STABILITY AND SEEPAGE ANALYSIS OF THE BRALORNE GOLD MINES TAILINGS DAM FOLLOWING A CHANGE IN USAGE FROM TAILINGS DAM TO WATER RESERVOIR DAM

by

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.............................................................

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The Bralorne Gold Mines Ltd. operates the historic Bralorne Pioneer Mine, near Goldbridge B.C. The tailings dam construction spanned from 2003 to late October of 2005. The mill discharged tailings for a short period subsequent to construction but since 2004, only the groundwater flowing from the mine adit has been pumped to the tailings impoundment. Some seasonal higher arsenic levels within the groundwater have prompted this action and monitoring of the seepage water leaving the dam consistently shows acceptable arsenic discharge levels. The tailings impoundment has proven very valuable in term of containment and attenuation of arsenic. However, the usage of the dam as a water reservoir versus its design as a tailings impoundment was a concern for the BC Inspector of Mines. A stability and seepage analysis of the dam in its new state was requested.

This undergraduate thesis analyzes the slope stability of the dam under this new regime and provides a model for the groundwater flows. 2D Limit Equilibrium Analysis based on data obtained from old reports, site visits and monitoring equipment, confirms that the dam is performing as designed. The computer models maintain a factor of safety greater than 1.5 for static analysis and above 1.15 for various seismic loading conditions.
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1. Introduction

The Bralorne Gold Mines Ltd. operates the historic Bralorne Pioneer Mine, near Goldbridge B.C. The mine has been operating at various intervals since the late 1800’s. Larger scale mining was underway from 1928 until 1971, at which date the mine was closed. However, underground dewatering was on-going until 1982. Between April 2004 and November 2005 production re-started intermittently.

Historically, tailings from the old mine were discharged in the Cadwallader Creek. For environmental concerns, a tailings impoundment was needed when production restarted. A tailings impoundment with an initial five year capacity has been constructed on the west side of Cadwallader Creek near the mill. The tailings dam construction spanned from 2003 to late October of 2005. Tailings are delivered to the impoundment by a tailings pipeline and a multi-stage pump.

Since 2004, when not in use for tailings, the tailings pipe has been used to pump intercepted free flowing groundwater from the mine adit (adit water) to the tailings pond. Adit waters have been directed to the tailings impoundment rather than the infiltration pond or the Creek Adit due to seasonal fluctuations in arsenic concentration level. The tailings impoundment has proven very valuable in term of containment and attenuation of arsenic. Until more tailings are put in the pond, the dam is acting more as a reservoir dam than a tailings dam.

Due to the change in the function of the tailings dam, the slope stability and seepage performance of the structure are analysed in this thesis. A review of the actual water balance model was done as well as a 2D Limit Equilibrium slope stability analysis. The stability of the
structure and the seepage under the dam were estimated from a model done with the software SLIDE 5.0 by RocScience.

2. Study Area

2.1 Location

The Bralorne Pioneer mine is located about 250 kms north of Vancouver, in the Cariboo Chilcotin Coast region of British Columbia (Figure 1). It is located on National Topographic System map 92J/15W in the Bridge River mining camp, Lillooet Mining Division, British Columbia, Canada. The latitude of the site is 50°46’N and longitude of 122°48’W. The site is accessible by government maintained road throughout the year. In the summer months, the site also accessible by the Hurley Road, located at the western end of the Pemberton Valley.
2.2 Topography

The mine is located in the southern Chicotin Mountains. The Chilcotin Plateau was formed 30 to 50 million years ago, while 10 and 20 million years ago, an upheaval of the earth formed the mighty Coast Mountains. The Chilcotin Mountains are located at the edge of the Coast Mountains and the Plateau. The last Ice Age sculpted the landscape as we see it today. The mine site is surrounded by mountainous terrain with slopes varying from moderate to steep. The topographic elevations vary throughout the property and range from El. 870m to El. 1615m. (Ball 2009)

2.3 Climate

The pioneer mine is in the Cordillera climatic zone of Canada but close to the border with the milder Pacific zone (figure 3). It is also rated as humid microthermal climate, more precisely in the humid continental with warm summer. It is rated Dfa (white) according to the W. Köppen world climate classification scale, which range from tropical climate-A to polar climate-E (Canadian Geographic 2007). See figure 4 below.

Figure 3 Climatic zone of Canada
As stated, summers are warm and dryer. Precipitation is moderate and snowfall occurs in the winter months. Accumulation exceeds three meters during the winter months. For comparison purposes, data from the closest Environment Canada weather station is used. Lytton is located 110 kilometres to the South-East of the mine. However, it should be noted that due to the mountainous terrain, the weather can be quite different at the two locations. According to the data obtained, the year 2007/2008 appears to have been on par with the average of the past 30 years in term of precipitation. The month of December was a lot dryer but overall, the 2007/2008 data appears to be within the norm and the estimated 653 millimetres yearly rainfall at the site should be accurate.

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation 2008 (mm)</th>
<th>1971 to 2000 average (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul-07</td>
<td>15.494</td>
<td>14.478</td>
</tr>
<tr>
<td>Aug-07</td>
<td>19.558</td>
<td>22.860</td>
</tr>
<tr>
<td>Sep-07</td>
<td>32.004</td>
<td>27.178</td>
</tr>
<tr>
<td>Oct-07</td>
<td>29.464</td>
<td>37.084</td>
</tr>
<tr>
<td>Nov-07</td>
<td>52.070</td>
<td>65.278</td>
</tr>
<tr>
<td>Dec-07</td>
<td>159.512</td>
<td>67.056</td>
</tr>
<tr>
<td>Jan-08</td>
<td>66.548</td>
<td>64.008</td>
</tr>
<tr>
<td>Feb-08</td>
<td>22.606</td>
<td>45.212</td>
</tr>
<tr>
<td>Mar-08</td>
<td>21.082</td>
<td>32.766</td>
</tr>
<tr>
<td>Apr-08</td>
<td>7.874</td>
<td>19.304</td>
</tr>
<tr>
<td>May-08</td>
<td>24.892</td>
<td>18.288</td>
</tr>
<tr>
<td>Total</td>
<td>451.104</td>
<td>413.766</td>
</tr>
</tbody>
</table>
According to the report by SRKR dated January 1996, the pond receives on average 653 millimetres of rainfall per year and the evapotranspiration is about 305 millimetres per year. The catchment is estimated at 291,000 m². The probably maximum precipitation and 200-year return period storm with a 6-hour duration would result in rainfall intensities of 0.38 and 0.13 millimetres/seconds (mm/s). Corresponding peak storm discharges would be about 0.57 and 0.17 meter cube per second (m³/s).

2.4 Bedrock Geology

The Bralorne Pioneer property is situated within the Bridge River mining district in southwestern British Columbia. The Bridge River district is at a tectonic boundary between the Cache Creek and Stikine allochthonous terranes and is called the Bridge River Terrane. According to the geological map of Canada (figure 5), the terrane is comprised of unit MJ (grey), Mesozoic Pennsylvanian Mississipian to Jurassic Stratified Sequences rocks. These rocks are complexes of oceanic basalt and gabbro and related ultramafic rocks, chert, basalt, shale and argillite. (Ball 2009)

The map also shows that the region has been intruded by unit Lki (bright pink) Cenozoic Late Creteceous Intrusive Rocks. Faults are common in the region and the generally strike to the northwest but at Bralorne, the fault swings abruptly to a northern strike. Faults on the northeast of the bend are referred to as the Bralorne Pioneer fault lens. (Ball 2009)

According to a classification of Canadian gold deposits by Poulsen and al. (2000), gold deposits are commonly distributed along major fault zones in deformed greenstone terranes.
Veins have strike and dip lengths of 100 to 1000 meters and are usually part of a complex vein network. The ores are gold-rich and have elevated concentrations of arsenic, tungsten, boron and molybdenum, with very low base-metal concentrations. Arsenic-containing bedrock formations are usually associated with higher concentration of arsenic found in groundwater. The presence of gold-rich ore would then explain the naturally higher concentration of arsenic in the adit waters.

Figure 5 Geological Map of BC (Environment Canada)

Figure 6 shows a more detailed geological map of the area and outlined the Bridge River Terrane with the ultramafic and basic intrusions.
2.5 Surficial Geology

The property is located in the Cordilleran Orogen Geological Province of Canada. The main surficial geological unit is Tv (green) on Figure 7, a Till veneer consisting of Thin and discontinuous till which may include extensive areas of rock outcrop. Unit Ra (pink) may also be present in the area and is named alpine rock complexes which include rock, colluviums, and till. It is characterized by alpine and glacial landform and described as a rock and Quaternary deposits complex.
2.5 Vegetation and drainage

Vegetation on the property consists of mature spruce, pine and interior Douglas-fir. Approximately 40% of the property has been clear cut.

3. Literature Review

The Bralorne Pioneer Gold mine has been operating at various intervals since the late 1800’s. As stated earlier, larger scale mining was underway from 1928 until 1971, at which date the mine was closed. However, underground dewatering was on-going until 1982. Between April 2004 and November 2005 production re-started intermittently.

Below is a table outlining the important dates of the mine’s history
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>First claims of Bralorne mine staked downstream from where Pioneer mine eventually established.</td>
</tr>
<tr>
<td>1928</td>
<td>New owners take over Pioneer Gold Mines, improved mill opens at 100 tons per day.</td>
</tr>
<tr>
<td>1931</td>
<td>Mr. Austin Taylor and associates acquire Bralorne property and finance construction of a 100 tpd mill.</td>
</tr>
<tr>
<td>1932</td>
<td>First gold brick, weighing 363 oz. (worth $6,217 in 1932 dollars) poured at Lorne Mine.</td>
</tr>
<tr>
<td>1971</td>
<td>Low gold prices force shutdown of entire operation.</td>
</tr>
<tr>
<td>1982</td>
<td>E &amp; B Exploration Inc. and Corona Corporation acquire Bralorne Mine.</td>
</tr>
<tr>
<td>1990</td>
<td>Avino Mines &amp; Resources discovers significant gold mineralization on adjoining Loco property.</td>
</tr>
<tr>
<td>1991</td>
<td>Avino acquires 100% interest in entire Bralorne operation from Corona Corporation et al.</td>
</tr>
<tr>
<td>1993</td>
<td>Avino continues to discover significant new gold zones in areas not previously explored along Fergusson fault.</td>
</tr>
<tr>
<td>1993</td>
<td>Bralorne Gold Mines negotiated an option to earn a 50% interest in the entire Bralorne project.</td>
</tr>
<tr>
<td>1995</td>
<td>Avino (50%) and Bralorne Gold Mines (50%) obtain Mine Development Certificate from British Columbia provincial government.</td>
</tr>
<tr>
<td>2002</td>
<td>Bralorne acquires Avino's interest in the mine.</td>
</tr>
<tr>
<td>2002</td>
<td>Exploration, trenching and surface drilling extends the peter zone by 1300 feet.</td>
</tr>
<tr>
<td>2003</td>
<td>Raise over $5.4 million, retiring all debts.</td>
</tr>
<tr>
<td>2004</td>
<td>Bulk sampling begins. First gold bar poured in April.</td>
</tr>
<tr>
<td>2004</td>
<td>Float concentrate shipped to Queenstake's Jerrit Canyon &amp; Barrick Gold Strike Mine.</td>
</tr>
<tr>
<td>2004</td>
<td>Major drill program intersects 12.19 oz/ton in 51B FW.</td>
</tr>
<tr>
<td>2004</td>
<td>Tunneling towards 51B Vein started.</td>
</tr>
<tr>
<td>2005</td>
<td>Miners reach 51B Vein and drifting started.</td>
</tr>
<tr>
<td>2005</td>
<td>Bulk sampling program completed.</td>
</tr>
<tr>
<td>2006</td>
<td>Phase 1 complete. Surface exploration between the historical mines. Bonanza grade intercepts of 11.7oz Au/ton</td>
</tr>
<tr>
<td>2007</td>
<td>Phase 2 begins. Discovery of the &quot;New BK (Gap between the historical Bralorne King Mines) zone&quot;</td>
</tr>
<tr>
<td>2007</td>
<td>Phase 3 begins. Underground development plans for new BK zone</td>
</tr>
<tr>
<td>2008</td>
<td>Phase 3 Continues to develop the new BK ZONE.</td>
</tr>
</tbody>
</table>
The Bralorne Pioneer Mine property spans over an area of approximately 2,422 hectares. The property is comprised of legal mineral properties registered under and subject to the Mineral Tenure Act and Mineral Land Tax Act of the Province of British Columbia. The following paragraphs provide a brief summary of past years constructions.

The engineering design of the Bralorne dam is based on work by SRK-Robinson Inc. (SRKR). In January 1996, SRKR prepared the “Design of Tailings Impoundment – Bralorne Gold Project” presenting design details for the tailings dam and associated facilities. The design was done in support of an application to the Mines Branch of BC Energy, Mines and Petroleum Resources. The construction permit was issued in 1996 based on the recommended design.

Dam construction was organized and supervised by Bralorne staff. Quality control and part-time inspection of fill placement was completed by field technicians from Jacques Whitford. The construction and progress details can be found in the the “2004 Construction Report – Bralorne Tailings Impoundment”, prepared by Jacques Whitford Limited in February 2005.

2003

The dam construction started in 2003 but was stopped due to weather conditions in November 2003. The dam was built across the watercourse at the southern alignment and to an elevation of 3447 feet. The 2003 Jacques Whitford report states that the permeability of the compacted glacial till used for the dam core construction was one or two orders of magnitude lower than the value used for the initial 1996 design. For that reason and due the high variability in the
distribution of the subgrade soils under the dam, they concluded that the 1996 estimated seepage through the tailing dams of 0.06 to 0.63 l/s was a very low estimate.

2004/2005

In July 2004, work resumed and the construction to the 5-year level of the tailings dam was completed by the third week of October 2005. The as-built survey has indicated that the crest of the dam varies up to 0.45m feet below the design grade of elevation 3459 feet. The construction required approximately 56 000 m$^3$ of silty glacial till and 16 000 m$^3$ of sand and gravel. These materials were extracted from Borrow Pits located on and around the construction site. In November 2004, Jacques Whitford Ltd. observed that the north and south seepage had been built to design. A total of 21 000 tons of tailings were deposited while the dam was still under construction.

The instrumentation installed on the site includes three monitoring wells and seven standpipe piezometers. Their installation was performed in November 15 and 16 2004, by Downrite Driling. Monitoring wells consisted of 50mm diameter Schedule 40 PVC pipe and standpipe piezometers consisted of 25 mm diameter PVC pipe. Two piezometer holes, P04-1 and P04-4 involved the installation of both a shallow and a deep piezometer in the same hole.

2007

In August of 2007, the downstream slopes of the dam between station 800 and 900 was re-sloped. The confirmation of the re-sloping is showed on the 2007 as-built survey, see Appendix B.

The steps of construction of the Bralorne Tailings Impoundment Facilities are fully detailed in the “2004 Construction Report” dated February 23, 2005, again by Jacques Whitford Ltd.
NRCAN personnel assisted with flume installations at the south and mid-south surface drainage collection areas (See Appendix A and B for location). Groundwater drill testing occurred at both north and south downstream zones, along with installation of one new groundwater monitoring wells at the south seep. No Tailings from Milling Operations were pumped and deposited into the tailings impoundment during 2008.

Bralorne Gold Mines Ltd provided a digital file that contains a plan of the dam site area and five sections through the dam. These plans and sections are based on surveys carried out in July 2000 and October 2008. A plan using showing the dam and instrumentation locations is provided in Appendix A.

Below shows a longitudinal section, figure 4A, to better visualise the stationing references in the water balance analysis.

![Figure 8 Longitudinal Section (PK Read Engineering)](image-url)
Cross sections of the Dam at two different sections were used for the modeling in SLIDE. The values given in the cross section were applied to the model.

![Cross section of south dam](image1.png)

**Figure 9 Cross sectional view of south dam**

![Dam Cross Sectional View North Dam](image2.png)

**Figure 10 Dam Cross Sectional View North Dam**

### 4. Methods

#### 4.1 Water level monitoring

Since the function of the dam changed, changes to instrumentation monitoring devices and monitoring techniques had to be made. Previous data collection was deficient and sporadic. The main changes in instrumentation monitoring records are as follows:
• Monitoring well was installed by Lorax at the south seep (Appendices X). The soil stratigraphy encountered at this monitoring well consisted of silt, sand, and gravel layers with bedrock at a depth of 13.7 metres below current grade.

• A groundwater investigation borehole was drilled at the north seep, adjacent to the existing groundwater monitoring well. No groundwater was encountered in the borehole and the soil stratigraphy encountered consisted of basal till with inter-bedded sand/gravel deposits.

• Lorax Environmental directed the drilling of 4 test holes for the purpose of potential groundwater sampling zones and delineation of the extent of any deeper groundwater flows from the dam and mine areas.

• Two Flow flumes installed at south and mid-south seeps to measure outflow rates. The north seep flow flume has been in place for a few years (again, appendice XX for location). A plastic bucket and a stop watch are used to monitor the flow rates. The readings are taken every week and compiled in an excel spreadsheet by an employee of the mine.

• A water level stick has been added at the south of the pond, a few meters from the discharge pipe. Pond readings are taken weekly and recorded by a mine employee.

• Settlement monitoring markers have been installed and an employee of the mine is recording the data.

The Manual for Operation and Inspection Bralorne Tailings Impoundment Facilities was prepared by Jacques Whitford and issued on February 16, 2004. The mine is not actively depositing tailings and the impoundment is used as a mine discharge water storage facility.
Currently the mine is reporting to the BC Ministry of Energy, Mines and Petroleum resources (Kamloops office) and provides:

- Water level on a weekly basis
- Water quality sampling results on a monthly basis

4.1.1 Water discharge system, volume and quality

The mine water discharge system is through a 5.1 x 7.6 centimetres HDPE pipe which runs from the mine to the impoundment (1.3 km long). The discharge occurs at the South end of the dam and is monitored by the mine employees. From October 15, 2007 to March 16, 2008, National Resources of Canada (NRCan) monitored and recorded the discharge four times a day. This monitoring data was made available for this slope stability analysis. The water quality is also regularly being monitored by NRCan and by Lorax Environmental.

4.1.2 Phreatic surfaces and piezometric data

Seven piezometers are located on and around the dam, in five different locations.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Top Elevation (m)</th>
<th>Approx. Station NW dam end feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>P04-1 (s)</td>
<td>1055.20</td>
<td>200</td>
</tr>
<tr>
<td>P04-1 (d)</td>
<td>1055.20</td>
<td>200</td>
</tr>
<tr>
<td>P04-2</td>
<td>1055.05</td>
<td>400</td>
</tr>
<tr>
<td>P04-3</td>
<td>1055.34</td>
<td>650</td>
</tr>
<tr>
<td>P04-4 (d)</td>
<td>1055.39</td>
<td>810</td>
</tr>
<tr>
<td>P04-4 (s)</td>
<td>1055.39</td>
<td>810</td>
</tr>
<tr>
<td>P04-5</td>
<td>1041.26</td>
<td>Within south seepage control dam approx. 250 feet downstream from the dam</td>
</tr>
</tbody>
</table>
4.1.3 Seepage occurrence and water quality

Seepage appears to be localized at a few sections around the dam. The first section, just above north seep, between markers 0 and 100 in appendix A, where a trench filled with big rocks is located, shows greater seepage. The toe of the dam is very wet, horsetails are abundant and a small stream is visible. Between markers 100 and 400, minor seepage is being collected in the drainage ditch. Around marker 300, seepage is once again greater and small erosion features can be seen on the downslope of the dam at this location. The seepage from the North section of the dam ends up in the outflow ditch and is measured at the north seep.

The region between markers 400 and 500, just above the mid south seep, clear water is coming out quite rapidly at the foot of the dam. No evidence of significant material transfer from the dam is evident.

As stated earlier, the newly added flow flumes are used to calculate the seepage through and under the dam from section 500 to 900. They are monitored every week. The three flumes capture most of the water coming from under the dam but there is still one section, between section 400 and 500 that is not accounted for in the water balance. Another flow flume should be installed in that area in order to monitor more accurately the water coming through and under the dam.

4.2 Water Balance Review

A review of the water balance model is carried out in this thesis. The new water balance is based on a combination of information provided in the original design documents (SRK-Robinson and Jacques Whitford Ltd.), in the 2008 annual report (Read) and from mine staff
and actual visit measurements taken from January to December 2008. It should be noted that values used in this review are based on data available during the period June 24th to July 4th 2008. It is also acknowledged that the original design water balance inflows assumed only “Mill Discharge” flows and did not account for the current condition of constant mine discharge. Data used for determining inflow rates in the water balance review are listed as follows:

- reservoir water level measurements taken by on-site personnel and from site visits
- discharge from the mine measurements taken by on-site personnel
- precipitation based on the Upper Bralorne BC Hydro weather station were on average 3.0 mm/day (BC Hydro)
- surface area of reservoir for precipitation inflow estimated at 7.5 hectares (Whitford, 2003)
- based on area and precipitation, inflow due to rainfall was calculated to be 2.59 L/s
- assumed catchment area of 0.716 km$^2$ (SRKR, 1995)
- typical runoff coefficient of 20% was assumed (Read, 2008)
- inflow due to rainfall runoff was calculated to be 2.01 L/s based on the estimated catchment area and runoff coefficient (calculated)

Data used for determining outflow rates in the water balance review is listed as follows:

- evapo-transpiration estimate is 0.50 L/s (Whitford 2003)

- Average measured period seepage rates through the toe of the dam at north, south and mid-south seeps (on site visits and mine personnel)
4.3 Dam stability monitoring

Site visits were done on May 26th and July 11th. The annual inspection of the dam was done on August 20th with the help of Karim Karimzadeghan from Horizon Engineering. Changes to the dam stability and/or surface water controls were minimal. The following were noted during the visits and taken into consideration for modeling and the results of the slope stability analyses are provided in the result section:

- The tailings impoundment area is used a mine water discharge reservoir
- Increased toe thickness and reduced slope at station 800 to 900
- No tailings put behind dam
- No reduction in free board and remains between 2.1 and 2.4 metre
- No cracks, bulges, sinkholes, sags or sloughs have been observed
- No changes in surface water control

4.3.1 Freeboard and storage availability

The SRKR, January 1996, report states that the minimum freeboard against the 200-year event is 1.04 metre. The 2004 as-built report has the top of the dam at El. 1054.1m for the south section and at El. 1053.7m for the north section. The highest recorded elevation of the water level in the pond during the year was El. 1051.5m. This equals to a freeboard of 2.17 metre. Even during a storm event, freeboard of 1.04 metre is guaranteed.

At the moment, the tailings storage capacity for the 75 000 meter square pond area is 150 000 tonnes. The water storage capacity is 45 500 meter cube. (Whitford 2003)
4.3.2 Settlement and lateral movement

Monitoring sticks were installed by mine personnel in order to measure vertical movement of the dam. The first reference points were collected and recorded on July 30\textsuperscript{th} 2008. This monitoring should be done continuously. Visually, there is no evidence of lateral movement. Movement monitor pins were installed and future survey pickups of these points will show lateral movement.
5. Results

5.1 Monitoring analysis

5.1.1 Water level

The average discharge for the period of July 2007 until June 2008 was 5.9 litres per second (L/s). The discharge was monitored and recorded every 6 hours by NRCan and the date was provided by the mine. The largest discharge for this period was 11.2 L/s while the smallest was 3.9 L/s. The discharge water is clear from a visual observation.

### Table 4 Average monthly discharges at the 800 level

<table>
<thead>
<tr>
<th>Month</th>
<th>Discharge (L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul-07</td>
<td>6.44</td>
</tr>
<tr>
<td>Aug-07</td>
<td>5.93</td>
</tr>
<tr>
<td>Sep-07</td>
<td>4.98</td>
</tr>
<tr>
<td>Oct-07</td>
<td>4.73</td>
</tr>
<tr>
<td>Nov-07</td>
<td>4.61</td>
</tr>
<tr>
<td>Dec-07</td>
<td>4.67</td>
</tr>
<tr>
<td>Jan-08</td>
<td>4.79</td>
</tr>
<tr>
<td>Feb-08</td>
<td>4.61</td>
</tr>
<tr>
<td>Mar-08</td>
<td>4.79</td>
</tr>
<tr>
<td>Apr-08</td>
<td>6.88</td>
</tr>
<tr>
<td>May-08</td>
<td>10.22</td>
</tr>
<tr>
<td>Jun-08</td>
<td>8.52</td>
</tr>
<tr>
<td><strong>Average year</strong></td>
<td><strong>5.93</strong></td>
</tr>
</tbody>
</table>

*Source: NRCan’s Discharge Monitoring at the 800 level portal*

A plot of mine water discharge and pond level in time is provided on figure 11. As expected, the pond level varies with the discharge and a lag of roughly 3 weeks is observed. The pond level reacts similarly to both increase and decrease of discharge rate which is a sign that the dam is performing according to design.
5.1.2 Phreatic surfaces

The mine personnel data acquired from the piezometers was unfortunately scarce; of the 7 piezometers, only 4 provided data. P04-2 was dry all year round. The section of the dam where P04-2 and P04-3 are installed is on sections of higher ridges of the original ground (see table 3). The majority of the seepage is presumably passing under this elevation at this section through native soils. For this reason, the graph does not take into consideration these zero values. Piezometers readings are plotted against the water level in figure 12 and the data shows a correlation between the pond water level and the water level through the dam, again implying that the dam is performing to design.
Figure 12 Piezometric Readings

Blue and Red lines show that North Piezometer (PO4-1) Deep and Shallow have little difference in pore pressure – suggesting little difference in material characteristics; either the core is more granular than silty, the drainage blanket is more silty than granular, OR that the deeper piezometer is silted up. Green and purple show the relative pore pressure change in deep and shallow piezometer, PO4-4, respectively. Green indicates reduced pore pressure in the granular materials under the dam in comparison with the pore pressures within the silty core. South drainage blanket appears to function well and there is a ten foot difference in measured water levels in PO4-4 in relation to PO4-1 in the north section. The deep piezometers are installed within the drainage blanket / native soil zone, and original topography of dam foundation differed by ten feet between north and south sections. Water pressure measured in PO4-5 under the lower south seepage (light blue line) remains relatively constant throughout the year.
5.1.3 Seepage Analysis

Overall, the dam shows no tension cracks, bulges, sinkholes, sags or sloughs. Several minor erosion channels are visible all along the dam, both on the upslope and the down slope. At the moment, the dam is not losing any material but maintenance should be ongoing to offset the erosion. The following table is a compilation of the seepage data obtained. The discharge value for the same period was not available.

Table 5 Measured Flow Rates at Seeps

<table>
<thead>
<tr>
<th>Date</th>
<th>South seep Flow (L/s)</th>
<th>North seep Flow (L/s)</th>
<th>Mid-south seep Flow (L/s)</th>
<th>Total Flow (L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22-Jun-08</td>
<td>0.38</td>
<td>1.96</td>
<td>8.39</td>
<td>10.72</td>
</tr>
<tr>
<td>27-Jun-08</td>
<td>0.38</td>
<td>2.02</td>
<td>8.33</td>
<td>10.66</td>
</tr>
<tr>
<td>04-Jul-08</td>
<td>0.32</td>
<td>2.02</td>
<td>7.70</td>
<td>10.09</td>
</tr>
<tr>
<td>11-Jul-08</td>
<td>0.32</td>
<td>2.02</td>
<td>9.15</td>
<td>11.48</td>
</tr>
<tr>
<td>18-Jul-08</td>
<td>0.25</td>
<td>1.96</td>
<td>9.53</td>
<td>11.73</td>
</tr>
<tr>
<td>25-Jul-08</td>
<td>0.25</td>
<td>1.96</td>
<td>7.32</td>
<td>9.59</td>
</tr>
<tr>
<td>01-Aug-08</td>
<td>0.25</td>
<td>1.96</td>
<td>7.38</td>
<td>9.59</td>
</tr>
<tr>
<td>08-Aug-08</td>
<td>0.25</td>
<td>1.96</td>
<td>7.32</td>
<td>9.53</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.32</strong></td>
<td><strong>1.96</strong></td>
<td><strong>8.14</strong></td>
<td><strong>10.41</strong></td>
</tr>
</tbody>
</table>

North Seep

At the northern end of the dam, from section zero to 400, seepage water flows in a collector ditch at the toe of the dam (Figure 13). The water is then directed into a PVC pipe at the north seep for flow measurement. At the time of the visits, north seep collected most of the water from that drainage ditch. A three foot thick drainage blanket underlying the downstream half of the dam collects seepage from within the dam and transports this water to a ditch along the
toe of the dam for controlled groundwater discharge. Horsetails (Equisetum) seen at the bottom of the down slope of the dam, close to the collection ditch, are an indicator of excessive ground moisture. The water is very clean in the ditch and the presence of green algae is noted.

The area between north seep and mid-south seep, section 400 to 600, is not monitored and this section of the dam was designed without a downstream drainage blanket seepage collection ditch. Groundwater discharge was noted at an area approximately 9.1 to 15.2 meters long within the forested terrain down slope from the original high ridge area. The forest floor was damp, no well-defined channelized surface water flow was noted and again the presence of horsetails was noted (Figure 14). Without a seepage collection system, there is no quantitative data regarding the rate or volume of seepage through this area. Based on the water balance review, it is estimated that the seepage through this area may account for the 1.8 L/s difference between inflows and outflows.
**Mid-south seep**

The Mid-South Section extends from station 600 to 750 and the tailings do not cover the original ground on the upstream face of the dam. Horsetails are in abundance around mid-south seep, confirming the higher moisture content of the soil in this area. As shown in figure 16, seepage has been collected through newly installed flumes this year and on average, 8.15 L/s flows through the flume. Based on the water balance review, this seepage accounts for 78% of the total discharge flow. Furthermore, the ground water modeling has shown that the tailings water from the pond has a relatively direct path through the original, native materials underlying the dam.

**Figure 15 Seepage at Mid-South section**
**Figure 16 Flow flume at mid-south seep**

**South Seep**

The South Section extends from station 750 to 950 and is monitored by south seep. This portion of the dam was constructed with a drainage blanket underlying the downstream half of the dam and the upstream slopes in this area are covered in tailings deposited from the mill. The drainage blanket collects seepage from within the dam and transports this water to a ditch.
along the toe of the dam for controlled groundwater discharge. The location of ground water discharge at the toe of the drainage blanket is evident by horsetail growth. Horsetail growth is also evident along the lower part of the right bank of the old channel which may be an indicator of seepage from the South Abutment and upper slope run-off. This area has a typical, minimum flow measured as 0.3 L/s at south seep which is only 3% of the measured dam outflows. Once again, the water is very clear both at the flume and in the pond

The intercepted average total flow rate is on average 10.4 L/s. A section between mid-south seep and north seep is not being captured at the moment, so a better estimate for the total flow rate might be around 12.5 to 13.0 L/s, six times greater than the 1996 design estimated rate. The presence of saturated sand and gravel layers underlying glacial till in the sides and base of the basin can explained the discrepancy. Variations in permeability in horizontal and vertical directions and the variability of the subsurface conditions can vary the seepage rate in the order of plus or minus 10 times (Whitford 2003). Lenses of high permeability in the native soil are therefore highly probable between sections 500 and 750 and would explain the higher seepage rate in that section.

Natural attenuation and dilution of potential contaminants contained in the seepage are considered to be sufficient to meet environmental standards. Water quality of groundwater below the dam should still be monitored. From the visual observation, the water quality appears adequate. The water is very clear without sediments.
5.1.4 Settlement and Lateral movement

To monitor if seepage is not transporting any soils from within the dam and causing internal erosion, surface monitoring points were established by mine personnel and surveyed once in July and once in October of 2008. The results of this survey provided by Bralorne Mine personnel indicated that no settlement occurred during this period. From the 2 site visits, visually there is no evidence of settlement.

Again from the site visits, there is no visual evidence of lateral movement. The monitoring pins, referenced above were installed on both upstream and downstream crests at Stations: 300, 600 and 850. These locations are adjacent to the three seepage collection flumes. Future survey measurement of these points will provide an indication of any lateral movement.
5.2 Water Balance

The following table summarizes the results of this water balance review:

<table>
<thead>
<tr>
<th>Water Balance Parameter</th>
<th>Current Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow (L/s)</td>
<td>13.1</td>
</tr>
<tr>
<td>Outflow (L/s)</td>
<td>11.3</td>
</tr>
<tr>
<td>Balance (L/s)</td>
<td>1.8</td>
</tr>
</tbody>
</table>

A negative water balance indicates that there is more water leaving than entering the reservoir. This corresponds with the measured fall of pond level during this period. It is noted that typical predicted seepage through the base in the design document was 2.8 L/s whereas the 2008 measurements indicate a total value of 11.3 L/s.

The reservoir water level was noted to have a variation of about 0.45 m throughout 2008. The maximum reservoir water levels were measured to occur during May to July and correspond with the maximum amount of seepage at mid-south seep. It should be noted that mid-south seep accounts for about 78% of the total measured seepage and may correspond with the presence of higher permeability subsurface soil types which is conceptually shown on figure 17. It should also be noted that the water balance doesn’t take into the seepage occurring in the section between north seep and mid-south seep, which is not being collected at the moment. From the visual inspection of the site, the amount of water not being collected would be sufficient to change the water balance from negative to positive.
Simplified water balance model

Period from June 28\textsuperscript{th} 2008 until July 4\textsuperscript{th} 2008

**INPUTS**

- Precipitation: 2.57 L/s
- Rainfall Runoff: 2.01 L/s
- Mine discharge water: 8.5 L/s

**OUTPUTS**

- Evapotranspiration: 0.5 L/s
- North Seep: 2.0 L/s
- Mid-south seep: 8.3 L/s
- South seep: 0.4 L/s
- Groundwater

**TOTAL INPUTS:** 13.1 L/s  
**TOTAL OUTPUTS:** 11.3 L/s

*Figure 18 Water balance model*
5.3 Computer modeling analysis

The current condition of this dam is different from the design assumptions; specifically, the amount of tailings storage is significantly less than the design condition and the impoundment area is being utilized as a mine waste water storage/reservoir. A 2D Limit Equilibrium Slope Stability Analysis was carried with the computer software program Slide 5.0 from RocScience. Groundwater seepage analysis can also be done with this software and was added to the model. Two sections of the dam were analysed: North and South sections (See figure 9 and 10 for dimensions). A series of slope stability analyses were run to examine the Factors of Safety with various seismic loading and the simplified Bishop method was preferred. The seismic values were obtained from the 2009 PKRead report. In compliance with the 2003 Jacques Whitford report, the following parameters were used for the analyses:

- Glacial till and Gravel: unit weight = 120 pcf; \( \phi = 35^\circ \)
- Granular drainage blanket: unit weight = 110 pcf; \( \phi = 33^\circ \)
- Native soils (predominantly till deposits): unit weight = 115 pcf; \( \phi = 34^\circ \)
- Tailings: unit weight = 90 pcf; \( \phi = 30^\circ \)

Appendix C outlines all the values and assumptions used in the modeling. Cross sections are also included in the appendix.
Figure 19 Factors of Safety for static and seismic loading conditions

<table>
<thead>
<tr>
<th>Applicable Conditions</th>
<th>South Section</th>
<th>North Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downstream Slope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep seated failure</td>
<td>Static 1.59</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>Seismic 0.1g</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>Seismic 0.132g</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Seismic 0.185g</td>
<td>1.14</td>
</tr>
<tr>
<td>Shallow surficial</td>
<td>Static 1.56</td>
<td>1.57</td>
</tr>
<tr>
<td><strong>Upstream Slope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep seated failure</td>
<td>Static 1.72</td>
<td>1.78</td>
</tr>
<tr>
<td>Shallow surficial</td>
<td>Static 1.50</td>
<td>1.74</td>
</tr>
</tbody>
</table>

The same software was also use to model the groundwater conditions. With the soil properties given above, the model and observed conditions were similar results for the North Section but more variable for the South Section. The mid-south section, where the probable high permeability lenses are located, would probably explain the lower seepage rate under the South section of the dam as water tends follow the more permeable material.

Table 7 Observed and modeled seepage rate

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Seepage from model (L/s)</td>
<td>2.23</td>
<td>1.41</td>
</tr>
<tr>
<td>Measured seepage at the flumes (L/s)</td>
<td>1.96</td>
<td>0.33</td>
</tr>
<tr>
<td>Difference (L/s)</td>
<td>0.27</td>
<td>0.81</td>
</tr>
</tbody>
</table>
6. Conclusions

As stated earlier, due on the new role of the dam, from a tailings dam to a water reservoir dam, the seepage performance and the slope stability of the dam had to be analysed. The monitoring equipment; namely the flow flumes, piezometers, water level sticks along with the construction report of the dam provided enough data to model the dam and analyze its performance with the RocScience software Slide 5.0. Visual observations were given a lot of consideration given all the uncertainties with the native soil properties.

Based on the analysis of the actual design stage of the dam (5 years), there are no indications that changes to the dam function decreased its existing stability or that there is an imminent slope stability problem.

As noted in table 19, the factor of safety for potential deep seated instability under static conditions is at least 1.50 for both the downstream and upstream faces of the dam. The North and South sections of the dam were analyzed for slope stability.

Due to the location of the dam, the current dam slope stability was also analyzed with design seismic conditions of a 2%, 5% and 10% probability of exceedance in 50 years. The Factor of Safety for the North Section was 1.14, 1.24 and 1.32 respectively. For the South Section, they corresponded to 1.14, 1.23 and 1.27. The seismic analysis was done in accordance to the Canadian Dam Association suggested design earthquake levels.

A more accurate determination of the water balance has been attained based on additional data which includes flume flow measurements and the drilling program. It has been determined that 70 to 80 percent of all pond inflows presently flow out through native
materials under the dam in the mid south section, typically around station 600. The construction sequence of this area of the dam remains unclear. The natural water flow was most likely changed with human construction and groundwater eventually found its natural course through native soil under the dam. The dam is still performing to the design standards outlined in the Whitford 2005 report, except for the section mentioned above. The water coming out of the dam at every section is very clear and shows no sign of fine material.

Based on the current dam condition, there is sufficient storage capacity to accommodate the 200 year storm precipitation event, and allow for the requisite freeboard. The present typical freeboard of 2.13 to 2.4 metres provides a reservoir capacity behind the current 5 year design stage dam, of up to 68 000 cubic meters. Using a 200 year storm intensity of 5mm/hr for 24 hr duration (PK Read 2009), it is calculated that the reservoir water level would rise less than 0.61 metres to El. 1051.8 metres. The design 0.9 metres freeboard minimum would therefore still be available even after such a storm event.

Finally, after site observations, water balance review and slope stability analysis, it is concluded that there is no significant change to the dam stability.
7. Recommendations for Further Work

According to the Canadian Dam Association of Canada, tailings dams in British Columbia are under the Ministry of Energy, Mines & Petroleum Resources and legislated under the Mines Act. However, since this tailings dam is acting more like a water impoundment, the regulations for this type of dam were also looked at. Again, in the province of British Columbia, the Water Supply Dams are under the Ministry of Environment, Water Stewardship Division and legislated under the Water Act (CDA 2009).

The Mines Act of British Columbia, states the following regarding Tailings Dams and monitoring:

10.5.2 An Operation, Maintenance and Surveillance (OMS) manual shall be prepared and provided to an inspector and to all employees involved in the operation of a major dam or major impoundment, prior to commissioning. The manual shall be revised regularly during operations, decommissioning and closure of the structure.

10.5.3 The manager shall submit an annual dam safety inspection report prepared by a professional engineer on the operation, maintenance and surveillance of the tailings and water management facilities and associated dams to the chief inspector.
The Water Act of British Columbia, the following Dam safety regulation should apply.

Table 8 Minimum Inspection Frequency and Dam Safety Review Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Very High Consequence</th>
<th>High Consequence</th>
<th>Low Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Surveillance</td>
<td>WEEKLY</td>
<td>WEEKLY</td>
<td>MONTHLY</td>
</tr>
<tr>
<td>Formal Inspection</td>
<td>SEMI-ANNUAL</td>
<td>SEMI-ANNUALLY or ANNUALLY</td>
<td>ANNUALLY</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>AS PER OMS MANUAL</td>
<td>AS PER OMS MANUAL</td>
<td>AS PER OMS MANUAL</td>
</tr>
<tr>
<td>Test Operation of Outlet Facilities, Spillway Gates and other Mechanical Components</td>
<td>ANNUALLY</td>
<td>ANNUALLY</td>
<td>ANNUALLY</td>
</tr>
<tr>
<td>Emergency Preparedness Plan</td>
<td>UPDATE COMMUNICATIONS DIRECTORY SEMI-ANNUALLY</td>
<td>UPDATE COMMUNICATIONS DIRECTORY SEMI-ANNUALLY</td>
<td>UPDATE COMMUNICATIONS DIRECTORY ANNUALLY</td>
</tr>
<tr>
<td>Operation, Maintenance &amp; Surveillance Plan</td>
<td>REVIEW EVERY 7 - 10 YEARS</td>
<td>REVIEW EVERY 10 YEARS</td>
<td>REVIEW EVERY 10 YEARS</td>
</tr>
<tr>
<td>Dam Safety Review</td>
<td>EVERY 7-10 YEARS</td>
<td>EVERY 10 YEARS</td>
<td></td>
</tr>
</tbody>
</table>

The latest Manual for Operation and Inspection for the Bralorne Tailings Impoundment Facilities was written by Jacques WHITFORD in February 2004. The Emergency Preparedness Plan (EEP) was written by PK Read Engineering in 2007. As stated in the Water Act and Mines Act of BC, these two documents should be followed and updated accordingly.

In order to maintain the validity of the slope stability analysis and seepage performance of the dam, the following recommendations should be considered for this particular dam.

- Monitoring of the existing equipments (pond water level stick, mine discharge, piezometres and seepage flow rate at the 3 seeps) should be carried weekly and recorded in a spreadsheet format. As stated in the Emergency Preparedness Plan
(NHC 2007) a “warning level/ zone” has been established on the spreadsheet, at which time the data should be immediately forwarded to the engineer responsible for the site.

- Same procedure should be followed for the newly installed survey monitoring of the settlement points, except they should be recorded monthly.
- As requested by both legislations, the annual dam safety report should be done by a qualified engineer.
- As a requirement in the Water Act, a spillway design should be implemented for this dam in order to control possible floods.
- A fourth seepage collection system should be installed at the middle north section. This would provide more complete flow information for further water balance reconciliations. It would also gauge the potential seepage reduction effectiveness of tailings which blanket the upstream face.
- Should milling operations recommence, an option to reduce relatively high seepage flows would be to place discharge spigots in the middle section of the dam to blanket the native materials on the upstream slopes. Accumulations of the tailings should decrease the seepage occurring presently under the dam at the middle sections. During tailings deposition a modified O & M procedure for the pond would need to be developed.
Acknowledgements

I would like to thank Phill Read, of P.K. Read Engineering for his guidance through this project. His knowledge and experience in geotechnical, geological and mining engineering were critical to the success of this thesis.

I would also like to thank Bralorne Gold Mines Ltd. for providing with the data needed to carry on this analysis and allowing me to publish this undergraduate thesis.
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Canadian Dam Association, Canadian Regulations, retrieved on November 25th, 2009 <http://www.cda.ca/cda_new_en/regulations/regulations.html>

Appendix A
Aerial View of the Mines
Appendix B
Plan and representative cross sections
Appendix C

The slope stability analysis was carried out based on the following assumptions:

<table>
<thead>
<tr>
<th>Material</th>
<th>unit weight (pcf)</th>
<th>$\phi$ ($^\circ$)</th>
<th>K (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacial till</td>
<td>120</td>
<td>35</td>
<td>$1.80\times10^{-7}$</td>
</tr>
<tr>
<td>Gravel</td>
<td>120</td>
<td>35</td>
<td>$4.11\times10^{-6}$</td>
</tr>
<tr>
<td>Drainage blanket</td>
<td>110</td>
<td>33</td>
<td>$3.28\times10^{-3}$</td>
</tr>
<tr>
<td>Native soils</td>
<td>115</td>
<td>34</td>
<td>$4.11\times10^{-6}$</td>
</tr>
<tr>
<td>Tailings</td>
<td>90</td>
<td>30</td>
<td>$1.20\times10^{-5}$</td>
</tr>
</tbody>
</table>

The dam cross sections that were used in the analyses were based on the 5 year design stage and associated geometry. Two dam cross sections were modelled and analyzed for different loading conditions. All model input date came from Whitford 2003 report.

The Simplified Bishop method was adopted for this, slope stability analysis and carried out using the RocScience software called SLIDE 5.0. A pseudo-static approach was applied to the slope stability model to evaluate the stability of the dam under various design seismic conditions.

The peak ground accelerations on firm ground were obtained from P.K. Read Engineering 2009 report. The values were based on the suggested design earthquake levels for a Low, Significant, and High dam classes from the Canadian Dam Association. They should have an annual exceedance probability of 1/500, 1/1000, and 1/2500, respectively and since this dam is not classified at the moment, the three conditions were analysed. The values used for the analysis are as follow:

<table>
<thead>
<tr>
<th>Percent Probability of Exceedance in 50 years</th>
<th>Peak Ground Acceleration</th>
<th>Peak Ground Acceleration for Pseudo-Static Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>0.277 g</td>
<td>0.185 g</td>
</tr>
<tr>
<td>5%</td>
<td>0.198 g</td>
<td>0.132 g</td>
</tr>
<tr>
<td>10% (original design value)</td>
<td>0.147 g</td>
<td>0.100 g</td>
</tr>
</tbody>
</table>
Appendix D
Pictures

View of the dam and water reservoir

View of the dam from South Seep
South Section

Hydraulic flow path and pressure heads
South Section

Downstream slope stability analysis with seismic loading 0.1g

Deep seated failure factor of safety FS= 1.27
Surficial failure FS= 1.30
South Section

Downstream slope stability analysis with seismic loading 0.132g

Deep seated failure factor of safety FS= 1.23
Surficial failure FS= 1.20
South Section

Downstream slope stability analysis with seismic loading 0.185g

Deep seated failure factor of safety FS = 1.14
Surficial failure FS = 1.11
North Section

Hydraulic flow path and pressure heads
North Section

Static upstream slope stability analysis

Deep seated failure factor of safety FS= 1.78
Surficial failure FS= 1.75
North Section

Downstream slope stability analysis with seismic loading 0.185g

Deep seated failure factor of safety FS= 1.14
Surficial failure FS= 1.09