Independent Expert Engineering Investigation and Review Panel

Report on Mount Polley Tailings Storage Facility Breach

Appendix F: Instrumentation and Monitoring

January 30, 2015

Report on Mount Polley Tailings Storage Facility Breach

Independent Expert Engineering Investigation and Review Panel

APPENDIX F: INSTRUMENTATION AND MONITORING

1.0 SUMMARY OF INSTRUMENTATION AND MONITORING ON TSF

1.1 TYPES, LOCATIONS, AND NUMBERS

Instrumentation for the Mount Polley tailing storage facility (TSF) consisted of:

- Inclinometers
- Vibrating wire piezometers
- Survey monuments (until about 2010)
- Drain flow monitoring

Instruments were installed during construction of many of the raises to add additional instruments or to replace damaged ones. In 2011, AMEC recommended further instrumentation installation [1], which took place later in 2011. [2]

Drawing F1 shows the locations of inclinometers and vibrating wire piezometers for the whole TSF. These were installed along 11 sections instrumented over the life of the facility. Attachment F1 provides information about all of the inclinometers and piezometers.

There were 10 inclinometers installed along all three of the embankments. The number of operating and non-operating vibrating wire piezometers at the time of the breach are summarized in **Table F.1.1**. [3]

TABLE F.1.1: VIBRATING WIRE PIEZOMETERS IN MOUNT POLLEY, AUGUST 2014

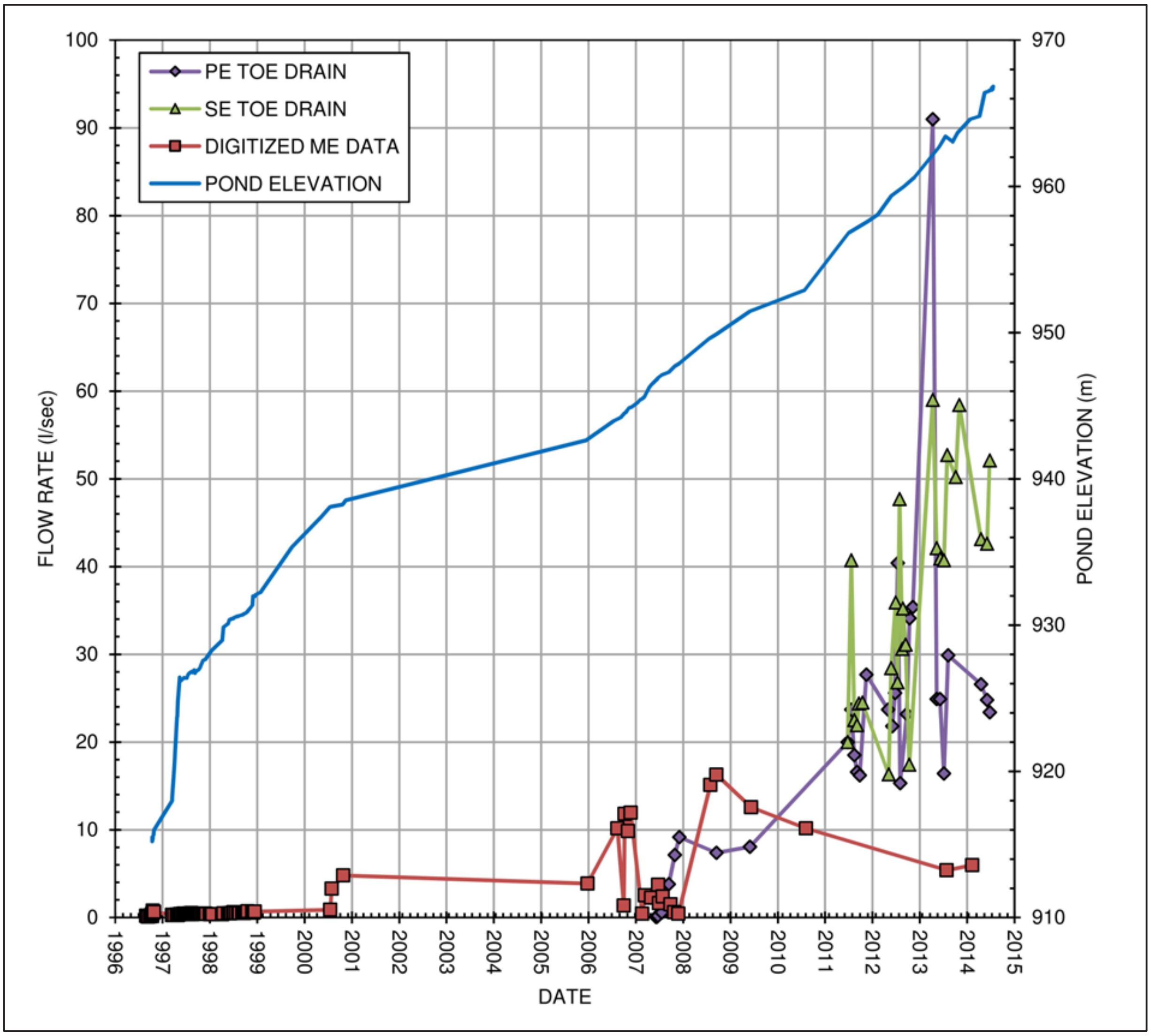
EMBANKMENT	OPERATING	NON-OPERATING
Main	47	34
Perimeter	9	13
South	8	5
Total	**64**	**52**

The most recent inclinometer displacement as well as the vibrating wire piezometer elevation head data are available in Appendix B and in the references cited above.

Drain flow measurements from the foundation drains and chimney drain were initiated for the Main Embankment during the first phase of construction. Flow measurements were also initiated when similar drains were installed in the Perimeter and South Embankments. Upstream drains were installed in the tailings (also referred to as “upstream toe drains” [4]) at all the dams as they progressed in height, and these flows were also measured starting in 1996. Flows from these drains report to the respective seepage collection ponds constructed downstream of each of the dams. These flows were measured on a monthly basis (weather permitting) in a manifold for the Main Embankment and across the ditch profiles close to the ends of the outlet pipe for the Perimeter and South Embankments. [5] Drain flow readings are shown in **Figure F.1.2**. [6]

[1] AMEC00264
[2] MP10012
[3] MP10010
[4] MP00037
[5] MP00044
[6] Figure 2.2 MP00044

FIGURE F.1.2: MAIN EMBANKMENT, PERIMETER EMBANKMENT AND SOUTH EMBANKMENT DRAIN FLOW READINGS (FIGURE 2.2 MP00044)



2.0 SUMMARY OF INSTRUMENTATION AND MONITORING NEAR BREACH AREA

Drawing F2 shows the locations of inclinometers and vibrating wire piezometers adjacent to the breach area. These were installed along two Sections identified as D and G. Two other section designations, 1 and 4, are shown to further clarify the instrumentation details provided in Drawings F3 and F4.

Attachment F2 provides details on the inclinometers and vibrating wire piezometers in the vicinity of the breach area. Monitoring results are only shown for the piezometers as the inclinometer data did not indicate any movements that implied consistent displacements potentially resulting in instability.

Drawing F5 provides a plan of the seepage collection elements near the breach area. The tailings toe drain, as well as its pipe, outlet through the embankment and conveyance pipe is shown in blue. The conveyance was later replaced by a drainage ditch.

3.0 INSTRUMENTATION TRIGGER LEVELS

During the first phase of construction in 1996/1997 artesian pressures were observed in three of the six foundation piezometers in the Main Embankment. This prompted the development of trigger, or action, levels for many of the piezometers in the foundation and drains.[7]

As part of their 2012 annual construction manual AMEC developed the instrumentation trigger framework shown in **Table F.3.1**.[8] This framework is for all the inclinometers and the Main Embankment foundation piezometers. The AMEC manual states that: "embankment construction will be suspended if the inclinometers or piezometers fall under the yellow or red condition described in the Table, and/or if embankment foundation piezometer data indicates a significant increasing trend". No corresponding trigger levels were established for the Perimeter Embankment piezometers because "Factor of safety values...are sufficiently high that monitoring of piezometric trends, without defined trigger levels, is deemed sufficient."[9]

TABLE F3.1: INSTRUMENTATION TRIGGER LEVELS

CONDITION	INCLINOMETER MOVEMENT RATE		MAIN EMBANKMENT FOUNDATION PIEZOMETER	
	(mm/day)	(Bi-Weekly)	Elevation (m)	Above Original Ground (m)
RED	> 1mm/day	> 14 mm	> 933 m	> 21 m
YELLOW	0.5 mm/day to 1.0 mm/day	7 mm to 14 mm	916 m to 933 m	4 m to 21 m
GREEN	< 0.5 mm/day	7 mm	< 916 m	< 4 m

[7] MP00019
[8] MP00040
[9] MP00040

4.0 SPECIFIC MONITORING RESULTS AND OUTCOMES

This section considers three specific monitoring outcomes based on a review of the inclinometer and piezometer data. The first relates to the tailings piezometer at Section G along the Perimeter Embankment. The second concerns foundations displacements in the GLU at inclinometer SI01-02 in the Main Embankment that was stopped by placing and increasing the buttress height. And the third pertains to high seepage rates from the upstream toe drain in the Perimeter Embankment and its relation to potential internal erosion of the core.

4.1 TAILINGS PIEZOMETER AT SECTION

Piezometer G3 at El. 947.85m at Section 4 is shown in Drawing F4. In project documentation this piezometer is considered to be part of Section G, as it is in close proximity. The upstream toe drain is at El. 946.3 m, immediately below the piezometer. The main purpose of piezometer G3 was to measure the elevation head upstream of the Perimeter Embankment and thereby provide information about the effectiveness of the upstream toe drain in draining the deposited tailings. The data in Attachment 2 to Appendix F show that the elevation head at G3 increased during its operating period (July 2007 to May 2014) as the tailings pond increased. Stability analyses presented in Section 6 rely on pore pressure conditions in piezometer G3.

4.2 INCLINOMETER SI01-02

Inclinometer SI01-02 was installed in July 2001. Drawing F6 and F7 show its location, the borehole log, and some notes related to the geotechnical characteristics of the lacustrine silts encountered in the borehole and movement observations. As indicated, movements were observed in 2009 during construction of Stage 6A, shown in Drawing F7, upon which a buttress was placed to El. 918 m. The embankment was 37 m high after placement of Stage 6A (refer to the notes in Drawing F6).

In 2013, some further movements were observed in SI01-02 and the buttress was extended. The embankment was about 40 m high when the second set of movements was observed.

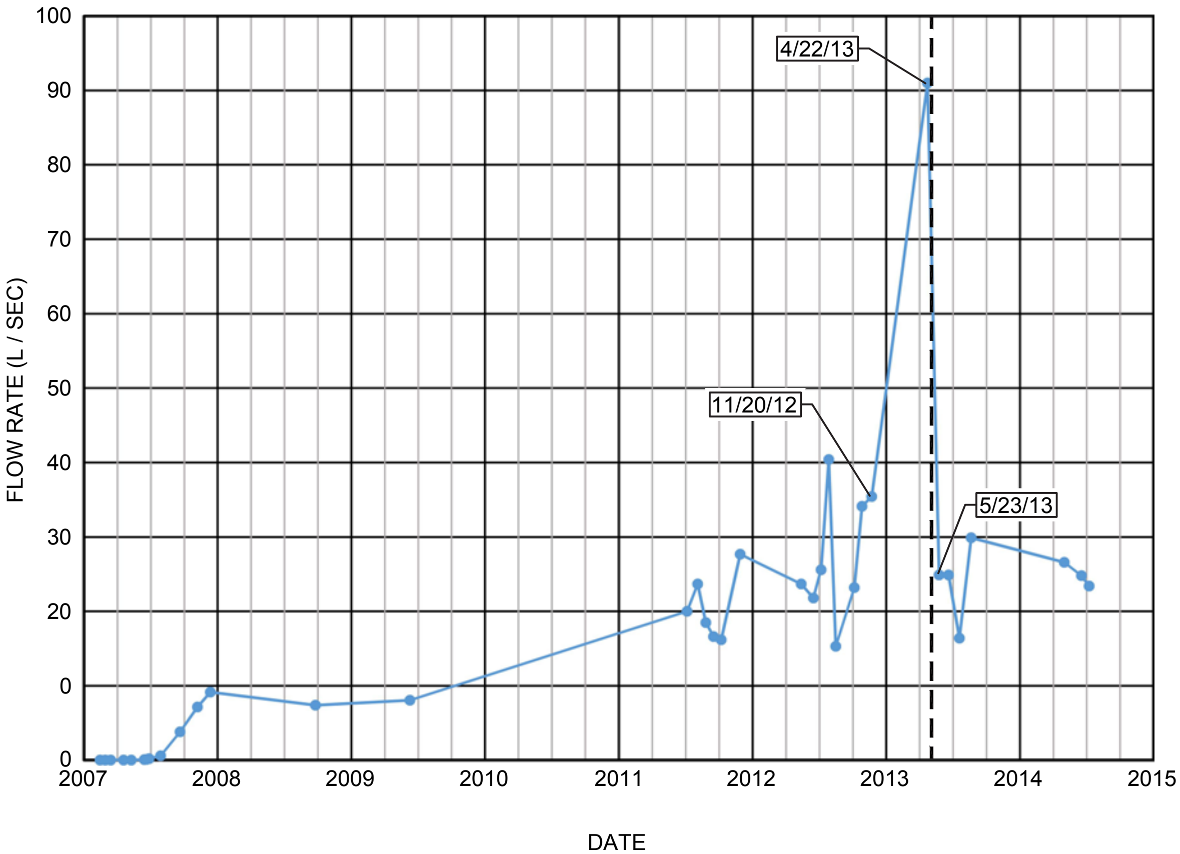
There were only small displacements measured in other inclinometers prior to the breach.

4.3 SEEPAGE FROM PERIMETER EMBANKMENT

As mentioned above, the "upstream toe drain," even though it has no relationship with the toe of the dam, was located at El. 946.3 m at the Perimeter Embankment. Its purpose was to provide drainage during deposition of beach tailings, to reduce the piezometric surface in these tailings, and to reduce gradients through the dam core.

At the same time, it afforded the opportunity to measure the volume of collected seepage as flow readings were taken at irregular and infrequent intervals between 2006 and 2014. Due to ambiguities and inconsistencies in data, means of conveyance, measuring locations, and other factors, it was necessary to reconstruct the best interpretation of seepage flows shown in **Figure F.4.1**.

FIGURE F4.1: PERIMETER EMBANKMENT INTERPRETED UPSTREAM TOE DRAIN FLOWS



Prominent in the figure is an anomalously high flow rate of 90 litres/sec on April 22, 2013, the sole reading during the winter of 2012-2013, bracketed by readings on November 20, 2013 and May 23, 2013. Toe drain flows also varied erratically before and after, although to a lesser extent. The true extent of variability in seepage flows is masked by linear interpolation between the infrequent readings plotted in the figure, for example the extended period between mid-2009 and mid-2011 where readings are absent altogether.

Nevertheless, qualitatively similar patterns of transient and frequent seepage spikes have been associated with internal erosion in till-core dams elsewhere.[10] Accordingly, this hypothesis was considered in relation to the Mount Polley Perimeter Embankment.

For reference, the toe drain is located 9.6 m above the cavity discovered in the core at the breach section, as documented in Appendix C. Also for reference, on April 22, 2013 tailings discharge into the Zone U cells was occurring between Stations 4+500 and 4+600 on the Perimeter Embankment.[11] A concrete-encased pipe conveying toe drain seepage passes through the dam at this location.[12]

[10] Vestad, H., 1976, Viddalsvatn Dam, a history of leakages and investigations, 12th Congress on Large Dams, International Commission on Large Dams, pp. 369-389, (ICOLD), Paris.

[11] MP10000

[12] MP00033

Concurrent piezometric response around the date of the seepage excursion was examined at Instrumentation Section D. As shown in Drawing F3, piezometer D2 (formerly D1-PE1-02) is located in a transverse offtake to what was once planned to be a longitudinal drain on the downstream slope of Raise 1. This drain was subsequently covered by cycloned sand deposited during the downstream trial conducted in this area. Piezometers D6 and D7 are located in glaciolacustrine and glaciofluvial units, respectively, beyond the toe of the dam at the same section. On, or about April 22, 2013, muted responses were detected in all three piezometers, with drain piezometer D2 responding somewhat before, and foundation piezometers D6 and D7 slightly after.

Together with the toe drain seepage spike, these piezometric responses could be interpreted as indicative of a hydraulic connection through the dam core produced by internal erosion.

However, a number of factors affect interpretation of the toe drain seepage data:

- It is difficult to reliably establish a characteristic pattern from the infrequent toe drain readings taken at irregular intervals.
- The toe drain discharge reports to an open-flow ditch upstream from the measuring point,[13] potentially allowing surface runoff contributions or other inputs from site activities.
- Re-routing of toe drain conveyances and other construction activities during 2012 and 2013 may have affected flow measurements and/or measured flows.
- It is not immediately clear how internal erosion of the core could increase seepage flows into the toe drain located upstream from it.
- It is not possible to establish the location of seepage entry into the toe drain.

For these reasons, on balance, the toe drain seepage flows are judged to be inconclusive with regard to internal erosion.

[13] MPMC00048

Appendix F: Drawings

- **Drawing F1**: Pre-breach Piezometer and Inclinometer Locations
- **Drawing F2**: Pre-breach Piezometer and Inclinometer Locations in Breach Area
- **Drawing F3**: Instrumentation Sections Near Breach Area
- **Drawing F4**: Instrumentation Sections Near Breach Area
- **Drawing F5**: Seepage Collection Elements Near Breach Area
- **Drawing F6**: Inclinometer SI01-02 Log and Notes
- **Drawing F7**: Inclinometer SI01-02 Monitoring Results

Appendix F: Attachments

- **Attachment F1**: Summary of Instrumentation Data – Entire TSF
- **Attachment F2**: Summary of Instrumentation Data – Breach Area
    - *Summary of Inclinometers in Breach Area*
    - *Summary of Piezometers in Breach Area*
    - *Piezometer Plots for Section D*
    - *Piezometer Plots for Section G*