kala 1997) as evaporation losses would exceed runoff from rainfall and snow melt. Pond levels decreased as predicted in the water balance. Based on a review of the available information, Knight Piésold (2014a) reports that the TSF is probably in a seasonal equilibrium at or near the recent pond levels of 699.0 m to 699.5 m.

A review of precipitation and evaporation rates at the TSF pond was undertaken by Golder as part of this water balance assessment.

The 1981 to 2010 climate normal data at Kamloops A suggest a mean annual precipitation amount of 278 mm. The mean annual lake evaporation rate as given in the Kala (1997) report is about 561 mm. A review of Environment Canada's map of mean annual lake evaporation rate suggests an annual rate of 600 mm.

Kala (1997) reports a seepage loss of about 126,000 m^3 from the pond. Using the following conditions: mean annual precipitation rate of 278 mm, a mean annual evaporation rate of 600 mm, a pond water surface area of about 35 ha at the seasonal equilibrium elevation of 699.5 m and a runoff coefficient of about 0.3 from the local area of 2.5 km^2 around the TSF, there is a resulting net loss of about 30,000 m^3 annually. This result corroborates the observations by Knight Piésold (2014a) that the TSF pond has essentially reached a quasi-equilibrium water elevation of about 700 m and is functioning as a "dry closure" pond.

The only recorded occurrences of unusual water level changes are as follows:

- In 2011, New Gold pumped water out of the Afton open pit into the Afton TSF to facilitate underground mine development.
- In 2012, New Gold pumped water out of the Afton TSF and into their new tailings impoundment for start-up.
- In the spring of 2014, Alkali Creek was diverted into the TSF during construction of the Alkali Creek Diversion Channel. Knight Piésold (2014c) reported a 0.5 m rise in the tailings pond in the year between the 2013 dam safety review site inspection and the 2014 annual inspection. The depth-area-capacity curve for the TSF surface suggests a storage capacity of approximately 245,000 m^3 between the 699.5 m and the 700.0 m contours, and this volume aligns very well with the estimated flow rates in the diversion for the three months during construction.

c) Any plans that are in place or that are under development to release surplus mine water to the environment

No such plans are envisioned at this time.

d) Provisions and contingencies that are in place to account for wet years

A review of annual precipitation amounts recorded at Kamloops Afton Mines climate station between 1977 and 1993 was undertaken to estimate total precipitation amounts during wet years. The average and standard deviation of recorded annual precipitation amounts at the Kamloops Afton Mines climate station are about 295 mm and 72.9 mm, respectively. Assuming normal probability distribution for the annual precipitation series results in a 100-year wet year annual precipitation of about 465 mm. The mean annual lake evaporation rate as given in the Kala (1997) report is about 561 mm. Kala (1997) reports a seepage loss of about 126,000 m^3 from the pond.

Using the following conditions: 100-year wet year annual precipitation rate of 465 mm, mean annual evaporation rate of 561 mm, pond water surface area of about 35 ha at the seasonal equilibrium elevation of 699.5 m and a runoff coefficient of about 0.3 from the local area of 2.5 km^2 around the TSF, there is a resulting net accumulated water volume of about 190,000 m^3. The available storage volume in the TSF pond between Elevation 700.4 m and the invert of the East Dam Spillway (reported capacity of 177 m^3/s) at Elevation 704.1 m (Kala 1997) is about 3.4 million m^3 (Knight Piésold 2014a). Hence, the TSF pond can safely contain the net inflow during a 100-year wet year assuming that the diversion structures on Alkali Creek do not fail. With the recent improvement in the Alkali Creek Diversion Channel to pass the peak flow from a 200-year, 24-hour storm event, failure of this diversion channel during a 100-year wet year is unlikely.

6.0 FILTER CONDITION

6.1 Introduction

The Ministry of Energy and Mines (MEM) has requested KGHM to review the filter as-built condition to assess if the dams associated with the TSF are at risk of failure due to inadequate filter performance. Items listed under the “Filter adequacy” section in MEM’s letter dated February 3, 2015 include:

- A review of the beach width and filter specifications necessary to prevent a potential piping mechanism.
- Whether the filter has been constructed in accordance with the design.
- If any gaps are identified, develop a plan and schedule for addressing these issues.

A review of the filter condition is performed targeting the specific areas listed in the MEM’s letter and the relevant information is presented in this section.

6.2 Design and As-Built Filters

The design of the filters was first presented in the “Report of Tailings Dams” design report (KL 1976). Two filter zones of granular material were designed between the upstream low hydraulic conductivity till and downstream rockfill. The filter was also designed to cover the foundation to prevent piping of the foundation soils into the rockfill.

The 1976 design report stated that:

- The fine filter shall consist of clean pit-run sand and gravel or crushed waste or quarried rock with a specific gradation shown in the report. The design report required compaction of the fine filter.

- The coarse filter shall consist of selected or processed mine rock with a specific gradation shown in the report. The design report required compaction of the coarse filter.
- Compacted rockfill should consist of hard, durable rock with a maximum size of 24” (0.61 m).

The filter gradations were designed based on the expected till gradation and local availability of material for fine and coarse filters. Some segregation was observed in the fine filter during its construction. As stated in the July 3, 1979 letter “Fine filter – Quality Control” (KL 1979a), segregation resulted in a filter ranging from silty sand with some gravel to gravel. A subsequent assessment of the filter resistance against cracks in the upper storage section of the dam was also conducted and reported in that letter. The investigation included several laboratory tests under varying hydraulic gradients to simulate performance if there was a crack in the upstream till zone of the dam cross section. The test results indicate that although at the early stages some of the till may move into the fine filter, the well-graded till was “self-healing” (meaning that the finer particles in the till tends to fill the cracks and complement the fine filter to form a stable soil from the perspective of fine particle migration). Because the upstream till is thick (at least 3.6 m losing some of the finer particles of the till into the fine filter was not considered an issue (KL 1979a).

The letter stated that the fine filter was produced on site by crushing and screening selected rock and was slightly coarser than the design criteria (KL 1979a). The gradation curves presented in the letter showed that the boundary of the coarse filter was changed in comparison to the original design (KL 1976). In the original design, the finer limit of acceptable coarse filter was slightly different from the coarse limit line of the fine filter. However, the 1979 gradation figures (KL 1979a) show that these two limits overlap each other. This was probably done to match available material.

Gradation curves for samples of the fine filter, coarse filter and compacted till are presented in the KL 1979 letter as well as in some of the yearly construction reports (KL (1979a), AOC (1981 to 1991)). Figures 7 to 9 show the particle size distribution (PSD) curves for the compacted till, fine filter, coarse filter based on information in the reports.

PSD curves for rockfill were not available but the maximum design particle size of the rockfill is 24” (610 mm). Photos of the rockfill are presented in the KL letter report “Results of Laboratory and Field Tests on Filter Material for Tailings Dams” (KL 1981). In the photos, the rockfill gradation appears to match the maximum particle size requirement of 610 mm apart from some larger boulders. The material also seems well graded. Based on this information, we developed a possible gradation range for the rockfill as presented in Figure 10.

Table 5 presents a summary of the range of the gradation parameters for different soils and filter layers in the TSF dams.

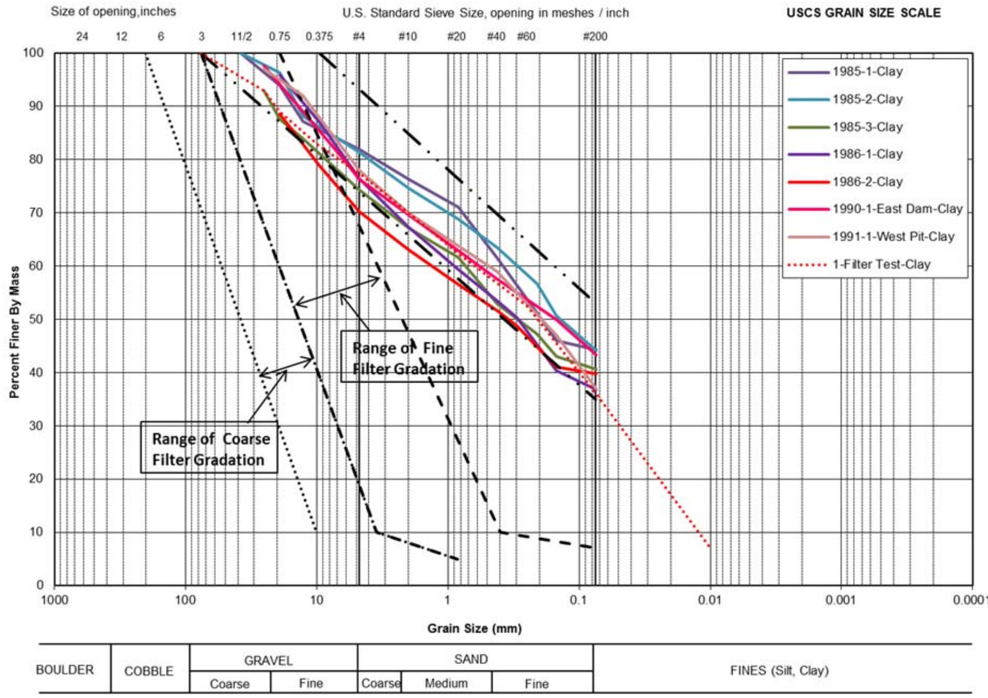

Figure 7: Compacted Till PSD Test Results

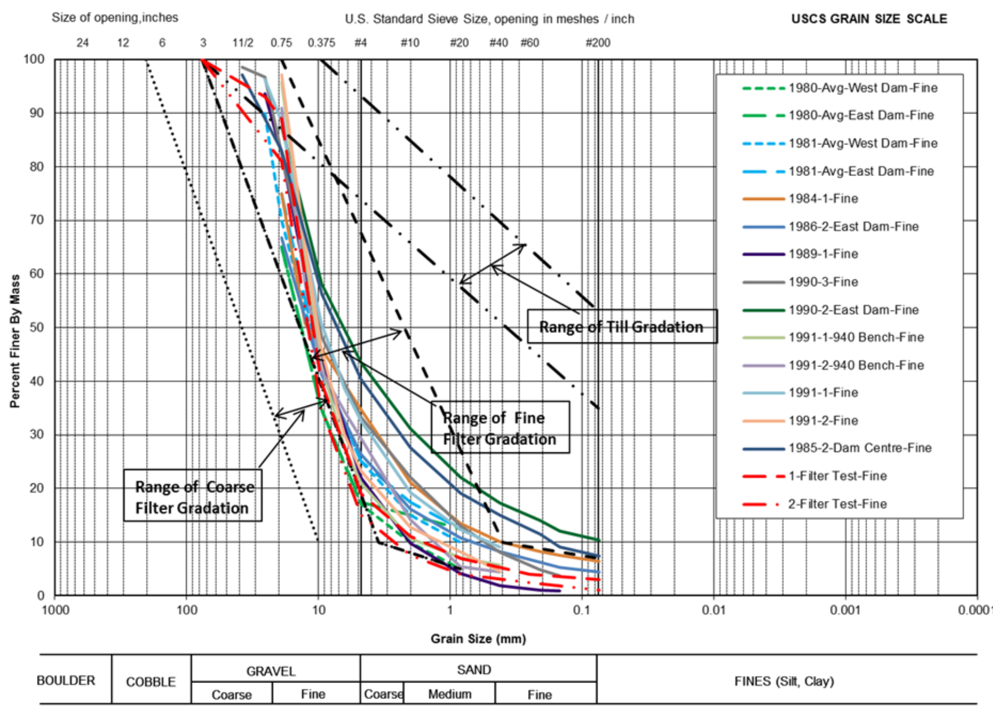

Figure 8: Fine Filter PSD Test Results

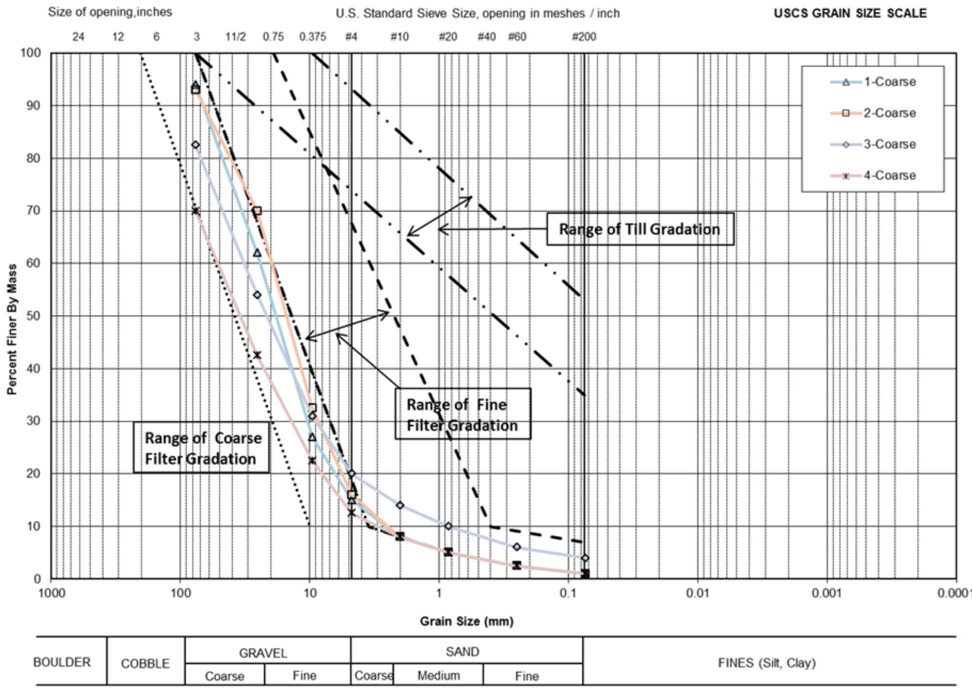

Figure 9: Coarse Filter PSD Test Results

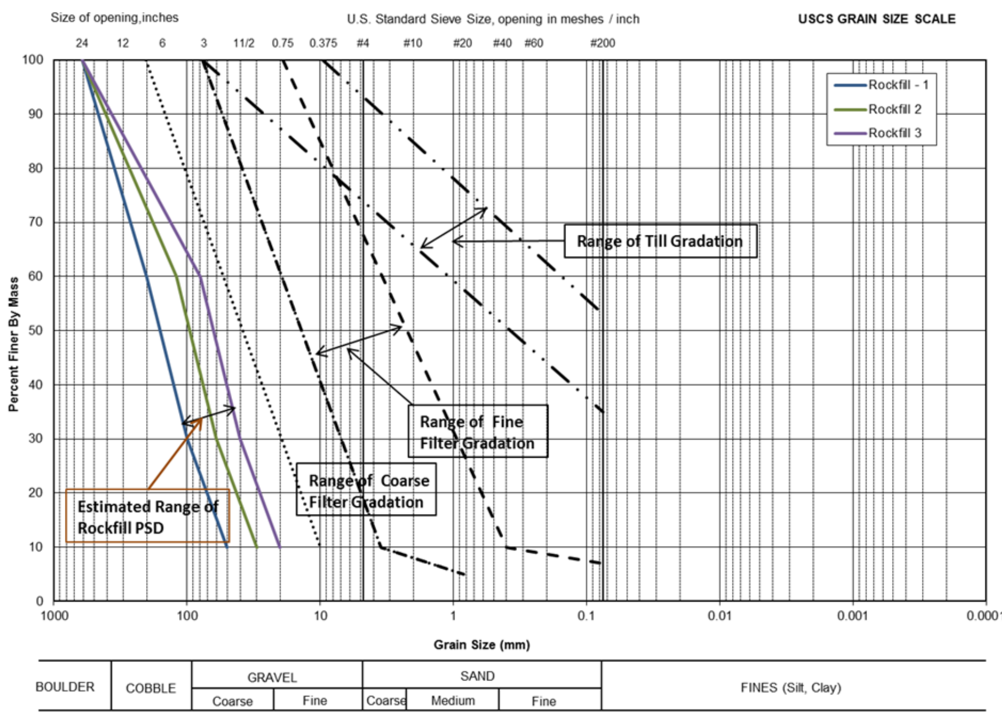

Figure 10: Estimated Range of PSD for Rockfill

Table 4: TSF Dam's Material Gradation Ranges

Material	Parameter	Range (mm)	Average (mm)	Comments
Compacted Till	D_{15}	0.01	0.01	Based on only one PSD curve
	D_{85}	7 to 13	8	-
Fine Filter	D_{15}	0.25 to 4.8	1.5	-
	D_{85}	12 to 22	19	-
Coarse Filter	D_{15}	2 to 5.5	5	One apparently anomalous curve was not considered
	D_{85}	50 to 120	70	Maximum range based on curve extrapolation
Rockfill	D_{15}	23 to 60	35	Gradation estimated as shown in Figure 10
	D_{85}	300 to 400	430	

6.3 Filter Criteria

A graded filter should satisfy the requirements outlined in the reference literature (e.g. Canadian Foundation Engineering Manual (CFEM 2006)). Some of the main filter requirements applicable to the Afton TSF dams are:

- Voids of the filter should be small enough to restrict particles of the adjacent soil from penetrating or washing through it, fulfilling a criterion of “soil retention”.
- The filter material should be more pervious than the adjacent soil, fulfilling a “permeability criterion”.
- The filter should be sufficiently thick to provide a sufficiently robust section to withstand differential settlement and facilitate construction.
- The filter should not segregate during processing, handling, placement, spreading or compaction.
- The filter material should be physically durable, and chemically inert.
- The filter should not be susceptible to internal instability, whereby seepage flow acts to induce migration of the fine fraction of the gradation within the filter itself.

The above criteria were checked for the as-built section and in-place material in the Afton TSF dams. The following sections provide more detail of this assessment.

6.3.1 Retention Criterion

This criterion is checked by limiting the ratio of the D_{15} of the filter (diameter where 15% of the particles pass) to the D_{85} of the adjacent soil (diameter where 85% of the particles pass) to less than 4 (for fine material) or 5 (for sand and gravel).

In the TSF dams, the fine filter needs to retain the compacted till, the coarse filter needs to retain the fine filter and the rockfill needs to retain the coarse filter. Therefore using the gradation information listed in Table 5, soil retention criterion checks were performed between the compacted till and fine filter, fine filter and coarse filter and coarse filter and rockfill. This comparison shows that despite some deviation from the original design PSD limits for the filters, this criterion is satisfied for all the above cases.

6.3.2 Permeability Criterion

This criterion is checked by specifying the ratio of the minimum value of the void characteristic grain size (D_{15}) of filter to the void characteristic grain size (D_{15}) of the adjacent soil to be more than 5.

In the TSF dams, seepage flow starts from the tailings then enters the compacted till, fine filter, coarse filter and eventually exits the coarse filter and rockfill at the toe of the dam. Using the gradation information listed in Table 5, the permeability criterion was checked between the compacted till and fine filter, fine filter and coarse filter and coarse filter and rockfill. This comparison shows that the permeability criterion is satisfied between the compacted till and fine filter and between the coarse filter and rockfill.

The average ratio of (D_{15}) of the coarse filter to (D_{15}) of the fine filter is about 3 which is less than the desired ratio of 5. However, we consider that the intent of the permeability criterion has been satisfied and that the coarse filter will adequately convey seepage from the fine filter for the seepage flows anticipated.

6.3.3 Filter Thickness

The filters in the TSF dams have a design thickness of 3.6 m. The coarse filter was built thicker than the design thickness. The thickness of the two filters is considered sufficiently robust.

6.3.4 Filter Segregation

The filter segregation depends on the maximum particle size and the range of the grain size. This is checked by comparison of coefficient of uniformity (C_u) of filter material to the maximum allowable C_u of 50 and maximum allowable particle size of 100 mm for filters.

The C_u of the fine filter is in the range of 5 to 10 and the maximum particle size is limited to about 75 mm (3’) (Figure 8). The C_u of the coarse filter is about 20 and the maximum particle size is limited to about 100 mm (Figure 9).

Although some segregation was reported during placement, the tested samples are taken from in-place material. It is our opinion that the segregation has been inherently considered in the filter criteria checks and that the as-built filters satisfy the standard filter criteria. Consequently, satisfactory performance of the as-built filters is expected.

6.3.5 Filter Durability

The mineralogy of the natural granular filter materials and their compatibility with the pH of the mine water was not reported in the reviewed documents. However, natural granular deposits are generally durable and perform adequately as filters.

6.3.6 Filter Internal Stability

The test results on the fine filter against cracks in the upper storage section of the dam (KL 1979a) indicate that the well-graded till was self-healing (meaning that the finer particles in the till tends to fill cracks and complement the fine filter to form a stable soil from the perspective of fine particle migration). Furthermore, the filters are well-graded which tends to be conducive for internal stability. Therefore, the as-built filters are considered to be internally stable soils.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Golder reviewed the Afton TSF design and construction information to assess if the dams associated with the Afton TSF may be at risk due to:

- undrained shear failure of foundation soils;
- water balance inadequacy; and
- filter inadequacy.

Previous sections of this report provided supporting information to respond to the MEM's specific questions. This section discusses the findings of the review and provides concluding remarks for each specific question listed in the MEM letter.

7.1 Risk Due to Undrained Failure of Clay/Silt Foundation Soils

MEM has identified several items that need to be addressed under this section. These are discussed as follows.

a) Including a determination with respect to whether or not similar foundation conditions exist below the dams on your site

The general geology of the area shows that the expected foundation layers are mainly till and bedrock. However, in some areas other deposits overlie the till and bedrock. These are mainly topsoil in higher ground surface elevations, but around the local water bodies and creek some alluvial/fluvial silt and clay deposits are also observed.

The Afton TSF was built on the historical Hughes Lake and the previous path of Alkali Creek (Figure 5). The borehole data show that silt and clay deposits up to 3.3 m thick exist in some locations beneath the West and East Dams. Based on Golder's review of construction documentation and design requirements, Golder expects that part of the silt and clay deposits were removed from the foundation during the starter dam construction and filter placement. However some silt and clay may still exist beneath the downstream portion of the dams. We also estimate that the applied vertical pressure from the dams is sufficient to make these soils become normally consolidated. Therefore the clay/silt deposits may be susceptible to undrained shear failure if the rate of new additional loading is sufficiently fast such as during future dam raise or seismic activity

b) Whether or not sufficient site investigation (drill holes, etc.) has been completed to have confidence in this determination

The original site investigation was done before start of construction in 1976. In subsequent years other site investigation mainly targeted the tailings pond material. Some of these boreholes penetrated to the foundation beyond the topsoil to give information on the clay/silt foundation soils.

Although it appears that a significant portion of these deposits under the starter dams may have been removed during the cut-off construction, it is possible that clay/silt deposits still exist under the downstream portion of the dams where only clearing and grubbing foundation preparation was followed. Therefore we have carried out stability analysis to assess their influence on geotechnical stability of the existing dams under undrained loading condition as discussed in Section 4.4 of this report.

c) If present, whether or not the dam design properly accounts for these materials

The stability analysis by the designers did not consider the possibility of normally consolidated clay/silt deposits in the foundations of the dams. We evaluated the stability, for undrained shear failure condition, of the existing West Dam for estimated extents and properties of the clay/silt deposits in the downstream foundation of the West Dam. The results show that the Dam Safety Guidelines (CDA 2007 and 2013), in terms of calculated minimum factors of safety, are satisfied when undrained shear failure of the clay/silt is considered in the analysis for the static condition and post-earthquake condition. However, depending on the assumed extent of the clay/silt despots under the downstream portion of the dam, the calculated minimum factor of safety from pseudo-static analysis can be slightly less than the CDA specified value.

It is noted that the dams have not been built to their design final elevation. The performance of the existing are reported to be satisfactory. The implication of undrained shear failure is more relevant should the dams be raised beyond their current configuration. The dam is under care and maintenance; current permits do not allow for dam raising. If the seismic stability of the West Dam is a concern for closure, consideration should be given to carrying out a detailed study on the seismic effects on the performance of the West Dam.

d) If any gaps have been identified, a plan and schedule for additional subsurface investigation

The West Dam foundation at the lower ground surface elevation area contains clay/silt deposits. The boreholes drilled in this area do not conclusively demonstrate if these soils had been removed to the extent used in the stability analysis presented in Section 4.4. Should the West Dam be raised, consideration should be given to drilling and sampling at least three boreholes in the area within 20 m distance from the downstream toe of the West Starter Dam to confirm the estimated extent of clay/silt deposits under the West Dam. A review of the stability for a higher dam is required if the results of this investigation show that the extent of the clay/silt is more than what is used in the stability analysis in this report.

7.2 Water Balance Adequacy

MEM has identified several items that need to be addressed under this section. These are discussed as follows:

a) Including the total volume of surplus mine site water (if any) stored in the tailings storage facility

The TSF is not used for water impoundment as it is currently a non-operational facility. There is minimal water collected in the TSF, most of which is direct precipitation and the local TSF catchment runoff (runoff contributing drainage area of less than 2.5 km^2). The tailings pond has not historically had a staff gauge or other precise means of determining the water level. During an average hydrologic year, there is a net loss of about 30,000 m3 annually, resulting in a quasi-equilibrium water elevation of about 700 m with the effect that the TSF is functioning essentially as a “dry closure” pond.

b) The volume of surplus mine water that has been added to the facility over each of the past five years

The TSF pond has essentially reached a quasi-equilibrium water elevation of about 700 m and is functioning as a “dry closure” pond. The only recorded occurrences of unusual water level changes are as follows:

- In 2011, New Gold pumped water out of the Afton open pit into the Afton TSF to facilitate underground mine development.
- In 2012, New Gold pumped water out of the Afton TSF and into their new tailings impoundment for start-up.

- In the spring of 2014, Alkali Creek was diverted into the TSF during construction of the Alkali Creek Diversion Channel. Knight Piésold (2014c) estimates the inflow volumes to have been approximately 245,000 m^3 during the three-month construction period.
- From December 20, 2014 to January 2, 2015 KGHM pumped approximately 330,000 m^3 from beneath an ice cover on the pond. Once the ice melted pumping was initiated again on April 10, 2015. From April 10 to April 19 an additional 150,000 m^3 was transferred out of the TSF. As of June 2015, the TSF is practically dry despite recent heavy rainfall (Rob Maciak, email dated June 15, 2015).

c) Any plans that are in place or that are under development to release surplus mine water to the environment

No such plans are envisioned at this time.

d) Recommended beach width(s), and the ability of the mine to maintain these widths

As presented in Figure 5, the minimum beach width with pond water at elevation 699.5 m is about 120 m in the West Dam. At this level the pond is about 250 m away from the spillway in the East Dam. Recent pumping from the Afton TSF pond reduced the water level to even lower than 699.5 m. It is estimated that the pond level is currently is more than 0.5 m lower than the 2014 pond level. With the beach slope observed, the beach length in the West Dam area is estimated to be about 250 m. A large percentage of the beach has been reclaimed. The beach length is expected to remain at 250 m, because there is no plan for additional tailings and water deposition into the Afton TSF.

The spillway invert elevation is at 704.1 m. If the pond rose to that level during possible future flooding, the pond would be about 70 m away from the West Dam and will start flowing through the spillway in the East Dam.

These beach lengths are expected to be sufficient to maintain adequate distance between the pond and the dams for geotechnical stability based on the average gradient in the foundation of about 0.1. Furthermore, the dams have a compacted till core at the upstream side which would prevent high gradient seepage through the dams in the unlikely event that the pond reaches the dam.

e) The ability of the TSF embankments to undergo deformation without the release of water (i.e.-the adequacy of the recommended beach width)

The settlement measurements on the West Dam show that most of the settlement in the dam happened during active dyke raises. Since 1997, very little settlement has occurred in the West Dam.

The East Dam also has small recorded settlements after the completion of the last dam raise in 1997. The rate of settlement in the dam crest is small (about 40 mm/year) (presentation dated May 27, 2015 via email).

The normal freeboard is more than 6.0 m and the freeboard during flood (spillway elevation is 704 m) is about 1.5 m. The observed settlement does not compromise the ability of the TSF to contain water as discussed in the next section.

f) Provisions and contingencies that are in place to account for wet years

The available storage volume in the TSF pond between Elevation 700.4 m and the invert of the East Dam spillway (capacity of 177 m^3/s) at 704.1 m (Kala 1997) is about 3.4 million m^3 (Knight Piésold 2014a). Based on the information presented in Section 5.2.3, the TSF pond can safely contain the net inflow during a 100-year wet year assuming that the diversion structures on Alkali Creek do not fail. Alkali Creek diversion channel was recently improved to increase its capacity to handle a peak flow of 4.4 m^3/s generated during a 200-year, 24-hour storm event.

g) If any gaps have been identified, a plan and schedule for addressing these issues

Although the current rate of settlement is not an issue for the East and West Dams, the effect of the Afton Pit operation on the East Dam needs to be investigated and observed. KGHM and New Afton Mine operators are collaboratively observing the settlement at the north area of the East Dam. The issue is currently under a joint investigation by KGHM and New Gold Inc.

7.3 Filter Adequacy

MEM has identified several items that need to be addressed under this section. These are discussed as follows:

a) Including the beach width and filter specifications necessary to prevent potential piping

The fine and coarse filters meet standard filter design requirements from the perspective of soil retention. The coarse filter samples have a small deviation from filter permeability requirements. Furthermore, the coarse filter is built thicker than design (see Figure 3 and 4) and coarser rockfill is located downstream. Therefore despite this deviation, the flow should be handled by the fine and coarse filter. Therefore the filters are adequate to meet the intent of the filter design for the West and East Dams.

b) Whether or not the filter has been constructed in accordance with the design

The as-built filter gradations are generally within the design limits and are expected to perform satisfactorily. The small deviations in the filter specifications are not expected to be an issue for the dam integrity based on assessment done with general filter requirements. The filters were constructed thicker than the design and this is a positive change.

c) If any gaps have been identified, a plan and schedule for addressing these issues

No gap in information is identified in connection with the filters.

8.0 CLOSURE AND LIMITATIONS

This report summarizes our view of the Afton Tailings Storage Facility (TSF) dams to address the specific questions listed in the letter by the Ministry of Energy and Mines of British Columbia (MEM) to KGHM Ajax Mining Inc. (KGHM). The review is based on the reports, the field investigations and laboratory testing data reported in design reports and made available to Golder.

This report has been prepared for the exclusive use of Golder Associates Ltd. (Golder) and KGHM Ajax Mining Inc. (KGHM) and their agents, for the specific application to the Afton Mine Tailings Storage Facility described in Section 1.0. Any use that a third party makes of this report, or any reliance on or decisions to be made based on this report are the sole responsibility of such third parties. Golder cannot accept responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. This report has been prepared in accordance with the current generally accepted geotechnical engineering practices. No other warranty is made, either expressed or implied.

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