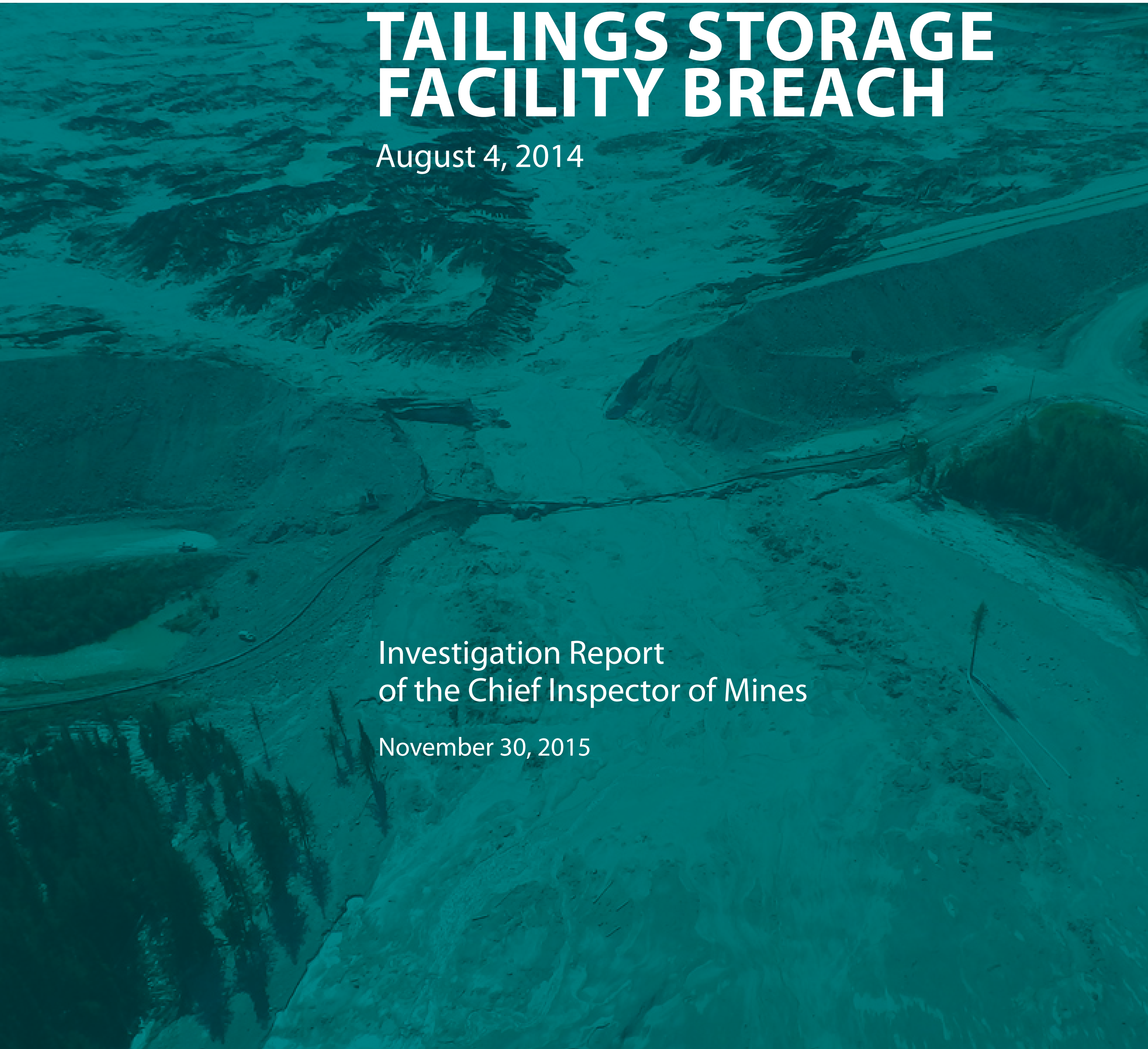
Mining and Mineral Resources Division
Ministry of Energy and Mines

MOUNT POLLEY MINE
TAILINGS STORAGE FACILITY BREACH

August 4, 2014



Investigation Report of the Chief Inspector of Mines

November 30, 2015

Mining and Mineral Resources Division
Ministry of Energy and Mines

November 30, 2015

The Honourable Bill Bennett
Minister of Energy and Mines and Minister Responsible for Core Review
Parliament Buildings
Victoria, British Columbia

Dear Minister Bennett,

I am pleased to transmit to you under my signature this report detailing the investigation carried out by my office on the breach of the tailings storage facility at Mount Polley Mine on August 4, 2014.

The report represents the process, findings, and recommendations of the office of the Chief Inspector of Mines for the Province of British Columbia, resulting from the investigation carried out from August 4, 2014 through November of 2015.

The report represents the labours of a dedicated and professional team of investigators from the Ministry as well as external geotechnical engineering expertise and consultative resources who met the challenge of a comprehensive, objective, and ultimately independent investigation. I am grateful to each of these contributions to the investigation.

This investigation is the first of this magnitude for my office. Recognizing its complexity, several learnings and processes have been adopted and will enhance investigations into the future.

The investigation was conducted in a manner that maintained the independence, integrity, and thoroughness of the process. As a result, the findings and recommendations are those in which the people of British Columbia, the mining industry, and the Government can be confident.

Sincerely,

Al Hoffman, P.Eng.
Chief Inspector of Mines

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LIST OF ACRONYMS AND ABBREVIATIONS

AMEC AMEC Earth & Environmental Division of AMEC Americas Ltd. (presently operating as Amec Foster Wheeler)

APEGBC Association of Professional Engineers and Geoscientists of British Columbia

ASTM American Society for Testing and Materials

MOE British Columbia Ministry of the Environment

BAP/BAT Best available practices / best available technologies

BGC BGC Engineering Inc.

C Centigrade

CDA Canadian Dam Association

CIM Chief Inspector of Mines

COS Conservation Officer Service

CPT Cone penetration test

CQA Construction Quality Assurance

DSI Dam Safety Inspection

DSR Dam Safety Review

DBE Design Basis Earthquake

ECFT Event and Causal Factor Tree

EIT Engineer in Training

EoR Engineer of Record

E&R III Evidence & Records III database

FOI Freedom of Information

FOIPPA Freedom of Information and Protection of Privacy Act

FoS Factor of Safety

GLU Glaciolacustrine unit

HSRC Health, Safety and Reclamation Code for Mines in British Columbia

H:V Horizontal : Vertical (slope)

ISO International Standards Organization

ITRB Independent Technical Review Board

KP Knight Piésold Ltd.

KCB Klohn Crippen Berger Ltd.

kPa kilopascal

kN kilonewtons

L/s Litres per second

LGLU Lower glaciolacustrine unit

LGT Lower glacial till (lodgment/basal)

MAC Mining Association of Canada

MCE Maximum Credible Earthquake

MCM Major Case Management

MDE Maximum Design Earthquake

MERP Mine Emergency Response Plan

MGT Middle glacial till

MPMC Mount Polley Mining Corporation

MEM Ministry of Energy and Mines

ME Main Embankment

NASA National Aeronautics and Space Administration

OBE Operational Basis Earthquake

OMS Operation, Maintenance, and Surveillance Manual

PAG Potentially acid-generating rock

PE Perimeter Embankment

P.Eng. Professional Engineer

PMP Probable Maximum Precipitation

PMF Probable Maximum Flood

QA Quality Assurance

QC Quality Control

RCA Root Cause Analysis

RCAT Root Cause Analysis Tool, NASA software/methodology

SCP Seepage collection pond

SE South Embankment

SOL Set-Out Line

SPT Standard penetration test

SSWQO Site-Specific Water Quality Objectives

tpd Tonnes per day

TSF Tailings storage facility

TSM Towards Sustainable Mining (Mining Association of Canada)

UGLU Upper glaciolacustrine units

UGT Upper glacial till

VWP Vibrating Wire Piezometer

WTP Water treatment plant

GLOSSARY OF TECHNICAL TERMS

Angle of repose The steepest angle, relative to horizontal, that a material can be piled without slumping.

Artesian pressure A condition in a confined soil layer in which the elevation of the water pressure head is above water pressure head in the overlying soils.

Barrier A passive defense in a system that prevents or mitigates a hazard from causing an undesired occurrence.

Blow count The number of hammer blows required to advance a sampler one foot into a soil during a standard penetration test.

Beach The portion of tailings in a storage facility that is not submerged below the pond.

Borehole A hole drilled through the ground to characterize soil or rock.

Buttress A structure used to add passive resistance at the toe of a dam to enhance stability.

Centerline construction A tailings dam construction method in which the centerline of the dam is held in the same position during subsequent raises. This requires that structural fill be placed both downstream and upstream of the centerline during raising and results in a vertical core.

Chimney drain A zone within a dam that has a relatively high hydraulic conductivity, compared with the dam core. The purpose of the drain is typically to reduce the elevation of the phreatic surface downstream of the core.

Command Triangle Interconnected leadership model in Major Case Management consisting of Team Commander, Primary Investigator, and File Coordinator.

Contact water Runoff water at a mine that has become contaminated by mine processes.

Contributory cause An event or condition that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence. Contributing factors change the probability of an undesired outcome.

Control An active defense in a system that detects a hazard and requires an intervention of some sort to prevent or mitigate the hazard from causing an undesired outcome.

Cracking Linear features caused by brittle deformation in a structural dam fill. Cracks can be oriented both parallel and perpendicular to the direction of movement.

Crest The top of the dam.

Cyclone sand The coarse fraction of a granular material that has been mechanically separated (cycloned) from the fine material.

Direct shear testing A laboratory-based soil test in which a sample is placed in a mold, saturated, consolidated to a defined vertical stress, and sheared at a rate slow enough to prevent generation of pore pressures. The test is used to determine the strength of the soil.

Downstream construction A method of dam construction in which the centerline is translated downstream with subsequent raises which results in a core inclined in the downstream direction. This method requires that structural fill be placed in the downstream shell during raising to support the inclined core.

Factor of Safety In geotechnical engineering, the ratio of resisting forces to the driving forces. A Factor of Safety (FoS) below one (or unity) means that failure will occur.

File Coordinator A member of the Major Case Management Command Triangle, the File Coordinator is responsible for managing and auditing all materials and information gathered, located and generated during the investigation.

Freeboard The vertical distance between the lowest elevation of a dam crest elevation and the pond elevation.

Glaciofluvial Soils that are transported and deposited by meltwater from a glacial river or stream.

Glaciolacustrine Soils that are formed in a lake bottom from sediments deposited by glacial meltwater.

Inclinometer An instrument used to measure horizontal movements in the ground.

Lower glaciolacustrine unit A soil unit present in the foundation of the Perimeter Embankment that is differentiated from the upper glaciolacustrine unit mainly based on its higher shear strength and higher overconsolidation ratio. This unit was found at a lower elevation than the upper glaciolacustrine unit.

Major Case Management An organizational philosophy developed by public safety agencies as a means of managing the complexities and uncertainties of large scale investigations. MCM focuses on investigative coordination, accountability, and a multi-disciplinary approach to secure the best information and evidence.

Mines Management System (MMS) Operational database in use by the Ministry of Energy and Mines.

Modified centerline construction A method of dam construction in which the centerline is translated upstream with subsequent raises which results in an upstream inclined core. The core and/or fill materials are partially supported by the tailings beach.

Overconsolidated The state in a soil that has previously been consolidated at a higher stress (e.g. with the weight of the ice in a glacier) than its current stress state. Overconsolidated soils behave differently under loading than "normally" consolidated soils, soils that have not been consolidated past their current stress state.

Overtopping A type of dam failure in which the elevation of the pond rises above the elevation of the crest of the dam and tailings and/or water could be released.

Phreatic surface The line of zero pressure within an embankment or foundation. Commonly referred to as the "water table."

Piezometer An instrument that is used to measure the water pressure head in a soil unit.

Piping The formation of internal erosion channels within an earthfill dam. Piping can lead to large scale internal erosion, loss of containment and collapse of a dam.

Pore pressures Pressure within the water that is contained within a soil's void space.

Primary Investigator A member of the Major Case Management Command Triangle, the Primary Investigator controls the speed, flow and direction of the investigation.

Pre-shearing A soil that has been historically subject to shear strain along a discrete plane, effectively reducing the available shear strength along that plane.

Process water Water that is used in milling or mineral concentration processes. Process water is used to transport tailings to the TSF, and is recycled for use in milling processes.

Proximate cause An event, including any condition(s) that exist immediately before the undesired outcome, that lead directly to the occurrence of the undesired outcome. The elimination or modification of a proximate cause would prevent the occurrence of the undesired outcome.

Quaternary history / geology The study of the geologic history of the Quaternary period (from present time to 2.6 million years ago). The Quaternary period includes the Pleistocene epoch (2.6 million to 10,000 years ago) during which the last glacial period occurred.

Residual strength The lowest possible strength of a soil that is reached after it has undergone large strains.

Root Cause Analysis A root cause is one of multiple factors (events or conditions) that are organizational factors that contributes to or creates a proximate cause and subsequently the undesired outcome. If a root cause is eliminated or modified, the undesired outcome would have been prevented or would not have occurred. Typically, multiple root causes contribute to an undesired outcome.

Runup The maximum vertical extent that a wave will reach above the pond elevation. Wave runup is one of the components used to calculate the required crest elevation (freeboard) of a dam.

Shear strength The greatest shear stress (pressure) that a material can sustain without failure.

Slope ratio The ratio of the horizontal component of a slope to its vertical component, usually presented in n.nH:1V format.

Slurry A mixture of tailings and process water, which is used to transport tailings to the TSF.

Site investigation Investigation of site characteristics including topography, hydrology, seismology, and foundation soil conditions through such means as testpit excavation, in situ testing, borehole drilling and laboratory analysis of soil samples.

Stratigraphy Layers of soil and/or rock.

Synoptic A comprehensive approach or model for observing systems that takes into account multiple perspectives (including different scales, different perspectives, and different points in time).

Tailings The material that is left over from the processing of ore, typically a mixture of sandy silt with a trace of clay particles.

Tailings Storage Facility (TSF) A constructed facility that is used to store tailings. Conventional facilities typically consist of one or more embankments used for tailings and reclaim pond retention.

Till General term used to describe unsorted sediment that is derived from erosion and placement from glacial movement.

Till borrow An area in which glacial till is excavated for use as structural dam fill material.

Toe The line of contact between a dam's downstream slope and the ground surface.

Undesired outcome A negative consequence of an event.

Undrained strength The shear strength that a soil exhibits when it is sheared more quickly than shear induced excess pore pressures can dissipate.

Varve A layer in a soil unit that represents a year of deposition. Varves are commonly seen in lacustrine deposits where coarser particles are deposited during the high energy spring and summer months and finer particles are deposited during the low energy fall and winter months.

Water balance A framework that describes the contributors to water flows into and out of a closed system.

EXECUTIVE SUMMARY 1

On the night of August 3-4, 2014, the dam enclosing the tailings storage facility (TSF) at Mount Polley Mine, a copper and gold mine in interior British Columbia, failed. Over the next 16 hours, the failure led to a progressive breach of the Perimeter Embankment of the dam, releasing over 21 million cubic metres of water and mine tailings into the surrounding environment and watercourses.

THE INVESTIGATION

was the largest and most complex of its kind in more than a century of regulated mining in British Columbia

Concurrent with the response taken by the mining company, the Chief Inspector of Mines took immediate actions including the launch of a formal investigation. The Chief Inspector has the statutory authority to investigate any incident that occurs on mine sites in the Province.

The investigation was the largest and most complex of its kind in more than a century of regulated mining in British Columbia. Its mandate included determining of the root and contributory cause(s) of the event and preparing findings to address the accountability of the industry, the Regulator, engineering practices, and any other contributors to the event. The investigation also determined how to reduce the risk of such an event occurring again; and made recommendations for regulatory changes for British Columbia and the mining community.

1.1. MOUNT POLLEY MINE AND TAILINGS STORAGE FACILITY

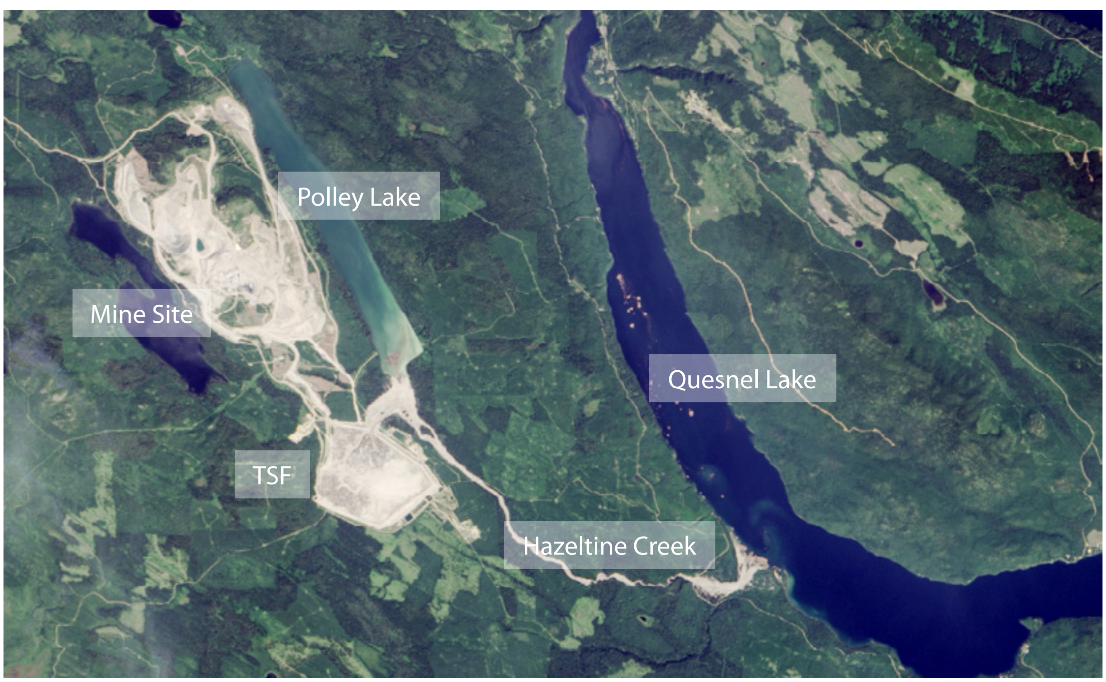

Figure 1.1 Immediate Aftermath of Breach on Hazeltine Creek, Quesnel Lake, Polley Lake NASA high-altitude imagery (August 5, 2014)

Mount Polley Mine is a copper-gold mine located in the Central Interior of British Columbia, approximately 65 km northeast of Williams Lake. The mine property is in the asserted traditional territory of the Williams Lake Indian Band and Soda Creek Indian Band. The mine is owned and operated by Mount Polley Mining Corporation (MPMC), a subsidiary of Imperial Metals Corporation. While in full operation, the mine employed approximately 400 people and processed 21,000 tonnes of ore per day. The ore was crushed and processed at the on-site mill, producing waste tailings transported as a slurry to the TSF encompassing approximately 300 hectares enclosed by an engineered earthen dam structure over 4 km long.

The mine commenced production on June 13, 1997. Mining operations continued until September 2001, when the mine entered care-and-maintenance status. Mining operations re-commenced in March 2005, continuing until the night of the TSF breach.

1.2. TAILINGS STORAGE FACILITY DESIGN

The TSF, 3 km southeast of the mill site, receives mill tailings by a gravity-driven slurry pipeline. In addition to storing tailings, the TSF serves as a collection pond for mine runoff water. Process water is recycled to the mill via a reclaim barge and pumped uphill to the mill.

The TSF was designed as a U-shaped earthen dam structure extending from rising terrain that forms the northwestern side of the impoundment. It was designed and built in a series of successive lifts, or stages, each of which raised the crest of the dam and increased its capacity. The dam, over 4 km in length and up to 50 m high, consists of three embankments: the Main Embankment (ME), the South Embankment (SE), and the Perimeter Embankment (PE).

Over the life of the facility, MPMC engaged a succession of three external engineering consultants. Knight Piésold Ltd. (KP) was the Engineer of Record (EoR) for the TSF from the feasibility design stage through 2010. AMEC Foster Wheeler (AMEC) took over in January 2011, and BGC Engineering Inc. (BGC) was intended to become the EoR following completion of Stage 9 later in 2014.

1.2.1. FOUNDATION SOILS

Site investigations in the vicinity of the TSF were carried out during initial design and continued during some of the subsequent development stages. These investigations were performed for a variety of purposes including embankment foundation characterization, borrow source determination, basin liner delineation, hydrological monitoring and instrumentation installation. The investigations consisted of test pitting and drilling by a variety of methods. A series of site investigations was conducted by the mine and its consulting engineers from 1989 to 2011.

The foundations soils were identified as interlayered glacial tills, glaciolacustrine (GLU) soils, and glaciaofluvial (GLF) soils, overlying bedrock. The site investigations included three deep sample drillholes in the 2-km length of the PE. The GLU was characterized as a stiff, overconsolidated silty clay.

1.2.2. STABILITY CALCULATIONS

Stability analysis measures the robustness of an embankment, calculating the Factor of Safety (FoS). Calculated through complex mathematical models based on the characteristics of the component materials of the dam itself, as well as the soils that comprise its foundation, the FoS quantifies the amount of strength required to resist failure built into a structure. A FoS of 1.0 (or unity) suggests that failure is imminent or in progress.

Both KP and AMEC calculated stability to comply with Canadian Dam Association (CDA) guidelines, based on two key assumptions: maintenance of a FoS of at least 1.3, and a foundation strength based on site investigations that identified the stiff, overconsolidated GLU. Based on their understanding of geotechnical conditions, the calculated FoS for the PE was 1.5 or greater.

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1.2.3. DESIGN ELEMENTS

The design of a TSF requires the integration of storage capacity for tailings and water; water management; geotechnical and environmental considerations; availability of construction materials; and site characteristics such as topography, climate, and seismology. In the case of Mount Polley, key considerations also included the following:

WATER BALANCE. Engineers had initially forecast a net water deficit for the mine; the projected deficit became a water surplus, which could not be treated and discharged, leading to a pond volume of 10.1 Mm^3 at the time of the failure.

BEACHES. The design included an expectation that tailings beaches would be maintained adjacent to embankments enclosing the TSF. Beaches can serve as a buffer to maintain separation between water in the tailings pond and the embankment structure.

EMBANKMENT ZONATION. Dam design utilized a zoned construction approach, with a core (Zone S) consisting of compacted glacial till; an upstream section (Zone U) comprising compacted tailings and mixed fill as required; and a downstream rock shell (Zone C). Between the core and the rock shell were two additional filter zones to drain excess water away from the core (Zones F and T).

1.3. CONSTRUCTION CHRONOLOGY

The TSF was designed to be built and permitted in stages over the life of the mine, with each stage driven by a number of variables, including mine plan, milling process water requirements, storage capacity for tailings, and storage capacity for mine-influenced water. The stages were also dependent on a sufficient supply of construction materials (quarry or run-of-mill rock) as well as construction capacity, including adequate time in a construction season and logistics limitations such as equipment availability or weather constraints.

The Ministry evaluated and issued permits under the *Mines Act* for each successive stage of construction. Periodic inspections by MEM geotechnical inspectors were conducted at the site.

1.3.1. CHRONOLOGY OF CONSTRUCTION STAGES

Stage Ia to 931m – 1995-1996. The initial *Mines Act* permit for Mount Polley Mine, issued August 3, 1995, approved the construction of a starter dam for the TSF to an elevation of 931 m, an embankment with a maximum height of 11 m.

Stage Ib to 934m – 1996-1998. The planned raise to an elevation of 934m was approved on September 23, 1996.

Stage 2 – 1998-2000. An application for a *Mines Act* permit amendment to raise the dam to 940 m was approved on April 7, 1998.

Stage 3 – 2000-2001. Stage 3 was approved on June 13, 2000, allowing a raise to 944 m. An additional *Mines Act* permit amendment application for Stage 3, to increase the raise to 945 m, was approved May 30, 2001.

Care and Maintenance – 2001- 2005. Mine operations were suspended in October 2001 and the mine was placed in care-and-maintenance status. Over the course of the closure, substantial water accumulated in both the pits and the TSF.

Stage 4 – 2005-2006. A restart permit was issued May 4, 2005. The accompanying application to raise the dam to 948 m was approved on May 25, 2005.

Stage 5 – 2006-2007. An application for a Stage 5 raise of the dam to 951 m was approved on August 2, 2006.

Stage 6a – 2007-2008. The Stage 6 raise planned for an elevation of 958 m was issued a *Mines Act* permit amendment on February 9, 2008, and resulted in a raise to 954 m.

Stage 6b – 2009-2011. The second year of construction completed the Stage 6 raise to 958 m.

Stage 7 – 2011-2012. An amendment application to raise the dam to 960.5 m was approved August 15, 2011.

Stage 8 – 2012-2013. The application for the Stage 8 raise to 963.5 m was approved on June 29, 2012. In the same construction season, an additional application amending the Stage 8 raise to 965 m was approved October 15, 2012.

Stage 9 – 2013-2014. The application for a Stage 9 raise to 970 m was approved August 9, 2013.

Stage 10 (Planned) – 2014. A Stage 10 design was produced, and a *Mines Act* permit amendment application was submitted, but no Stage 10 raise was commenced due to the failure of the TSF embankment.

The Stage 10 raise was planned to achieve a crest elevation of 972.5 m, raise the buttress along the ME, and add a buttress along the full length of the PE.

The chronology of each stage of the TSF is presented in Chapter 6.

1.3.2. THE PERIMETER EMBANKMENT PRIOR TO THE FAILURE

The design profile of the PE at the close of Stage 9 (at the time of the failure) is shown in Figure 1.2. The elevation of the crest is 970 m; the height of the embankment at its highest point (where the breach occurred) is approximately 40 m, and the downstream slope is at 1.3H:1.0V.

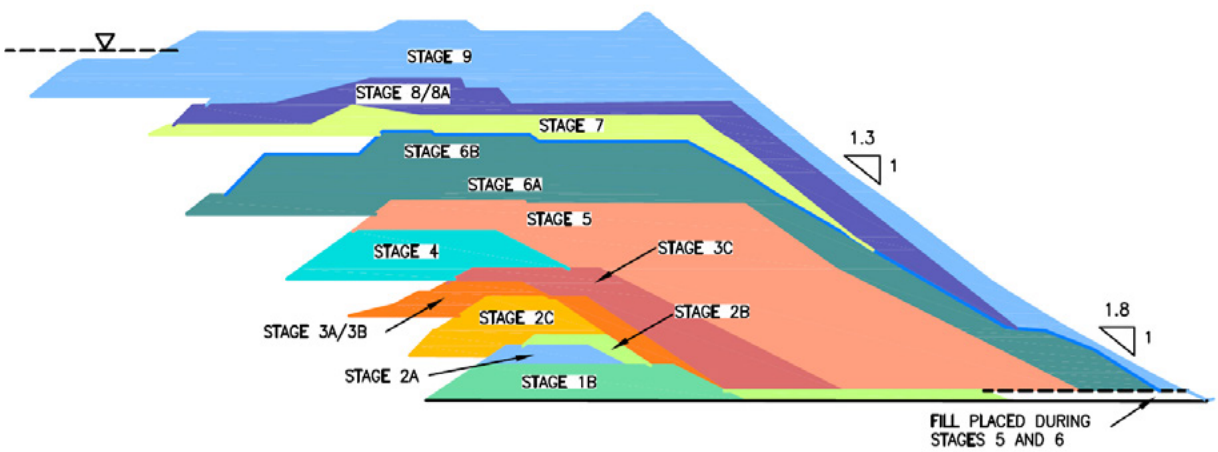

Figure 1.2 Embankment Stages Appendix 3, Fig. 2.6

1.4. GEOTECHNICAL CONDITIONS

Post-failure site investigation and laboratory analyses revealed a complete picture of the characteristics of foundation soils in the area of the breach. These investigations characterized a previously unrecognized clay/silt layer, the upper glaciolacustrine unit (UGLU).The UGLU was deposited in the period between glaciations of the region in a glacial lake. The history of the UGLU, the amount of consolidation it received (by pressure from above caused by a glacier advancing over the UGLU), and the level of attention it received from engineering consultants all plays a significant role in the dam failure event.

This clay layer was shown to have a higher moisture content, higher plasticity, higher clay content and higher liquidity index (indicating less overconsolidation) than the lower glaciolacustrine unit (LGLU), a layer that was identified during initial site investigations and used in all subsequent stability calculations. To the extent the foundation conditions were revealed by post-breach site investigations, the UGLU was largely confined to the area of the failed embankment.

Limited site investigation, first during the initial design and subsequently at each progressive lift stage, did not reveal this layer of weaker glaciolacustrine clays roughly 10 m beneath the ground surface. Neither its potential presence nor its strength was taken into account in any stability analyses conducted pre-breach, so the Factor of Safety (FoS) values calculated by these analyses were intrinsically in error. As the dam height increased, the forces exerted by the dam exceeded the resisting forces of the UGLU.

1.5. MECHANISM OF FAILURE

The dam failed by sliding on the UGLU. The weight of the 40 m high tailings dam subjected the UGLU to vertical stresses up to 800 kPa and substantial portions of the UGLU beneath the dam were loaded to stresses well above the pre-consolidation pressure.

The shear strength of the UGLU is controlled by the higher plastic zones within the clay layer. The UGLU is also a strain-weakening material which loses appreciable strength when deformed past its peak strength, in both drained and undrained loading conditions. The strain-weakening nature of the UGLU was observed in direct shear tests, direct simple shear tests and undrained triaxial compression tests.

1.6. CAUSES OF THE EVENT

Applying the concepts and tools of Root Cause Analysis (RCA), the Chief Inspector determined the root and contributory causes of the breach event. RCA helps determine not only *what* happened and *how* it happened, but also *why* it happened. It also identifies absent or deficient defenses that could have prevented or mitigated the undesired outcome.

A root cause is an organizational factor that contributes to or creates a direct cause of a failure (an "undesired outcome"). If a root cause is eliminated or modified, the undesired outcome would be prevented. Typically, multiple root causes contribute to an undesired outcome.

RCA recognizes that most complex engineering failures do not exhibit a simple linear process, but tend to result from a complex system of factors and their relationships.

1.6.1. ROOT CAUSES OF THE EVENT

RCA exposed two discrete undesired outcomes at Mount Polley: the breach of the dam, which resulted in the uncontrolled release of water and tailings into the environment; and a structural failure of the embankment, which itself was one direct cause of the breach.

The breach required a second direct cause in order to be triggered: the conditions of insufficient beaches and surplus water in the TSF. Both causes, the structural failure and the lack of beaches/surplus water, were necessary to cause the breach event.

Three causal conditions were necessary to trigger the structural failure of the PE, and include the weak clay of the UGLU, an open sub-excavation at the embankment toe, and geometry of the embankment (too steep/too high).

THE DAM FAILURE MECHANISM WAS GEOTECHNICAL:

sliding failure on a weak clay layer 10 m below the surface

THE DAM BREACH MECHANISM WAS HYDROLOGIC:

insufficient beaches to protect the embankment from the surplus of water in the tailings pond once the embankment failed

THE ROOT CAUSES OF THE EVENT WERE ORGANIZATIONAL:

mistaken belief that adequate foundation studies were completed -- misplaced faith in the Factor of Safety that resulted -- overconfidence in the reliance on professional judgement -- narrow planning perspective in mine management -- failure to adequately understand and act on risk

In addition to these direct (or "proximate") causes of the failure and breach, a number of defenses were either defeated or not present. A defense can intervene and break a causal chain, mitigating or preventing an undesired outcome.

Failed defenses include site investigations that were not conducted with sufficient detail, requests by the Regulator for information or clarification that were discounted, adequacy of site supervision and risk identification, missing procedures, misplaced confidence, mistaken belief, and organizational voids in key management areas.

1.7. FINDINGS OF THE CHIEF INSPECTOR

It is the responsibility of the Chief Inspector of Mines to make formal determinations regarding any event investigated pursuant to the *Mines Act*. A finding is a considered, objective conclusion issued by the Chief Inspector based on his assessment and consideration of the facts and analyses conducted as part of the investigation.

IT IS THE FINDING OF THE CHIEF INSPECTOR THAT:

1 a structural failure of the Mount Polley Mine tailings storage facility Perimeter Embankment occurred at approximately 11:40 pm on August 3, 2014; that the failure led to a major and ongoing erosion breach at approximately 1:08 am on August 4, 2014; and further that the breach resulted in uncontrolled release of tailings and process water into the environment.

2 undesired consequences beyond the mine site resulted directly from the breach, affecting the environment, the mining industry, First Nations, and the citizens of British Columbia.

3 the structural failure of the embankment occurred because of three proximate causes: an uncharacterized glaciolacustrine unit in the native soil foundation of the dam structure; an over-steepening of the downstream slope of the dam, coupled with the constructed height; and an unfilled excavation at the toe of the embankment at the site of the failure.

4 the mechanism of the structural failure was a sliding failure through the lightly overconsolidated glaciolacustrine clay unit (UGLU) located approximately ten metres into the foundation. The failure caused the embankment crest to drop approximately 5 metres, and can be considered the initiating event of the breach of the tailings dam.

5 MPMC and its engineering consultants did not fully recognize and manage geotechnical and water management risks associated with the design, construction, factor of safety, and operation of the tailings storage facility.

FINDINGS RELEVANT TO FOUNDATION SOILS

6 adequate studies of the embankment foundation were not conducted on the Perimeter Embankment, and site investigations for the Perimeter Embankment did not meet generally accepted standards of practice for embankment structures. There was an assumed degree of certainty that the foundation soils were dense and strong, which was not supported by a robust understanding of the foundation characteristics.

7 initial site investigations at the Perimeter Embankment foundation did not include adequate geotechnical characterization of soils at depth, and further, no subsequent site investigations were conducted on the Perimeter Embankment until 2011; drillholes were widely spaced and were principally for the placement of instrumentation and the assessment of lower glaciolacustrine soils.

8 although the upper glaciolacustrine unit (UGLU) was detected during site investigations, its significance remained unrecognized, and the risk associated with the extent and characterization of strength of this layer was a proximate cause of the embankment failure. Multiple opportunities to review and characterize the foundation soils arose, either in response to queries by Government inspectors, or available in extant drillcore records; but these opportunities were unnoticed, ignored, and/or discounted.

FINDINGS RELATED TO SUPERNATANT WATER AND BEACH ADEQUACY

9 the structural failure of the embankment alone did not cause the breach, but coupled with the condition of the tailings pond — with insufficient beaches and too much supernatant water — a progressive erosional failure of the embankment rapidly widened into a complete breach.

10 adequate beaches could not be continuously maintained primarily as a result of surplus supernatant water.

11 an adequate water management plan did not exist. Mount Polley Mining Corporation failed in its management of the water balance with respect to long term planning, including site integration, effective treatment, discharge plans and permits. There was no qualified individual responsible for the water balance, and MPMC did not adequately characterize the risk of surplus supernatant water, which had been compounding since the mine reopened in 2005.

FINDINGS RELEVANT TO MPMC MANAGEMENT

12 it was the responsibility of Mount Polley Mining Corporation to maintain a safe structure, irrespective of the Mine's reliance on external geotechnical engineering expertise. Mount Polley Mining Corporation did not meet this responsibility.

13 delegation of engineering tasks to a contractor with the skills, knowledge, and abilities to perform a required task — even when the contractor is licensed and regulated as a professional engineer by APEGBC — does not release the Permittee from this responsibility. The responsibility resides with the mine; it cannot be delegated.

14 Mount Polley Mining Corporation did not recognize the risk of the excavation for the buttress foundation, resulting in a small reduction in the FoS. This work was not recognized as a substantial departure from the approved work plan by MPMC, and the Chief Inspector was not notified.

15 Mount Polley Mining Corporation did not identify or manage risks associated with changing Engineers of Record at the tailings storage facility.

16 concerns regarding steep slope, dam construction material availability, buttress subexcavation, and supervision were identified by employees but not elevated for action by MPMC management.

17 the mine failed to conduct a risk assessment, in accordance with *Towards Sustainable Mining* (TSM) guidelines developed by the Mining Association of Canada (MAC), which may have been sufficient to identify concerns about the steep geometry, the toe sub-excavation left open and unfilled, and the absence of sufficient site investigations.

FINDING RELEVANT TO MEM

18 the Regulator works within the bounds of professional reliance; but the implementation of professional reliance is not adequately structured or formalized in policy.

1.8. LESSONS LEARNED

In addition, the Chief Inspector recognizes the opportunity to learn, benefit and evolve from the hard-earned lessons of the Mount Polley TSF failure of August 4, 2014. The Chief Inspector identified a number of such lessons for the benefit of the mine operator, the mining industry, associated professional organizations, and the Regulator itself. These lessons are presented in Chapter 12.

1.9. RECOMMENDATIONS OF THE INVESTIGATION

The Chief Inspector has developed a series of seven recommendations on the basis of the investigation directed toward the mining operator (MPMC), mining industry, professional organizations and the regulator.

1.9.1. RECOMMENDATIONS FOR THE MINING OPERATOR

RECOMMENDATION 1: PROPONENT GOVERNANCE

Recommendation 1-1: Mine Dam Safety Manager

Any mine with tailings storage facilities (TSFs) should have a qualified individual designated as a mine dam safety manager responsible for oversight of planning, design, operation, construction and maintenance, and surveillance of the TSF, and associated site-wide water management. The individual must possess the requisite knowledge, skills, and abilities to perform these responsibilities. Functions of this role may include coordinating relevant parties involved with the TSF (*e.g.*, consultants, contractors); ensuring appropriate approval of all activities has been obtained; maintaining compliance with applicable permit conditions, *Mines Act*, and Code; life-of-mine planning for water, waste and tailings management; site integration; integration of the OMS and MERP; and consideration of potential factors that may influence tailings dam safety.

A qualified individual in this this role may prevent a TSF failure or breach by anticipating, recognizing and preventing conditions from developing that could impact the safety of the tailings dam.

Recommendation 1-2: Water Balance Management

Water management and water balance issues for mining projects must be designed by a qualified professional. These issues require the integration of relevant mine departments. Mine operators should designate a responsible qualified individual to oversee site-wide water management and water balance.

A qualified professional design and a qualified individual to oversee the water balance and water management plan will be able to anticipate site conditions and long-term considerations towards water management. Effective water management may prevent a structural failure from developing into a breach.

Recommendation 1-3: TSF Operations, Maintenance and Surveillance Manual

The mine manager should ensure the Operation, Maintenance and Surveillance manual (OMS) required by the Code for all impoundments adheres to applicable CDA and MAC guidelines. Additional guidance for the OMS should include incorporation of an annual risk assessment/risk management plan and relevant findings of an independent technical review board. The OMS emergency response section should be written so that it can be effectively utilized during an emergency, and should be integrated into the Mine Emergency Response Plan (MERP).

An effective and well-implemented OMS will make all related personnel more attuned to hazard identification and mitigation, knowledgeable in potential downstream consequences, and capable in emergency response.

Recommendation 1-4: Mine Emergency Response Plan

The mine manager must ensure that the Mine Emergency Response Plan (MERP) adheres to applicable regulations, is maintained on a regular basis for currency, incorporates appropriate response measures to emergencies including those involving the TSF, and is written and distributed in such format as to serve as a procedural guide during an emergency or other event. Site emergency response plans should be practiced and integrated across possible eventualities on the mine site allowing for coordination of resources. Training should also be provided to improve effective emergency response.

An effective MERP gives responding site personnel an actionable plan to implement during an emergency, which can be instrumental in protecting lives and the environment.

Recommendation 1-5: Risk Recognition and Communication

All mine personnel have a role to play in recognizing and reporting risk conditions, especially those that could affect health, safety and environmental protection; and should be educated in the recognition of conditions and events that could impact TSF safety or contravene applicable permit conditions and regulations.

An effective reporting mechanism for employees' safety or environmental concerns on the mine site (whether directly or anonymously) should be established, implemented and monitored.

Personnel educated in risks associated with TSF-related activities can offer ongoing insight into conditions that may compromise the safety of the structure.

1.9.2. RECOMMENDATIONS FOR THE MINING INDUSTRY

RECOMMENDATION 2: TSF DESIGN

Recommendation 2-1: Design Objectives

Tailings storage and water management systems and structures should be designed for worker and public safety and the protection of the environment. TSF design should incorporate a comprehensive feasibility assessment that considers technical, environmental, social, and economic aspects of the mining project in sufficient detail to support the submitted design. An assessment of the applicable best available technologies and best available practices for the project should be incorporated into the design considerations to reduce the risks associated with the TSF for life-of-mine from construction to post-closure.

Design based on a comprehensive feasibility assessment will reduce the likelihood of unexpected conditions developing that could negatively impact the safety of the structure.

Recommendation 2-2: Independent Technical Review Board

Mines with impoundments should each develop independent technical review boards (ITRB) to provide additional perspectives on site investigation, site selection, design, construction, maintenance, operations, surveillance, water management and closure. The ITRB's review should provide additional oversight to include BAP/BAT for tailings storage and water management. The ITRB would include one or more individuals with appropriate engineering expertise with similar structures; and its opinions should be integrated into the mine's TSF management system. The requirement for an ITRB should be determined and incorporated into the Code.

ITRBs will strengthen oversight and risk management by providing review, professional opinion, and feedback to the EoR and the mine regarding the TSF.

1.9.3. RECOMMENDATIONS FOR PROFESSIONAL ORGANIZATIONS

RECOMMENDATION 3: PROFESSIONAL AND ASSOCIATION STANDARDS

Recommendation 3-1: Professional Reliance Standards

The Chief Inspector recognizes the necessity of reliance on professional practice for the design, construction, operation and closure of mines and mine facilities. The Regulator does not design the mine or associated structures, and thus is reliant on the professional practice of the designer.

Reliance on professional practice requires that the organizations overseeing the professionals or developing guidelines and standards for the professional community incorporate best available practices into their oversight. Organizations supporting such standards include:

Association of Professional Engineers and Geoscientists of BC (APEGBC). Responsibilities include professional practice guidelines. APEGBC should develop specific practice guidelines for site investigation, roles and responsibilities of the Engineer of Record (EoR), standards of practice for transfer of EoR, especially when the transfer involves changing engineering companies, and standards for engineering presence on site during construction.

Mining Association of Canada (MAC). Responsibilities include participatory guidelines applicable to tailings and water management, including applicable safety, operations, design, construction, surveillance, and planning; and corporate governance standards of practice. MAC should review existing guidelines to define the roles and responsibilities of the mine dam safety manager, and should develop guidance on what is required to document the tailings management system such that it can be audited by a qualified third party such as the International Standards Organization (ISO).

Canadian Dam Association (CDA). Responsibilities include the ongoing development of design guidelines for water and mining dams. CDA should update safety guidelines to reduce ambiguity, and develop specific guidelines for mining embankments which recognize the continued changes and raises during the life of the TSF and the consequence classification associated with a tailings dam failure.

Strengthening standards of practice will enable better design, construction, and operation of impoundments, improve governance, and establish benchmarks to evaluate these practices.

Recommendation 3-2: Integration of Standards

The Regulator should consider and incorporate as appropriate guidelines from these external associations as applicable and consistent with MEM objectives.

The Regulator will be able to incorporate improved standards and guidelines to better align with appropriate professional and industry practices.

1.9.4. RECOMMENDATIONS FOR THE REGULATOR

RECOMMENDATION 4: REGULATOR FUNCTIONS

Recommendation 4-1: Review of the Code

MEM should undertake a comprehensive review of the Code to ensure that the lessons learned and recommendations from this report are fully considered and appropriately incorporated; and that all relevant standards and guidelines from external bodies (such as MAC, CDA, and APEGBC) are fully considered in the review as appropriate.

Enhancements to the Code will assist the inspectorate in the enforcement of necessary management and engineering standards and guidelines.

Recommendation 4-2: Life-of-Mine Planning for Permitting

Short-term, incremental *Mines Act* permit amendment applications can obscure life-of-mine conditions and long-term risks. The Regulator should ensure a perspective that spans the life of the mine be considered for *Mines Act* permit applications, while acknowledging that the nature of mining frequently requires changes to the life-of-mine plan.

Requiring life-of-mine planning in TSF design and the permitting process will enhance the robustness of the overall design of proposed structures.

Recommendation 4-3: Investigation, Compliance and Enforcement Review

The Regulator must enhance its investigative capacity, as well as its ability to exercise its existing compliance and enforcement authority under the *Mines Act* and Code. A supported director-equivalent position specific to investigation, compliance and enforcement should be established to evaluate and oversee these roles. This oversight should extend to applying recommended standards to the Regulator's compliance and enforcement function. A full range of regulatory tools, such as incentives, administrative penalties, outside agency collaboration and other best practices should be considered.

Improved investigative and enforcement capacity will enhance the ability of the Chief Inspector to increase compliance and achieve greater safety at mines, improve industry practices, and lead investigations in the future.

Recommendation 4-4: Geotechnical Oversight

The Regulator has a responsibility to oversee the decisions of the EoR. The Regulator must maintain sufficient technical capacity to conduct appropriate oversight of the professional opinions on which it relies. A Regulatory Dam Safety Manager dedicated to the coordinated regulatory oversight of tailings dams in the Province could be responsible for ongoing policy development, technical review, and inspection capacity as it relates to tailings impoundments.

Effective oversight of professional reliance in the design, maintenance, and operation of tailings impoundments will increase compliance with engineering and operational standards, reducing risk in tailings storage facilities across mines in the Province.

Recommendation 4-5: Organizational Review of Inspectorate

There exists an ongoing need to adequately support the increased tempo of review, monitoring and inspection that would be placed on MEM's inspectorate. It is recommended that a comprehensive internal review of operational and business practices be conducted.

An organizational review of the Inspectorate is warranted by the scope and urgency of the recommendations of this report, and will strengthen MEM's ability to fulfill the Chief Inspector's obligations to the citizens of BC.

RECOMMENDATION 5: STRENGTHENING RECORDS MANAGEMENT

Recommendation 5-1: Internal Records Management

A formal MEM management system of documentation for all mines from development to post-closure should be established. The system will assist the Chief Inspector in integrating regulatory oversight capabilities; assist with investigation, project tasking, formal documentation and indexing; and enhance the ability of MEM to meet the expectations for transparency and appropriate disclosure within the limits of privacy considerations.

An effective records management system will support long-term, integrated decision making by the Regulator, the permittee and consulting professionals.

RECOMMENDATION 6: REGULATORY INTEGRATION

Recommendation 6-1: Alignment of Regulatory Objectives

Agency objectives (environmental protection, worker health and safety, facilities integrity) overlap but are not always integrated. MOE and MEM interests, disciplines and standards should be reviewed for alignment opportunities to support timely and effective program outcomes while optimally fulfilling the mandates of both agencies.

Recommendation 6-2: Permitting Process Alignment

Separate permitting processes for MEM and MOE should be reviewed for opportunities to integrate and align these processes as appropriate to avoid duplication and increase efficiencies. There should be a mechanism to flag each agency's participation in the process to ensure that risks, such as those related to the discharge permitting process, are adequately characterized and prioritized.

RECOMMENDATION 7: FOSTERING INNOVATION

Recommendation 7-1: Collaborative Education

MEM, the industry, professional organizations, and educational institutions should continue to seek new collaborative opportunities to foster education (including formal academic, onsite or online employee-focused, public-facing, and professional continuing education). This initiative could include the availability of standards for education to better define the knowledge, skills, and abilities for various accountabilities within mining; and to increase the knowledge base, information sharing, and innovation. MEM could ensure that resources are allocated to enable the implementation of this objective.

Recommendation 7-2: Research and Development

Current technologies in tailings processing, dewatering, and discharge water treatment have not achieved a sufficient level of technical and economic feasibility in many projects. Both government and industry should support research and development efforts to improve these technologies for practical application.

1.10. NEXT STEPS: TOWARD A SAFER MINING INDUSTRY IN BC

As government, industry and others prepare to respond to the Chief Inspector's recommendations, action in response to the Mount Polley TSF breach is already under way. For example, the Province has accepted all the recommendations of the Independent Expert Engineering Panel and has begun working with the mining industry, unions and First Nations to conduct a major review of the Code. The review is focused on a number of areas, including:

- Application of best available technologies (BAT) and best available practices (BAP) in mining
- Enhancing validation of safety and regulation of all phases of a TSF
- Improving dam safety and TSF management requirements

The BC Environmental Assessment Office has established additional requirements for evaluating tailings management options for proposed major mines in BC. It has also taken steps to ensure that best available technologies will be part of the environmental assessment process.

All mines in the Province were ordered to conduct accelerated Dam Safety Inspections and assess the safety of their impoundments. APEGBC, which represents professional engineers and geoscientists, is developing professional practice guidelines for dam site characterization assessments, to help ensure that future dams are built to consistent safety standards. CDA and MAC are likewise moving forward with revisions to their guidelines.

These steps suggest that all affected parties are willing and able to work together to act on the lessons learned from the Mount Polley dam breach, helping to improve the safety of workers, communities, First Nations, and the environment.

The recommendations of the Chief Inspector will continue to focus the attention and commitment of Government and the mining community to build a safer, more sustainable industry in BC.

INTRODUCTION 2

On the night of August 3-4, 2014, the dam enclosing the tailings storage facility at Mount Polley Mine, a copper and gold mine in interior British Columbia, failed. Over the next 16 hours, the failure led to a progressive breach of the dam, releasing over 21 million cubic metres of water and mine tailings into the surrounding environment and watercourses.

The release washed away a forested area and flowed upstream into Polley Lake, creating a debris plug at the outlet of the lake, which raised the lake level by approximately one metre. The nearby Hazeltine Creek, a narrow creek connected to the outlet of Polley Lake, was scoured into a 150-metre wide mudflow stretching 7 km to Quesnel Lake. The discharge created a new delta at the outflow of the creek on the shore of Quesnel Lake, one of the deepest lakes in the province, and introduced a turbidity plume of tailings slurry to the lake.

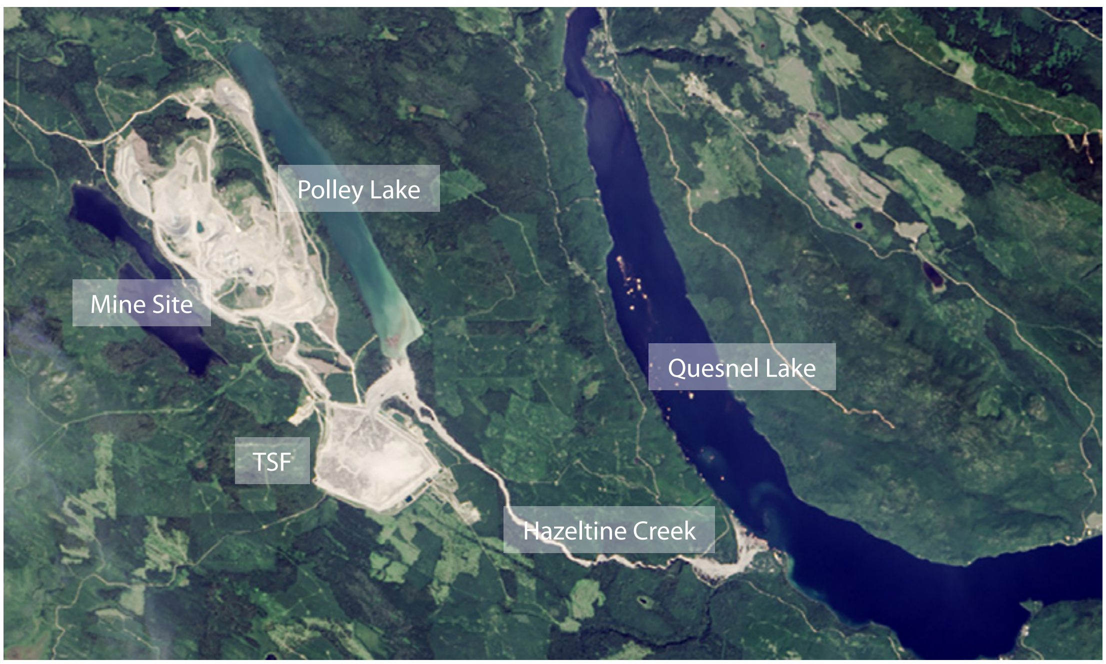

Figure 2.1 *Immediate Aftermath of Breach on Hazeltine Creek, Quesnel Lake, Polley Lake NASA high-altitude imagery (August 5, 2014)*

The failure of the dam took place suddenly, without any warning signs. The failure of the embankment led to a breach of the dam, which became uncontrollable in less than two hours. In the ensuing days and weeks, as the mine ceased operations and began the challenge of stabilizing the immediate surroundings and assessing the environmental damage, the full scope of the event began to take shape. Imperial Metals Corporation, the owner of Mount Polley Mining Corporation (MPMC), estimates that between 21 and 25 million m^3 of discharge was released in the breach, including 10 million m^3 of process water stored in the tailings storage facility (TSF). Both Polley Lake (upstream from the dam breach) and Quesnel Lake were impacted by the debris flow; tailings and debris were introduced into recreational and drinking waters; and the public's confidence in the industry and government oversight were shaken severely.

VOLUME OF DISCHARGE

between 21 and 25 million cubic metres of water and tailings were released in the breach

2 INTRODUCTION

Concurrent with the response by the mining company, the Chief Inspector of Mines took immediate actions including launching a formal investigation. The Chief Inspector has the statutory authority to investigate any dangerous occurrence on mine sites in the province. The investigation of the Mount Polley Mine dam breach is the largest and most complex ever conducted by the Ministry of Energy and Mines in more than a century of regulated mining in British Columbia.

The investigation mandate included a determination of the root cause(s) of the event; any contributory causes; and the preparation of findings that address the accountability of the industry, the regulator, engineering practices, and any other contributors to the event. The Chief Inspector's intent was to determine how to reduce the risk of such an event occurring again, make recommendations for regulatory changes for British Columbia and the mining community.

This document and its accompanying appendices comprise the final report of the investigation of the Chief Inspector.

2.1. MOUNT POLLEY MINE

Mount Polley Mine is a copper-gold mine located in the Central Interior of British Columbia, approximately 65 km northeast of Williams Lake (see Figure 2.2). While in full operation, the mine had approximately 400 employees and processed 21,000 tonnes of ore per day from both open pit and underground works. The ore is crushed and processed at the on-site mill, producing a copper-gold concentrate using selective flotation. The process produces waste tailings, which are transported as a slurry to the tailings storage facility (TSF) encompassing approximately 300 hectares enclosed by an engineered earthen dam structure over 4 km long.

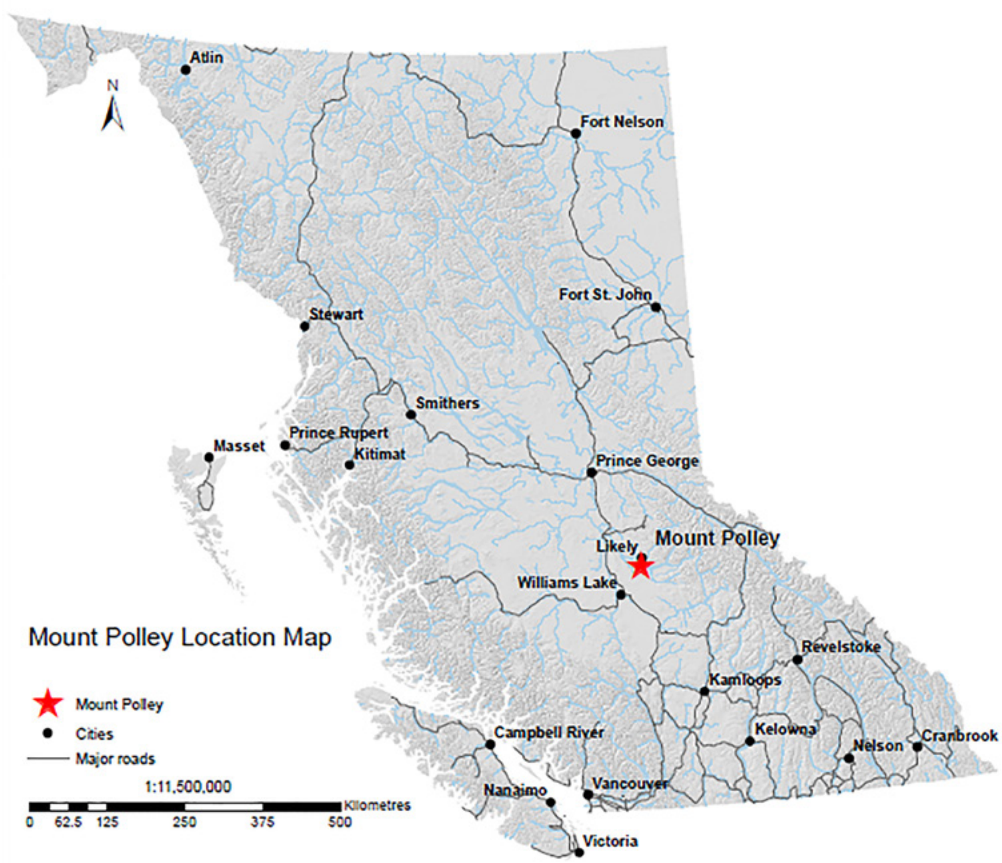

Figure 2.2 Locator Map of Mount Polley Mine

2.2. INVESTIGATING COMPLEX SYSTEMS

Complex systems – such as those involved in the operation and oversight of a large mine – exhibit complex cause-and-effect relationships. These relationships can be identified to describe the physical causes of a failure in an engineered system. Determination of what occurred at the Mount Polley TSF is outlined well in both the *Assessment of Failure Mechanism*, March 23, 2015 by Klohn Crippen Berger, appended to this report; and the *Report on Mount Polley Tailings Storage Facility Breach*, published by the Independent Expert Engineering Investigation and Review Panel, dated January 20, 2015.

Identifying why the TSF was breached requires further exploration of the complex organizational relationships within the system. These factors may include professional reliance, regulations, accepted practice, behaviours of multiple individuals, and program oversight. The more layers, the more interwoven and complex the relationships become. With more complexity comes the increased possibility to misunderstand interactions or impacts of these relationships on the whole, or to fail to recognize signs of a hazard altogether.

Designers, builders, operators, and users within complex engineered systems often unknowingly have access only to incomplete information or a limited understanding of the information. As such, system conditions may elicit complacent responses to unrecognized warnings due to an ongoing misplaced faith in the design or system.

The discipline of systems engineering has evolved to address complex systems in an effort to eliminate — or at least mitigate the damage from — failures of the system. And as systems become more complex, the potential routes of failure also become more complicated.

Notable engineering failures of the last century such as the Challenger space shuttle explosion, the 1940 collapse of the Tacoma Narrows Bridge, and Three Mile Island all occurred because of multiple points of unrecognized weakness in the system. These disasters featured a layering of failures of material properties that were not known or well understood; failure of the system to be built with a sufficient safety factor; failures of the human operators of the system to adequately respect the risks inherent in the system's operation, often characterized by a mistaken belief in the robustness of the design or construction; complacency in the performance of routine maintenance; lack of understanding of how altering inputs to the system – often in an obscure or marginally connected corner of the structure – could affect the whole; and finally, faith in the mechanical barriers engineered into the system, leading to unwarranted exposure to harm when those barriers were circumvented or misunderstood.[1]

Another common trait in structural or systems failures over time is the cascading nature of the failure itself. Rarely is there a single physical failure in isolation. One event or condition will trigger or enable another, with specific impacts emerging from each one.

Recognizing these realities, Root Cause Analysis was developed as a means of examining engineering failures by isolating the events, conditions, causes, and contributing causes of the failure chain. Root Cause Analysis tends to define the root, or fundamental, causes of a failure as *organizational* in nature — that is, the most fundamental causes of an event are based in human or organizational behaviours rather than in physical properties of materials or limitations of systems. The Mount Polley TSF investigation made extensive use of the discipline and structure of Root Cause Analysis (see Chapter 10).

The investigation exposed the same characteristics shared by historic engineering failures: a mix of physical material properties and human responses to a complex structure, relationships and information; lack of understanding of the impacts of actions and events on the system as a whole over time; complacency or mistaken faith in the design; and a cascading of events and conditions. All of these factors led to the ultimate breach and release of the contents of the Mount Polley Tailings Storage Facility on August 4, 2014.

2.3. ORGANIZATION OF THE REPORT

This report contains three principal components: narrative and historical, analytical, and forward-looking. Chapters 3 through 9 present a review of factual data collected by the investigation. Chapter 3 describes the organization, authority, and structure of the investigation itself. Chapter 4 provides a background and overview of Mount Polley Mine. Chapters 5 and 6 describe the history of the TSF, from design through its construction chronology from 1995 to 2014. Chapter 7 summarizes the extensive assessment of knowledge on the geotechnical characteristics of the site and the foundation of the embankment structure. Chapter 8 is a description and timeline of the breach event and its immediate aftermath. Finally, Chapter 9 provides an engineering assessment of the mechanism of failure of the TSF.

The report's analytical elements build on the factual data gathered to achieve an understanding of the root causes of the failure. Using the discipline of Root Cause Analysis, Chapter 10 describes the chain of events and conditions that contributed to the failure, back to root causes; and uncovers failed or defeated defenses that could have contained the event at multiple points in the causal chain. Chapter 11 describes the findings of the Chief Inspector with respect to the breach event.

Finally, the report assesses the breach and its impacts into the future. Chapter 12 outlines the broader impacts, and reviews the lessons we can learn from the event. Chapter 13 concludes the report with recommendations addressed to the mine owner, the mining industry, the geotechnical engineering community, and Government.

Attached as Appendix 1 is a review of the actions of the Chief Inspector relating to both Mount Polley Mine and the preventive measures taken in similar tailings facilities across BC in the period following the breach. Also included as appendices are two engineering documents prepared by Klohn Crippen Berger, *Mount Polley tailings dam failure: Assessment of failure mechanism* report (Appendix 2) and *Mount Polley tailings dam failure: A summary of opinions in support of CIM investigation report* (Appendix 3).

Also incorporated into this report are the original texts of all references cited. To the extent permitted by law, these documents are accessible at the following website: *www.gov.bc.ca/mountpolleyinvestigation*

FOOTNOTE

1 *Presidential Commission on the Space Shuttle Challenger Accident (1986)*

ORGANIZATION OF THE INVESTIGATION 3

Upon notification of the dam breach by Mount Polley Mine to the Ministry of Energy and Mines on August 4, 2014, Chief Inspector of Mines Al HOFFMAN, P.Eng., initiated a formal investigation of the event. The investigation was governed by the *Terms of Reference* developed by the Chief Inspector.[1]

3.1. STATUTORY AUTHORITY

The Chief Inspector is the authority whose primary mandate is "to ensure worker health and safety, public safety and reclamation and protection of the land and watercourses affected by mining and exploration in B.C."[2] The position and its authority are authorized under the *Mines Act (RSBC 1996, c. 293)*.

The Chief Inspector is specifically authorized to:

- have full access to all parts of the mine property;
- lead the investigation;
- obtain testimony from any witnesses, company officials, employees, or third parties;
- compel the conveyance of any documents or other things deemed relevant to the investigation;
- issue findings of contravention of the *Mines Act, Regulation, Health, Safety and Reclamation Code for Mines in British Columbia* (the "Code") and/or the mine's permit number M-200;
- issue orders; and
- recommend further action by competent authorities under applicable legislation of the Province.

3.2. OBJECTIVES

The objectives of the Mount Polley Mine TSF breach investigation were to:

- determine the root causes of Mount Polley Mine Tailings Storage Facility breach on August 4, 2014;
- determine contributory causes, if any, to the dam breach;
- determine the nature of contraventions of the *Mines Act*, Mines Regulation, *Mines Act* Permit M-200 and/or Code, if any, occurred;
- determine orders, if any, that should be issued relative to the event;
- determine how best to reduce the risk that such an event could occur in the future on this site or any mine site in British Columbia, and which actions, orders, or recommendations for changes to relevant sections of the *Mines Act, Regulation*, or Code would support this objective;
- based on the findings, to consider whether to prepare a report for Crown's consideration; and
- based on the findings, make recommendations to the mine, the mining industry, the geotechnical engineering community, and Government as warranted to reduce the risk that such an event could occur in the future;

3.3. SCOPE

The investigation was convened principally to investigate the root and contributory causes leading to the breach of the TSF. Included in this are many investigative themes, including but not limited to the design, construction, maintenance, expansion, and surveillance of the tailings impoundment; inspections and oversight by external engineering experts as well as inspections and orders by the Ministry of Energy and Mines (MEM). The investigative boundaries are deliberately broad, so that the investigation may trace all possible causes and contributing factors of the event.

CONDUCT OF THE INVESTIGATION

the Chief Inspector committed to an open, honest and objective investigation

The Chief Inspector's statutory authority is limited to mines. With respect to remediation activities, the Chief Inspector identified the area under the mine permit to include both the mine site and areas downstream of the breach to the Gavin Lake Road bridge over Hazeltine Creek. Any terrain beyond this point was determined to be beyond the scope of the investigation. Impacts off the mine site — including detrimental environmental impact, mudflow in Hazeltine Creek and Quesnel Lake, inundation in Polley Lake and Quesnel Lake, and other issues around water quality — are the purview of other agencies.

While the investigation was bounded spatially by the statutory authority, the investigative team explored some external impacts of the event on the mining industry, the internal regulatory process and the geotechnical engineering community, as well as the scale of impacts affecting the relationship and trust of the local community, First Nations and citizens of British Columbia. The following were included in the scope of the investigation:

- available documentation, records, reports, and any other information considered relevant to the investigation.
- actions, plans, designs, operations, engineering, policy, and any other contributing things occurring on Mount Polley Mine, by MPMC, or by its parent company, Imperial Metals.
- actions, plans, designs, operations, engineering, policy, and any other contributing things under the control of any third parties deemed relevant to the investigation, including engineering firms, subcontractors, outside agencies, or any other person(s) or entities considered relevant to the investigation.
- appropriate unsolicited information from the public, voluntary information from the mine employees and managers, the public, First Nations, or any other party with relevant information.
- findings of contravention of the *Mines Act*.

3.4. ENABLING LEGISLATION

This section provides an informal summary of the legislation that enabled the investigation to proceed.

3.4.1. *MINES ACT* (RSBC 1996, C. 293)

§7 An inspector may, and on the direction of the chief inspector must, make an investigation of and report about an accident that has caused serious personal injury, loss of life or property or environmental damage.

§8 (1) for the purposes of conducting an investigation under §7, an inspector may make an order requiring a person to do either or both of the following:

(a) attend, in person or by electronic means, before the inspector to answer questions, on oath or affirmation, or in any other manner

(b) produce for the inspector a record or thing in the person's possession or control.

§10 (9) An owner, agent, manager or permittee must

(a) hold and maintain a permit for the mine,

(b) ensure that no work takes place in, on or about the mine, except under and in accordance with a permit, and

(c) comply with all the conditions of the permit.

§15(4.1) If an inspector believes on reasonable grounds that a person has contravened or is contravening an order under this section or a provision of the Act, the code, the regulations or a permit and that the contravention has a detrimental environmental impact, the inspector may order the owner, agent, manager, permittee or any other person apparently in charge in, on or about a mine to do any of the following:

(a) take immediate remedial action;

(b) suspend regular work until remedial action is taken;

(c) close the mine or part of it until remedial action is taken.

(5) If an inspector is of the opinion that a delay in remedying a hazard would be dangerous to persons or property, the inspector must issue an order

(a) for immediate remedial action,

(b) to suspend regular work until remedial action is taken, or

(c) to close the mine or part of it until remedial action is taken.

(6) Within 15 days after receiving the inspection report, the manager must

(a) submit a written report outlining the remedial steps taken and the work still outstanding, and

(b) promptly provide a copy to the inspector, and, in the case of health and safety matters, the occupational health and safety committee and the local union.

§18 The inspector may order the owner, agent, or manager to provide at the owner's expense an independent study prepared by an engineer or other licensed professional acceptable to the inspector

(a) respecting health and safety at the mine or safety of its equipment, buildings, workings or structures, or

(b) in connection with an accident or a dangerous occurrence that the inspector is investigating.

§37 (1) A person who obstructs, impedes or otherwise interferes with an inspector in carrying out the inspector's duties under this Act commits an offence.

(2) A person who contravenes a provision of this Act, the regulations, the code or an order made under any of them commits an offence.

(3) A person who commits an offence is liable to a fine of not more than $100 000 or to imprisonment for not more than one year or both.

(3.1) The time limit for laying an information to commence a prosecution for an offence under this Act is 3 years after the date on which the chief inspector learned of the facts on which the information is based.

3.4.2. MINES REGULATION (BC REG. 126/96)

§1 An inspector may, during the exploration, development, operation, closure or abandonment of a mine, investigate any matter relating directly or indirectly to the health and safety of any person or the public, including an investigation with respect to

(a) death or injury,

(b) accidents,

(c) dangerous or unusual occurrences, or

(d) complaints or allegations relating to health or safety,

and, for purposes of an investigation, management must provide the inspector with access to all of the mine, including the underground and surface portions, and all mine records.

3.4.3. THE CODE

The *Health, Safety, and Reclamation Code for Mines in British Columbia* ("the Code") gives direction with respect to the requirement for the mine manager to conduct an investigation subsequent to a "dangerous occurrence" occurring on a mine site. Definitions of a dangerous occurrence pursuant to Parts 1.7.3 (2) and (11) of the Code include:

(2) cracking or subsidence of a dam or impoundment dike, unexpected seepage or appearance of springs on the outer face of a dam or dike; loss of adequate freeboard, washout or significant erosion of a dam or dike, any of which might adversely affect the integrity of such structures, and;

(11) any other unusual accident or unexpected event which had the potential to result in serious injury.

Part 10.1.11 of the Code addresses departures from approval, stating:

The owner, agent or manager shall notify the chief inspector in writing of any intention to depart from the mine plan and reclamation program authorized under sections 10.1.1 or 10.1.2 of this code to any substantial degree, and shall not proceed to implement the proposed changes without the written authorization of the Chief Inspector.[3]

3.5. STRUCTURE OF THE INVESTIGATION

3.5.1. CONDUCT OF THE INVESTIGATION

The following guiding principles were adopted by the Chief Inspector to inform the conduct of the investigation:

- Independent conduct of investigation, with respect to influences from Government and interests of industry, labour, other interested parties, and the public;
- Independent from any other investigative efforts surrounding the event;
- Objective, evidence-based, thorough, defensible findings and recommendations;
- Conducted with the understanding that time is of the essence, subject to the demands of objectivity and thoroughness;
- Conducted in a manner in accordance with law that guides the investigative process;
- Oriented toward enhancing the safety and security of the public, the worker, the environment;
- Respectful of the interests of First Nations, local and regional government, professional organizations, and labour;

- Structured and implemented in accordance with the organizational and operational principles of Major Case Management (MCM) best practices.

3.5.2. MAJOR CASE MANAGEMENT

Major Case Management (MCM) is an organizational philosophy developed by public safety agencies as a means of managing the complexities and uncertainties of large-scale investigations. Developed and implemented in police agencies across Canada, including the RCMP, Ontario Provincial Police, and agencies in British Columbia, MCM focuses on investigative coordination, accountability, and a multi-disciplinary approach to secure the best information and evidence.[4]

MCM recognizes that large investigations are complex; there are many variables creating potential for uncertainty, high volumes of information and multiple individual investigators to be managed. MCM builds on the ability to respond to findings produced by the investigation over time, and to provide an integrated base for coordinating and sharing information that may have investigative value.

MCM provides discipline, structure, integrity, flexibility, and responsiveness for the conduct of major investigations. It is particularly well suited to the dynamic and fluid environment that characterizes major investigations, and provides an operating ethos as well as an overall command and execution structure. The tenets of MCM are broadly applicable to any large-scale investigative requirement, and have been successfully implemented in a variety of investigations, both criminal and civil disaster. For example, principles of MCM were employed in the Swissair Flight 111 crash near Peggy's Cove, Nova Scotia in 1998.

Given the scope of the Mount Polley investigation, MCM integration was seen as a prudent approach to organizing the structure and decision making process of the investigation team.

The fundamental structures, organizational rules, definitions of roles and responsibilities, and best practices in communication and records management are applicable to this investigation. Principles of MCM have been included within the goals of the investigation offering a formalized investigative platform for the Chief Inspector's investigation.

Central to MCM is the Command Triangle, which establishes the significance of management and control of files (all documentation, evidence, and potential exhibits), and lays out operational procedures for primary investigation.

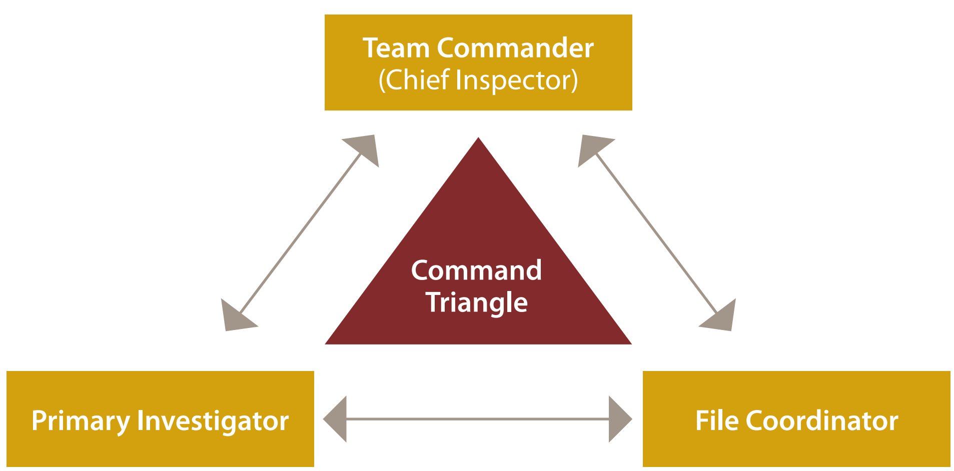

Figure 3.1 Major Case Management Command Triangle

Three separate individuals in the roles of Team Commander, Primary Investigator, and File Coordinator presupposes independent minds working together with individual responsibilities and the ability to interchange roles , allowing for both continuity of the investigative process and systematic cross-checking that is organic to the investigation itself, to minimize such challenges as investigator bias, "tunnel vision," selective analysis, and other issues that can affect the integrity and objectivity of large investigative efforts.

In addition to the Command Triangle, the investigation applied a number of technical skillsets to the analysis of the event, including the following:

- Geotechnical engineering
- Mining engineering
- Health and safety
- Human factors
- Information analysis
- Quaternary geology
- Geography and environmental studies
- Environmental law
- Human rights and society
- Law enforcement/investigation
- Legal services
- Database administration

Other supporting services were drawn from many competencies, including:

- Industrial Hygiene
- Emergency Preparedness
- Permitting
- Transcription Services

The investigation team consisted of the Chief Inspector, plus seven dedicated team members, with the assistance of several additional operational staff. Additional resources in database administration, law enforcement, and file management were utilized. Additional training in file coordination and investigative techniques were obtained.

3.5.3. CONCURRENT INVESTIGATIONS

The Chief Inspector required that any parallel investigations be treated and maintained as independent. Any sharing of information complied with strict limitations to protect the integrity and independence of each.

Independent Expert Engineering Panel. On August 18, 2014, the Minister of Energy and Mines established an independent panel of distinguished experts in the field of geotechnical engineering and dam failure analysis to investigate the root cause of the failure of the TFS.

The panel's terms of reference outlined a mandate to identify the mechanisms of failure of the TSF; to identify any technical, management, or other practices that may have caused or contributed to the mechanism(s) of failure; and to identify any changes that could be considered to reduce the potential for future such occurrences.[5]

To preserve the integrity of the subsurface conditions, a coordinated geoforensic investigation was performed and information shared between MPMC, the Independent Expert Panel, and the Chief Inspector.

The panel report was issued January 30, 2015.

Additional Investigations. The Conservation Officer Service (COS) of the Ministry of Environment is also conducting an investigation pursuant to the *Environmental Management Act*; and Federal Fisheries Officers pursuant to the *Federal Fisheries Act*.

3.5.4 LOGISTICAL SUPPORT

The sensitivity and scope of the investigation warranted a dedicated workspace to provide a secure base of operations. An operations centre was established for this purpose at MEM's Victoria headquarters. The computer server used to support database operations was isolated from any network connections external to the investigation, including the Government of British Columbia intranet system.

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3.6. RECORDS MANAGEMENT

A key element of MCM is the filing, indexing, and management of records pertinent to the investigation. Investigators must have the ability to seek common threads of information and create linkages between facts that may have been collected from a broad variety of sources in many different formats. To achieve this demand, the Chief Inspector conducted an audit of available records. The audit, completed in September 2014, identified approximately 4,500 documents, including photographs, permit documents, technical documents, communications, and drawings and large-format documents in the possession of MEM. It also made specific recommendations on the capture, storage, access, indexing, and control of documentation to assist in the investigation.[6]

A total of 935 documents pertaining to Mount Polley Mine and Permit M-200 were contained in MEM's internal information management system, the Minerals Management System (MMS). In addition, approximately 200 documents in offsite archival storage were scanned into machine-readable format.

Shortly after the event, MEM inspectors requested access to documents from MPMC management. The mine instituted a SharePoint electronic file transfer site to facilitate document delivery. MEM staff would request documents by email; the mine would mount the documents requested on the SharePoint site and send a confirming email. Documents already in the MEM inventory would be discarded.[7] The process ensured information security and flow control of documents from MPMC.

Orders to provide information in accordance with Section 8(1)b of the *Mines Act* were issued to engineering consultants such as KP, AMEC and BGC on September 24, 2014, and included orders for named personnel to attend an interview. [8]

The Chief Inspector was mindful of the balance to be struck between individual rights versus the public's right to know what transpired at Mount Polley, since the possibility of action by the Crown against MPMC or various individuals involved in the mine's operations and design existed throughout the course of the investigation.

The investigative team continued to amass relevant information stretching back to 1989, and eventually had access to approximately 100,000 pages of documentation.

3.7. SUPPORTING RESOURCES

3.7.1. RCMP DATABASE

A document indexing system was implemented to manage, index, and reference documentation in MEM's possession. This system was also referenced when dealing with a variety of *Freedom of Information and Protection of Privacy Act* (FOIPPA) information requests to MEM.

In accordance with the principles of Major Case Management, all documents were controlled to maintain the integrity and independence of the overall investigation. This practice continued regardless of the actions of external bodies with respect to document release (including MPMC and the Expert Panel).

The records management database is a critical tool to support the investigative process. After considering a number of investigative management software tools, the team borrowed Evidence & Records III (E&R III) from the RCMP. E&R III is a relational database application designed to support major investigations with a tailored thematic database that applies business rules to manage the tasking of data, document, and evidence collection; and to manage tasking of actions to ensure accountability and seamless data integration. The application software was installed on a SQLserver platform on an isolated server, not connected to any local or wide area network, and is accessible only in its secure location in the Investigation Operations Centre. The server data will remain in the possession of the Chief Inspector.

INVESTIGATIVE TOOLS

RCMP supplied E&R III software for records management
NASA supplied RCAT for Root Cause Analysis

3.7.2. ROOT CAUSE ANALYSIS TOOL (RCAT)

To assist with the formal, objective, structured analysis of all information collected by the team for such an extensive investigation, a Root Cause Analysis software application was essential. The team evaluated several commercially-available packages, and opted to utilize the Root Cause Analysis Tool (RCAT), a flexible event analysis tool developed by the National Aeronautical and Space Administration (NASA) to support the full spectrum of incident investigations by the agency, from small local accident reports to large-scale spacecraft loss events. The RCAT software and root cause analysis principles are discussed more fully in Chapter 10.

3.8. INVESTIGATIVE AVENUES

3.8.1. FAILURE HYPOTHESES

The investigation's adoption of Major Case Management principles assisted to maintain an open, honest, objective, and comprehensive inquiry for all potential failure modes for the breach. The following is a summary of failure modes that could reasonably be considered to contribute to such an event:

- Shear failure through foundation due to self-weight of structure
- Pond water level and phreatic surface upstream of the core leading to breach
- Excessive rate of material placement leading to excessive pore pressures leading to slope failure
- Artesian pressures leading to slope failure
- Seismic or rock blast vibration
- Convex corner at breach leading to slope failure
- Overtopping through excessive water volume, extreme precipitation, or extreme wind event leading to surface erosion of the dam
- Piping or cracking
- Drainage pipes through dam foundation
- Sabotage, terrorism, or other deliberate human malfeasance

3.8.2. GEOTECHNICAL ENGINEERING

The Chief Inspector engaged as technical advisors Klohn Crippen Berger (KCB), a Vancouver-based engineering firm with extensive experience in designing, constructing, and evaluating the safety of earthen dam structures. The senior engineers on the project also had significant experience analyzing failures of such structures, including investigation of the Aznalcollar tailings dam failure near Sevilla, Spain in 1998, and the investigation of the Omai tailings dam failure in Guyana in 1995.

INVESTIGATIVE RESOURCES

dedicated investigative team for thorough, comprehensive, independent investigation

The geotechnical investigation was carried out in two phases: field observations and a drilling program, and laboratory analysis of drillcore samples. KCB engineers conducted extensive investigation of the breach site, including field mapping, site inspection, post-failure movement surveillance, and a program of borehole drilling and logging carried out between September and December 2014. The purpose of the field investigations was to characterize the physical aspects of the breach, embankment structure, and foundation characteristics; to collect evidence to assess the potential failure modes; and to make a determination on the mechanism of failure.

In addition, the KCB team was contracted to investigate the failure, and events and conditions prior to the failure, from a geotechnical perspective.

The full KCB reports on the mechanism of failure, an investigation into the events leading to the failure, site investigation data and laboratory analysis, and review of engineering and management practices are incorporated into this report, and appear as Appendices 2 and 3.

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3.8.3. STATEMENTS

Investigative staff collected nearly 100 statements from a broad array of individuals who could contribute perspectives on the breach, background on procedures and operations, and other information germane to the investigation.

Interviews were conducted at various locations throughout the province from August 2014 through May 2015.

Interviews were carried out with the following groups:

- MPMC employees: superintendents, equipment operators, mill operators, shifters, TSF inspectors, trainers and personnel in health and safety, engineering , environmental, electrical and maintenance roles. Construction contractors: Peterson Construction – equipment operators and supervisors.
- Consultants: Knight Piésold Ltd. (KP), Amec Foster Wheeler (AMEC), and BGC Engineering Inc. (BGC).
- Senior managers and executives of MPMC and Imperial Metals.
- MEM inspectors: Health and Safety and Geotechnical Inspectors of Mines

The purpose of the interviews was to understand what happened and what might have caused the failure. The Chief Inspector's objectives were to:

- gain an understanding of the site conditions and possible mechanism of failure;
- collect information that could be used to improve future internal and external policy decisions and state of practice;
- understand the communication and management systems that were in place; and
- determine if there were any contraventions of the *Health, Safety and Reclamation Code* ("the Code").

All of the interviews were recorded by the Chief Inspector for permanent record purposes, transcribed, and entered into the database. The purpose of the interviews was to elicit witness statements regarding two main areas of interest:

1. Engineering and construction practices relevant to the mechanism of failure, site conditions and design.
2. Practices relevant to the management of the TSF, which may have had some influence on the facility's construction, operations oversight and safety of the facility.[9]

In addition to formal interviews, the investigative team solicited information and comment from a broad variety of sources, including First Nations and the general public.

3.8.4. DOCUMENT EXAMINATION

The investigative team assembled, to the extent possible, relevant documentation in electronic or hard copy form, related to MPMC and the Mount Polley Mine. This documentation included, but was not limited to:

- Permit applications and supporting attachments
- Technical reports
- MPMC documentation, including operating and emergency response manuals; dam safety reviews and safety inspection reports; design and construction manuals; as-built reports; periodic facility monitoring, instrument monitoring, and construction reports;
- Geotechnical, mechanical, electrical, and health & safety inspection reports and inspection orders
- Electronic correspondence between MPMC and MEM
- Statement transcriptions
- Technical documentation, electronic communications, and other records received from KP, AMEC and BGC

Documents were catalogued and indexed, and received a review by MEM investigators; all technical documentation was reviewed and abstracted by engineers from KCB, and all relevant documentation was reviewed in detail by the investigative team.

Following formal business rules, each document was entered into the E&R III database. The relational database facilitated indexing of each document as well as the extraction of general themes related to the investigation.

FOOTNOTES

1 *Ministry of Energy and Mines (2014b)*

2 *Ministry of Energy and Mines (2013) p. 1*

3 *Ministry of Energy and Mines (2008)*

4 *Ministry of Community Safety and Correctional Services, Government of Ontario (2004)*

5 *Independent Expert Engineering Investigation and Review Panel (2015) p. 1*

6 *Ard (2014)*

7 *Ard (2014) pp. 6-7*

8 *Hoffman (2014c), Hoffman (2014d), Hoffman (2014e)*

9 *Klohn Crippen Berger (2015b) pp. 8-9*

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MINE & TSF OVERVIEW 4

Mount Polley mine is located in central British Columbia, approximately 65 km northeast of Williams Lake (see Figure 2.2). The mine property is in the asserted traditional territory of the Williams Lake Indian Band and Soda Creek Indian Band.

The property is located in the Quesnel terrane or Quesnellia, which extends from south of the United States border to north-central British Columbia."Quesnellia hosts several major porphyry copper deposits such as Highland Valley, Copper Mountain, Afton-Ajax and Mount Milligan." [1]

4.1. MINE OVERVIEW

4.1.1. OWNERSHIP

MPMC operates the Mount Polley property as a subsidiary of Imperial Metals Corporation, which is publicly traded on the Toronto Stock Exchange (TSE: III). Imperial Metals is a Canadian mining company, with its corporate head office in Vancouver, British Columbia.[2]

Generally, with metal mines of this size and complexity, the mine manager engages an outside engineering consultant to provide technical expertise in site investigation, design of structures, and development of operational, maintenance and surveillance standards.

Figure 4.1 View of TSF and barge pump-house, June 21, 2014, Mount Polley Mining Corporation (2014b)

4.1.2. MINE DEVELOPMENT AND OPERATIONS

Exploration of the ore bodies on the Mount Polley claim began in the 1960s, culminating in the issuance of an operating permit for the mine on August 3, 1995. Construction of the mine and milling facility began in May 1996, and was completed in June 1997.

MPMC received project certification in the form of a Mine Development Certificate in 1992. When the *Environmental Assessment Act* came into force in 1995, this certificate continued in force as an Environmental Assessment Certificate.

Figure 4.2 Mount Polley Mine Prior to Dam Breach, October 2013
AMEC Environment and Infrastructure (2014a)

Mount Polley produces a copper-gold concentrate. Mining operations include both extensive open pit activity and underground works. Standard hard rock drilling and blasting techniques are used to produce ore for milling operations.

Run-of-mine ore is trucked to the mill and processed through a primary gyratory crusher to reduce the rock to a nominal 200 mm. A hydraulic rock breaker is used to break the oversize material, and the crushed ore is discharged onto an apron feeder which feeds onto a conveyor to the coarse stockpile.

Further ore preparation is provided by a grinding circuit, consisting of parallel rod mill/ball mill circuits and a pebble mill circuit. When crushed to a size appropriate for mineral separation, the fines are pumped to the flotation circuit.

The selective flotation process separates the valuable minerals from the waste rock, producing a concentrate. Initial separation is done in a rougher/scavenger circuit. Rougher concentrate is further upgraded in a cleaner circuit to produce the final product, which is dewatered and shipped to market on 40 tonne trucks.[3]

MINERAL PRODUCTION

at peak, Mount Polley Mine produced 20,000 tonnes of gold/copper ore per day

Tailings from the mill, a slurry of ground rock and process water, is transported by pipeline to the tailings storage facility.

The mine commenced production on June 13, 1997. Mining operations continued until September 2001, at which time operations were suspended due to low metal prices and the mine entered into care and maintenance. In August 2004, Imperial completed a feasibility study which included an updated ore reserve statement and a new mining plan, and confirmed the viability of restarting operations at Mount Polley Mine.

In October 2004, a *Mines Act* permit amendment was granted, and milling operations commenced in March 2005, operating continuously until August 4, 2014, the day of the TSF breach.

The mine development expanded over the life of operations to comprise five open pits and approximately five mine rock waste dumps. In later years, an underground operation was also developed.

At startup, the mill throughput was approximately 13,500 tonnes per day (tpd), but by 1997 the projected throughput was increased 32% to 17,808 tpd[4] for an annual throughput of 6.5 million tonnes per year. By 2013 this throughput had increased to approximately 20,000 tpd, or 7.3 million tonnes per year, an increase of nearly 50% [48.5%] over the initial throughput projections.

4.1.3. TSF OVERVIEW

During the feasibility study and environmental permitting phase for the mine, MPMC commissioned KP to carry out site investigations and a feasibility design for the TSF for a planned crest elevation of 965 m. The planned TSF would be approximately 4.4 km long and up to 45 m high. The TSF was to be raised annually in stages of approximately 2 to 3 m in elevation. The dam design utilized a modified upstream geometry, which included a slight tilting of the core zone in the upstream direction and placement of a drain pipe around the upstream side of the core zone, which exited to the downstream seepage collection system.

A *Mines Act* permit of the TSF was issued for the starter dam (927 m) and amended for each of the nine successive raises.

The TSF is located 3 kilometers southeast of the mill site, and receives mill tailings by a gravity-driven slurry pipeline. Tailings are stored in the facility, which also serves as an attenuation (collection) pond for mine runoff water. Water is recycled to the mill via a reclaim barge and pumped uphill to the mill. Figure 4.2, taken near the eventual site of the breach during the 2014 construction season, indicates the scale of the dam crest and the construction activity undertaken in Zone C rockfill placement.

Figure 4.3 Placement of Zone C Rock near the area of the breach, June 26, 2014, Mount Poilley Mining Corporation (2014c)

4.1.4. TSF OVERSIGHT

MPMC oversight of the TSF consisted of both internal and external roles. Internally, the roles included to MPMC, management roles involved in the TSF included the mine manager, mill operations superintendent, mine operations superintendent, mine superintendent, environmental superintendent, and tailings project coordinator. Various personnel with different knowledge, skills and abilities transitioned in and out of these roles over the history of the project. In recent years, MPMC oversight of the TSF included elements of the Mining Association of Canada (MAC) guidelines for tailings management systems. An Operations, Maintenance and Surveillance manual (OMS) was used to guide and document roles and responsibilities, instrumentation and water management systems, and other elements of the TSF.

Over the life of the facility, MPMC engaged three successive external engineering consultants: Knight Piésold Ltd. (KP), Amec Foster Wheeler (AMEC), and BGC Engineering Inc. (BGC).

KP was the Engineer of Record (EoR) for the TSF from the feasibility design stage up until the completion of Stage 6 in 2010. Although there is no formal definition, the EoR is commonly assumed to be the Professional Engineer (P.Eng.) with the responsibility for certifying the structure; in general terms, the EoR represents their company in this role. During its tenure KP was responsible for most aspects of the TSF and maintained QA/QC supervision during all construction works.

In January 2011, MPMC designated AMEC as the EoR. The transfer included a larger role for MPMC in the QC of the TSF construction. Students were trained for inspection duties and mine personnel assumed a larger role in the oversight of dam construction. MPMC also established a water management group responsible for site wide water management.

At the time of the breach, MPMC was in the process of transferring the EoR responsibilities to BGC, as a result of key personnel transfers from AMEC to BGC. BGC was intended to become the EoR following completion of Stage 9.

Further information regarding MPMC and tailings management practices are detailed in Appendix 3.

4.2. REGULATORY REGIME

Various regulatory agencies are involved in oversight of the mining industry in British Columbia. Mine operators interact with these agencies in varying capacities throughout the life of the mine.

The Ministry of Energy and Mines is responsible in the review, consultation and authorizations of the *Mines Act*. Its scope of oversight includes review of design plans, operational activity and permitting of the *Mines Act* M-200 Permit. The oversight specific to the TSF includes permitting, inspections (including geotechnical), and compliance with the *Mines Act*, Permit and the *Health, Safety and Reclamation Code for Mines in BC* (the Code). Details of permitting and geotechnical inspections are presented in Chapter 6 as they relate to each stage of the TSF.

Mines Act permit application review must rely on the professional expertise of the designer, who in many cases represents an engineering firm with significant worldwide experience in embankment design and construction. Permit applications were reviewed and the EoR stamp was required as a professional certification of the design, in accordance with the requirements of the Association of Professional Engineers and Geoscientists of BC (APEGBC). MEM geotechnical inspectors do not critique the professional design once satisfied that certain key elements are present or have been addressed.

The regulatory regime that oversees mining in the province includes the Ministry of Environment, which is involved in the permitting of discharges to the environment under Effluent Permit PE 11678; and the Canada Department of Fisheries and Oceans, which oversees activities and discharges affecting aquatic habitat for local and anadromous species.

4.3. POST-BREACH OPERATIONS

The breach on August 4, 2014 resulted in the release of tailings and water into Hazeltine Creek, Polley Lake and Quesnel Lake. Ongoing environmental monitoring and site assessments have been conducted in the impacted area. Activities by MPMC include water quality monitoring, sediment sampling and toxicity testing in accordance with a Pollution Abatement Order from the Ministry of Environment. As of the date of this report, MPMC continues remediation activities in Hazeltine Creek, Edney Creek and their outlets to Quesnel Lake. Extensive ongoing monitoring is in place throughout the impacted area.

To date, MPMC has completed a repair to the breached area of the TSF and buttressing of the PE, in accordance with a *Mines Act* permit amendment issued on December 17, 2014 to allow for its use as a contingency during the 2015 freshet. Work is ongoing to ensure site-wide water management requirements are met. A restricted restart permit amendment was issued on July 9, 2015, following consultation with First Nations, the public and detailed technical review by the Cariboo Mine Development Review Committee. On October 22, 2015 a *Mines Act* permit amendment was issued to allow construction of a buttress along the Main Embankment (ME) to ensure that the existing structure meets minimum Factor of Safety (FoS) requirements of 1.5.

The FoS is a key measure of the robustness of an embankment. Calculated through complex mathematical models based on the characteristics of the component materials of the dam itself, as well as the soils that comprise its foundation, the FoS quantifies the amount of strength required to resist failure built into a structure. A FoS of 1.0 (or unity) suggests that failure is imminent or in progress.

FOOTNOTES

1 *Mount Polley Mining Corporation (2013) p. 24*

2 *Mount Polley Mining Corporation (2013) p. 11*

3 *Mount Polley Mining Corporation (2013) p. 17*

4 *Knight Piésold (1997b) p. 1*

TSF DESIGN 5

The tailings storage facility (TSF) design was developed by Knight-Piésold (KP) to support the environmental assessment of the project and the initial permit application for the facility. The design was to be implemented in stages, over the life of the mine, with separate *Mines Act* permit amendment applications for each stage.

The TSF was designed as a U-shaped earthen dam structure extending from rising terrain that forms the northwestern side of the impoundment. The TSF is underlain primarily with natural surface glacial till, or lined with imported till for basin areas without a sufficient native layer. The dam comprises zoned earth/rockfill embankments approximately 4.3 km long, and as high as approximately 50 m. The TSF measures approximately 1.8 by 1.6 km, covering an area of about 304 hectares.

The capacity of tailings storage facilities is driven by a number of engineering and environmental considerations, including anticipated quantity of tailings slurry discharged from the mill process, estimated runoff of precipitation on the mine site, the area of the mine site draining into the TSF, and the estimated maximum precipitation from a design storm event.

At Mount Polley Mine, associated TSF facilities include seepage collection ponds, surface runoff diversion ditches and flow control structures, sediment control structures, gravity-fed tailings distribution system, and a water reclaim system.

5.1. SITE SELECTION

During the initial design phase, three potential sites for the TSF were investigated. These locations are illustrated in Figure 5.1 as Areas A, B, and C. Area B was selected "because it will provide secure tailings storage that would meet all environmental and closure requirements at the least cost. Further, it would minimize potential impacts to both Polley and Bootjack Lake catchments and would keep mine tailings and any leachate confined to the Edney Creek Tributary watershed."[1]

Designs for the alternative sites would have incorporated a system of much higher embankments so engineering prudence, along with economic concerns, were likely instrumental in determining the location of the TSF.

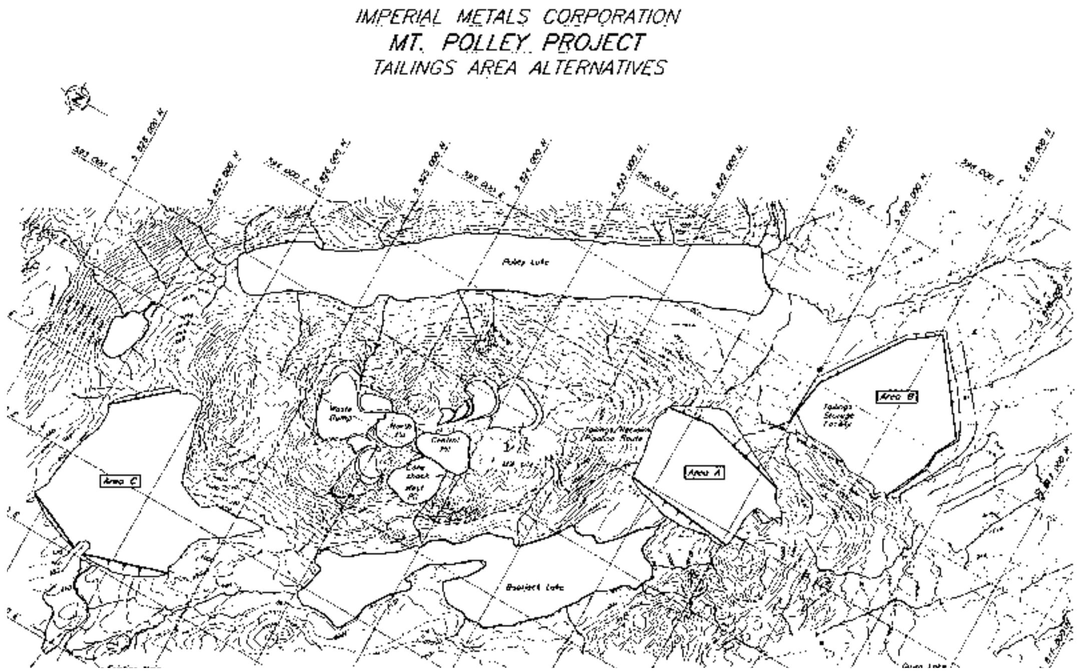


Figure 5.1 *Tailings Site Location Alternatives*
Knight Piésold (1995a) Fig. 4.1

5.2. SITE AND TAILINGS CHARACTERIZATION

The site selected for the TSF is a nearly flat basin, with a hillside forming the northwestern side of the storage basin. In the initial year, the Main Embankment (ME) closed off the gentle valley that formed the base of the TSF; in subsequent years, a South Embankment (SE) on the southwest side of the TSF and Perimeter Embankment (PE) to the northeast and east enclosed the rising storage facility.

5.2.1. HYDROLOGY AND CLIMATE

Documentation of climatic conditions at the mine site was compiled by the EoR, KP, as part of the design report for the TSF.[2] Weather records of varying duration are available for a number of locations within the general region. Two Forest Service stations in comparable terrain within 40 km of the site, at Likely (established in 1989) and Horsefly (1985) provide automatically generated meteorological data on an hourly basis. The regional climate is relatively temperate: the mean annual temperature at Likely, the nearest station, is 4.0 C with extremes of 33.9 C and -37 C. At Quesnel, more distant but with records maintained for roughly 70 years prior to mine development, records show extremes of 40.6 C and -47.6 C. Frost-free days in the area range from 199 at Horsefly Lake (elevation 788 m) to 244 at Barkerville (elevation 1244 m).

Precipitation is generally well-distributed throughout the year, with winter precipitation in snowfall. This climatic regime leads to the primacy of the spring freshet in planning for maximum runoff events, in addition to unusual precipitation events.

5.2.2. CHARACTERIZATION OF FOUNDATION SOILS

Site investigations in the vicinity of the TSF were carried out prior to construction of the starter dam, and continued as a part of ongoing design during some subsequent stages. The investigations were performed for a variety of purposes, including embankment foundation characterization, borrow source determination, basin liner delineation, hydrogeological characterization and instrumentation installation. The investigations consisted of test pitting and drilling by a variety of methods. A series of site investigations were conducted from 1989 to 2012.

The foundation soils were identified as interlayered glacial tills, glaciolacustrine (GLU) and glaciofluvial (GLF) soils, overlying bedrock.

During this phase, exploration of foundation soils underlying the PE foundation was focused on the drilling program on the ME, the site of the starter dam. The GLU was characterized as a stiff, overconsolidated silty clay.

KP's initial design focused on till borrow areas, both inside and outside the confines of the TSF embankments, to supply adequate materials for the Zone S till core. A large number of test pits (over 130 in 1996 and 61 in 1997) were dug or bored to identify and characterize borrow areas; in contrast, only 4 shallow pits were developed for PE foundation studies.

5.2.3. TAILINGS CHARACTERIZATION

Tailings consist of silt (64%) and fine sand (30%) with a trace of clay (6%). Chemical analysis focused on the tailings' potential to generate mine acid and associated risks to the environment. As shown in the table below, the analysis determined that the "balance between acid producing components (primarily pyrite) and acid consuming components (carbonates and other rock types with neutralizing capabilities)" produced a material that not only is not acid producing, but has a "significant net neutralization potential."[3]

SUMMARY OF ACID BASE ACCOUNTING TEST RESULTS

Sulphur (percent)	**Paste pH**	**Acid Potential** (kg CaCO3/t)	**Neutralization Potential** (kg CaCO3/t)	**Net Neutralization Potential** (kg CaCO3/t)
0.02	8.22	0.6	24.6	24.0

Additional testing using an ASTM waste extraction test revealed benign characteristics with "very low levels of water leachable constituents in the extract, all at concentrations below the lower range concentration for the pollution control objectives for final effluent discharge."[4]

5.3. DESIGN BASIS

KP established design criteria for the TSF at the outset of the project. "The principal objectives for the design of the tailings storage facility are to ensure complete protection of the regional groundwater and surface water flows both during operations and in the long-term, and to achieve effective reclamation at mine closure."[5]

The design requirements were also specific:

- "Permanent, secure and total confinement of all solid waste materials within an engineered disposal facility.
- Control, collection and removal of free draining liquids from the tailings during operations for recycling as process water to the maximum practical extent.
- The inclusion of monitoring features for all aspects of the facility to ensure performance goals are achieved.
- Staged development of the facility to distribute capital expenditure over the life of the project."[6]

Initial design assumptions included:

- The embankment crest will be raised progressively throughout the life of the project; and
- Excess water from the catchment areas will be diverted to maintain a water balance that will not require discharge of process water to the environment.[7]

5.3.1. CONSEQUENCE CLASSIFICATION

At the design stage in 1995, the Canadian Dam Association (CDA) *Dam Safety Guidelines for Existing Dams* were interpreted to assess a "LOW" consequence classification to the facility. The design criteria for a LOW consequence tailings dam include a minimum flood design with a 1/100 to 1/1000 year return period and a minimum seismic design with a 1/100 to 1/1000 year return period. (Subsequent changes in the CDA (2007) Guidelines increased the number of consequence classification from 3 levels to 5 levels and this was considered in later design stages.)

5.3.2. STABILITY

In the opinion of the EoR, KP calculated stability to comply with existing CDA guidelines: "minimum acceptable factors of safety of 1.3 and 1.5 have been adopted for this design for static conditions during operations and at closure respectively. A minimum acceptable factor of safety of 1.1 is considered appropriate for the tailings residual strength condition."[8]

Stability calculations conducted by KP were based on two key assumptions: the geometry of the rising embankment, which would maintain a 2H:1V downstream slope, and calculations of foundation material strength that took into account the stiff, overconsolidated GLU.

5.3.3. FLOOD DESIGN CRITERIA

One critical factor in maintaining a safe water balance is the anticipation of a major precipitation event. This statistic, known as a Probable Maximum Precipitation (PMP), is determined by calculating rainfall into the mine's catchment area. It can be converted into freeboard requirements (the vertical distance between the lowest point of the crest of the dam and the pond's water level). Planning for a PMP, as well as consideration of wind-driven wave run-up, provides for sufficient freeboard to maintain safe water levels following a significant rainfall or snowfall event.

At the outset, KP envisioned a 10-day PMP. "An emergency storage volume of at least 0.68 million m^3 will also be available on the tailings surface, both at start-up and during on-going operations. This storage volume corresponds to the maximum total runoff from a 24 hour PMP event centered on the tailings facility and the catchment area immediately above the facility, assuming complete failure of the diversion ditches and a 95 % runoff coefficient. …The volume is derived from a 24 hour PMP value of 203 mm. … There is a minimum of one metre freeboard available above the PMP runoff volume inside the impoundment for wave runup and emergency flood storage. The 10 day PMP runoff volume is projected to be approximately 1.36 million m^3 which can also be completely contained within the impoundment. Therefore adequate storage capacity will always be available within the tailings impoundment for complete containment of the PMP event, and an emergency spillway will not be required during operations."[9]

The design storm event calculations, based on precipitation predictions and wave run-up calculations, resulted in a design minimum freeboard of 1.4 m.

5.3.4. SEISMIC DESIGN

Generally, the seismicity of the surrounding physiographic region is reliably low. Initial probabilistic analyses completed by the Pacific Geoscience Centre in 1995 indicated that "the Northern B.C. magnitude 5.0 earthquake corresponds to a worst case event occurring directly beneath the project site with a focal depth of 20km. … A Maximum Credible Earthquake (MCE) of M=6.5 causing a bedrock acceleration of 0.13g" was assigned to the site.[10] The selected Maximum Design Earthquake (MDE) was assigned a value of 50% of the MCE, e.g. 065g.

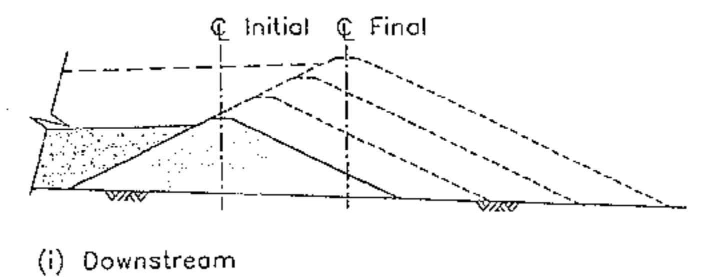
KP noted "as a result, the Design Basis Earthquake (DBE) for operations will be taken as the 1 in 475 year return period event. This corresponds to a maximum firm ground acceleration of 0.037g."

KP's assessment of the nature of foundation soils, based on site investigation and case studies, suggested that "amplification is negligible through dense soil deposits overlying bedrock," so that maximum bedrock ground motion parameters would apply to design of the TSF.[11]

5.4. EMBANKMENT DESIGN

5.4.1. MODIFIED CENTRELINE DESIGN

Tailings dam geometry varies from upstream to centreline to downstream. The overall design of the Mount Polley TSF incorporated a zoned construction approach using a combination of centerline and modified centreline methods. The modified centreline design used in the construction of the TSF was employed by Knight-Piésold in mining applications in Montana and Alaska prior to its introduction at Mount Polley. Its chief benefit is the significantly reduced requirements for downstream rock fill volumes compared to approaches typically deployed (centreline and downstream).[12] Numerous subsequent documents prepared by KP for MPMC incorporated the modified centreline paper coauthored by Haile and Brouwer as an attachment.



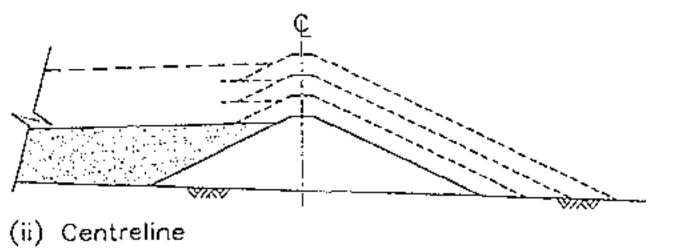


Figure 5.2 Centreline and Downstream Embankments. Haile and Brouwer (1994)

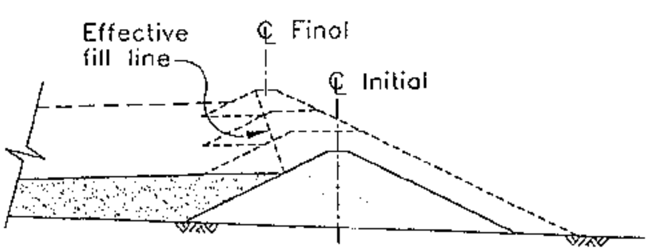


Figure 5.3 Modified Centreline Embankment. Haile and Brouwer (1994)

5.4.2. DESIGN PARAMETERS

According to specifications, the TSF embankment was designed to maintain a crest width of 8 m, and have maximum dimensions of 4,300 m in length and 50 m in height. The design capacity for mill throughput was a maximum of 13,425 tonnes per day.[13]

The initial design called for incremental raises over the life of the mine, to accommodate growing volumes of water and tailings. "The tailings embankments have been designed for staged development during operations in order to minimize initial capital expenditures and maintain an inherent flexibility to allow for variations in operation and production throughout the life of the mine."[14]

The ultimate height of the dam was intended to be at the 960 m level; however, the initial design anticipated that raises above this level, if accompanied by downstream toe extension, would safely increase storage capacity beyond the initial design limits: "Embankment raises above the proposed final crest elevation of 960 m would be constructed as required by incorporating a down-stream extension of the embankment toe. In addition to an increased storage capacity for the facility this would also ensure that embankment stability is maintained. *Detailed stability analyses would be performed in the design of future embankment raises.*" (italics added)[15]

The design parameters of the TSF, particularly the rate of rise of the embankment, were based on a projection of filling rate driven by a production rate of 13,425 tonnes per day (tpd). The design manual stated, "after approximately 3 years of operation the tailings surface area is sufficiently large that the on-going rate of rise is less than 2.5 metres per year. Also, by Year 6 of operations the rate of rise remains constant at approximately 2 metres per year." This projection was built around two key assumptions:

- the mine would operate in a *deficit* water balance state; and
- the production rate was 13,425 tpd.

"The tailings facility has been designed to contain 68.6 million tonnes of tailings solids … with a flat tailings surface. … additional storage capacity has also been incorporated into the design for 2 million m^3 of process (reclaim) water on top of flat tailings surface."[16]

5.4.3. EMBANKMENT ZONATION

The PE was designed with a simple zoned system, with a core zone of glacial till, an upstream zone of sand and/or tailings, and a downstream zone of rockfill shell (see Figure 5.4; Figure 5.6).

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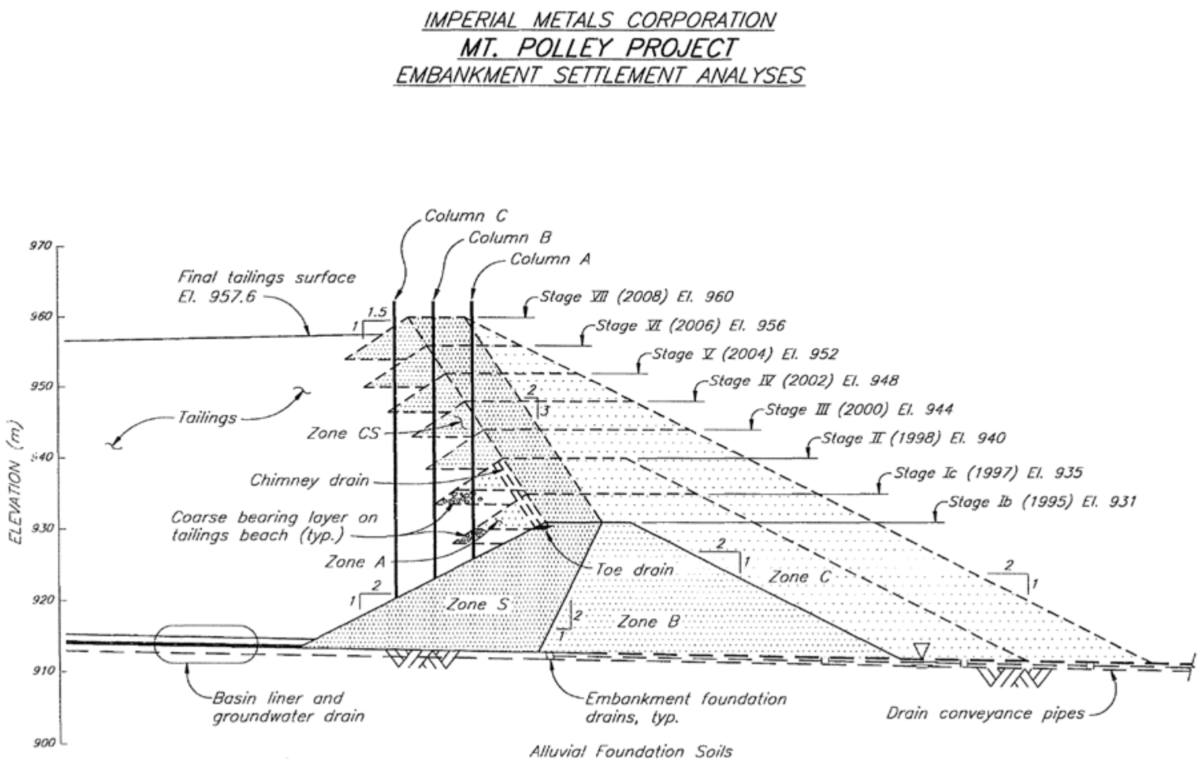

Figure 5.4 Representative Profile of Planned Embankment Construction Zonation Knight Piésold (1995a), Fig. 6.6

5.4.4. TAILINGS BEACHES

According to the initial design specification, "the tailings slurry will be deposited from a series of spigots situated along the crest of the embankment. The coarser fraction is expected to settle more rapidly to form sandy beaches with an average slope of about 1 percent. Finer tailings particles will be transported further before settling, with an overall slope of about 0.25 percent expected."[17]

The design included an expectation that tailings beaches above the supernatant water surface would be maintained adjacent to embankments. "Although an average tailings beach slope of 0.5% is assumed, slopes adjacent to the upstream face of the embankment are typically in the range of 1-2 percent. This assists in maintaining the supernatant pond and phreatic surface away from the upstream face of the embankment during periods of high runoff into the facility."[18]

"Tailings beach development and the embankment drainage system have been designed to maintain the phreatic surface away from the upstream face of the embankment. However, the conservative case of a phreatic surface within the embankment core zone was also examined as a worst case condition."[19]

5.4.5. EMBANKMENT DRAINAGE

The embankment drainage system included drainage provisions both upstream and downstream of the core zone.

"Toe drains will be constructed at the Main and Perimeter Embankments and will run the full length of each embankment. The toe drains will consist of perforated CPT tubing with a filter sand surround. The perforated CPT pipes will be connected to solid conveyance pipework which runs to the drain monitoring sump of the Main Embankment. At the Perimeter Embankment, the conveyance pipe will flow directly into the seepage collection pond. The drains will be constructed so that future extensions are easily constructed in subsequent embankment raises."[20]

"The embankment drains will also be extended during on-going embankment expansions… The Stage Ic expansion of the embankment will include extension of the blanket drain and riser pipes. Some of the subsequent stages will include placement of an additional horizontal toe drain with a perforated pipe that ties into the riser pipework. In general, every second embankment raise will include the installation of a new toe drain. Additional outlet pipeworks to the seepage collection ponds will be included as required based on operational monitoring. These additional toe drain sections and extensions of the pipework will ensure that the drains remain functional during operations and after closure even if minor embankment settlements due to tailings consolidation or earthquake induced deformation occur."[21]

The KP design also included an upstream drain placed upstream of the core zone in the embankment to reduce pore pressures in the tailings adjacent to the embankment.

5.4.6. LINER CONSIDERATIONS

Initial design considerations focused on the natural glacial till layer that would form the lining of the TSF. The design document noted, "well graded low permeability glacial till extends over most of the tailings basin, except at the lower basin and at the Main Embankment where saturated glacial lacustrine fine sand and silt are exposed at surface. These materials are typically dense to very dense and have been heavily overconsolidated by glaciers."[22]

"A 5 metre minimum thick cover of dense, low permeability glacial till blankets the majority of the tailings basin and the Perimeter Embankment footprint as encountered in test pits….. The till liner will act as a seepage barrier to prevent the migration of water out of the tailings facility and into the foundation."[23]

5.5. WATER MANAGEMENT

The Mount Polley TSF was designed to fulfill three functions: storing tailings, providing process water for mill operations, and storing runoff from mine-influenced portions of the mine site.

The initial plan stated, "the tailings impoundment will be utilized as a water reservoir both prior to start-up and during operations, thus eliminating the need for a dam on Polley Lake."[24] They adopted this approach given the projections of a deficit operating state for site and process water.

The facility was designed to capture runoff to use as process water, including construction of diversion ditches and runoff collection ditches to "allow diversion of the required amounts of surface runoff into the tailings storage facility to meet process water quantity requirements. The diversions will have flow control structures to divert excess water from normal runoff and during storm events out of the facility, as and when required."

Water balance projections calculated at the planning stage yielded a net water deficit for the mine on an annual basis. There was also a requirement for additional water from Polley Lake during extreme low water periods to ensure sufficient process water for mill and tailings transport operations.

Water management objectives updated in 1997 were stated as follows:

- "Maximizing the capture of surface and groundwater flows from within the project area.
- Maximizing the use of the poorest quality water recovered from within the project area in the milling process.
- Minimizing the volume of fresh water extracted from Polley Lake.
- Monitoring the quality of surface runoff from disturbed areas and groundwater flows within the project site.
- Releasing only the highest quality water from within the project boundaries in accordance with permitted requirements.
- Managing the tailings supernatant pond to optimize the volume of water stored on the tailings surface during operations and at closure."

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KP developed water balance models for different hydrologic conditions for each of the 14 years of operation (the anticipated lifetime of the mine at that time). Modelling indicated that as much as 300,000 m^3 of water would need to be supplied from local waterways to supplement stored water from the first year of impoundment (estimated at 1,500,000 m^3). However, water management would avoid the need for drawdowns from Polley Lake "except during the most extreme combinations of dry years."

The water balance estimates produced in 1995 included assignment of 150,000 m^3/year for dust control and 250,000 m^3/year lost due to enhanced evaporation. Most of the scenarios included some discharge of surface runoff from undisturbed areas of the mine property, but such "clean" runoff could also report to the TSF to meet operational minima.

5.6. STARTER DAM AND STAGED EXPANSION

5.6.1. CONSTRUCTION PLAN

The TSF was designed for staged expansion over the lifetime of the facility, with an initial starter dam constructed in 1996 to a crest elevation of 927.0 m, and progressive raising over the life of the facility.

The starter dam consisted of a homogeneous compacted till fill embankment. Discharge of tailings into the impoundment commenced in the summer of 1997. The starter dam, which expanded to become the core of the ME, is shown in Figure 5.5 (note the designated borrow areas within the TSF, and the reclaim barge channel dug to facilitate the pickup of reclaim water from the starter dam impoundment).

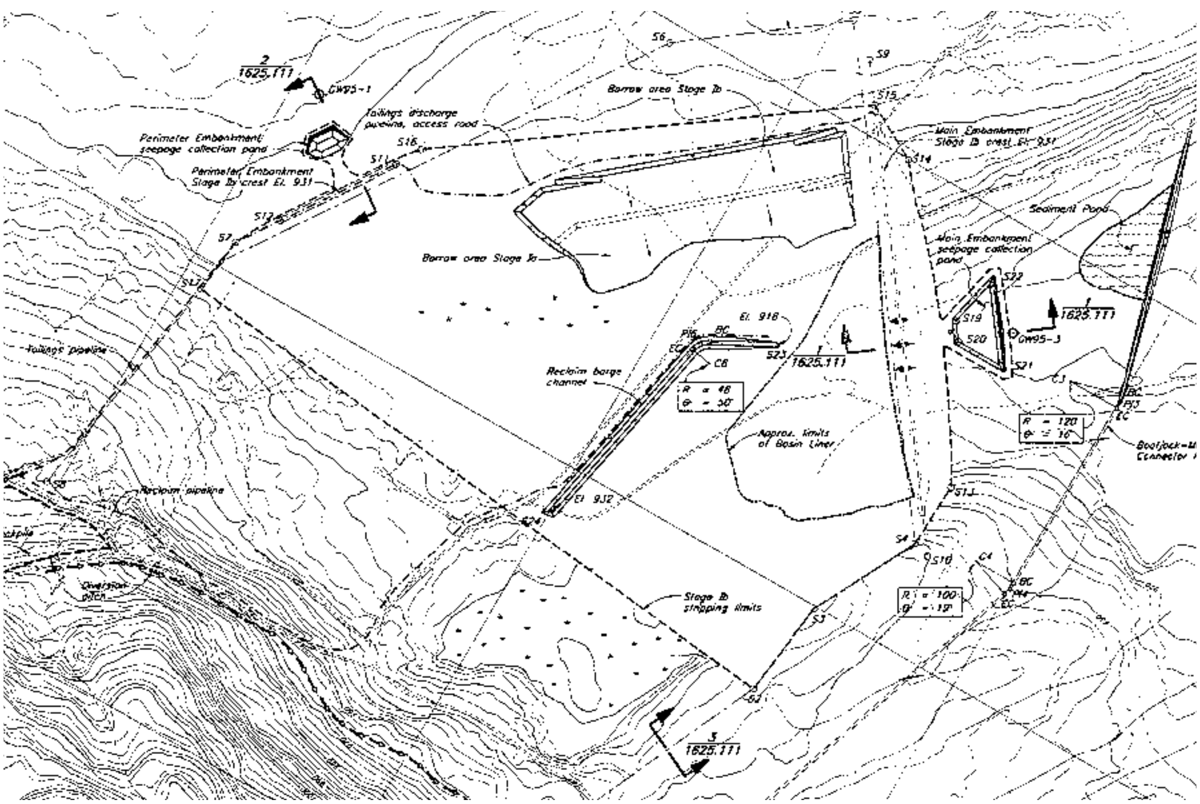

Figure 5.5 Starter Dam Layout KP (1995a) Dwg. No. 1625-110

During construction of the starter dam, the earthworks in the PE area comprised foundation preparation for future construction. KP proposed the staging of the PE as shown in Figure 5.5.

5.6.2. EMBANKMENT ZONATION

The dynamic nature of this approach was underlined in the initial design documentation. KP noted, "the staged expansions will incorporate a combination of centreline and modified centreline construction methods and will utilize glacial till, cycloned sand and random fill for the various embankment zones. The random fill zones will likely be constructed from glacial till from local borrow areas, placed and compacted in 600 mm lifts. However, the specific requirements will be determined after construction and operation of the first phase of the project. The on-going embankment raises will be re-evaluated during mine operations to ensure that adequate storage capacity and embankment freeboard are maintained throughout the life of the mine..." The design will be reviewed on an on-going basis and modifications to drainage systems incorporated as required based on operating experience and monitoring records.

The design was later modified to include two filter zones between the core and the downstream shell: a fine filter of sand to drain excess water away from the core, and a transition filter to maintain separation between the filter and shell zones. The eventual construction design incorporated nine zones *as-placed* in the embankment as described in as-built records and reports, summarized in the table below (see also Appendix 2, Section 2.3.3).

Zone	Material Type	Function
S	Glacial Till	Till Core
B	Glacial Till, Glaciolacustrine or Granular Material	Fill Zone
C	Rockfill	Downstream Shell Zone
T	Fine Rockfill	Transition Zone/ Confining berm/Haul Road
F	Sand and Gravel	Chimney Drain, Longitudinal/Outlet Drain
G	Drain Gravel	Foundation/Longitudinal/Outlet drain
CBL	Random/Select Rockfill	Base Layer for Upstream Fill
CS	Cycloned Sand	Hydraulically or Mechanically Placed as Upstream Fill
U	Random Fill and Tailings Sand	Upstream Fill

Glacial Till Core (Zone S and Zone B). Fine-grained glacial till for Zones B and S were sourced from borrow areas around the perimeter of the TSF or within the TSF impoundment (during early years of construction). Zone S was reported to be glacial till comprising a medium to low plastic silty sand to sandy silt material, with some gravel, and trace to some clay. Zone B was only placed in Stages 1 and 2.

Upstream Support for the Till Core (Zone U, Zone CS, and Zone CBL). The material used in the support zone upstream of the till core varied throughout operation and has a high variability in gradation and material characteristics. Zone U generally comprised gravelly sand fills with variable fines content (3% to 62%) or zones of tailings placed hydraulically in cells (silty sand with fines content of 10% to 45%).

Downstream Support for the Till Core (Zone C). Zone C rockfill materials were quarried from rock exposures or mine pits. Zone C is rockfill comprising fine to coarse gravel with trace to some sand, some cobbles and trace of boulders. As-built records report up to 10% fines. Compaction was applied by a vibratory smooth drum roller and by the passage of trucks and other construction equipment. Zone C was designed with a downstream slope of 2H:1V, which was also the slope required for site restoration once the mine closed.

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Filters (Zone T and Zone F). Filter materials for Zones F and T were processed from the rock-fill by crushing and/or screening. Zone F (fine filter) comprised sand and gravel and Zone T (coarse filter) comprised gravel with some sand and trace cobbles. Fines content typically ranged from 0% to 15% for both materials.

Embankment zonation generally conformed to this plan throughout the dam's construction. The photo of the dam crest on the South Embankment (Figure 5.6), taken after the 2012 construction season, show the typical layout of these zones.

Figure 5.6 Typical Embankment Zonation
AMEC Environment and Infrastructure (2013a), photo 19

5.6.3. QUALITY ASSURANCE/QUALITY CONTROL

KP set out a Construction Quality Assurance (CQA) program for TSF construction in a site inspection document in May 1995 with specifications, standards, procedures, and criteria for site QA. The program was duplicated with little change throughout the lifetime of the facility in periodic operations, maintenance, and surveillance (OMS) manuals.

The CQA program included appointment of a Resident Engineer, a KP representative on site to oversee all activities at the TSF, including construction carried out by MPMC or a construction contractor. The program called for a Resident Engineer, a Senior Technician, and a part-time Project Manager — all KP employees — to represent the Engineer of Record on site.

Procedures for approval of work at key points (Construction Hold Points) were listed, and included a written approval process for work completed at each point.

A comprehensive inspection procedure included the following elements of the TSF embankments:

- Inspection of setting out criteria;
- Inspections and testing of embankment foundations;
- Inspection of the installation of the foundation drains and pipeworks;
- Inspection and installation of the foundation instrumentation;
- Inspection and testing of the borrow and fill materials;
- Inspection of the toe drain and pipework installations; inspection and testing of pond foundations and berm fill materials; and
- Inspection of the installation of the drain monitoring sump.

Responsibility for timely and accurate as-built reports and plan drawings was incorporated into the CQA program as well.

5.7. MINISTRY REVIEW

Review of the TSF was carried out as part of the overall mine project approval. At that time the MEM review of the initial KP design report queried three main areas:

Adequacy of Storage Capacity for Future Mining Opportunities. In an update planning document dated January 25, 1996, the issue was questioned by MEM: "In the event that Imperial Metals may find more ore and tailings volume increases, the dam should only be increased in height by the downstream method." Subsequent dialogue between KP and MEM geotechnical engineers suggest that KP was designing to accommodate additional dam raises beyond 960 m.

The inquiry received the response as follows: "The design currently incorporates a buffer zone of approximately 35 m immediately downstream of the toe of the final embankment limits. The storage capacity of the tailings impoundment could be easily expanded to accommodate over 30 million additional tonnes of tailings by raising the final embankment crest by about 17 m using the centerline construction method."

Adequacy of Site Investigations. Additionally, the sparse number of test boreholes for the dam foundation was raised by MEM. "Only one drill hole appears to have been drilled in the main embankment area. *In B.C. valleys there is always the possibility of buried high permeability zones*. It is recommended that 2 more boreholes to expand the geotechnical information be drilled and tested." (italics added)

The KP designers agreed with this assessment, and in fact drilled three additional boreholes to develop those data points. During this period of initial construction of the TSF, the focus of foundation characterization remained on the Main Embankment, which was the location selected for the additional boreholes.

Detailed Design Review. Ongoing review of the design, leading into permitting, was carried out by MEM and included retention of two external review consultants. These activities are further described in Section 6.2.5 of this report.

FOOTNOTES

1 *Knight Piésold (1995a) p 15*
2 *Knight Piésold (1995a) p. 5*
3 *Knight Piésold (1995a) p. 12*
4 *Knight Piésold (1995a) p. 13*
5 *Knight Piésold (1995a) p. 21*
6 *Knight Piésold (1995a) p. 21*
7 *Knight Piésold (1995a) p. 60*
8 *Knight Piésold (1995a) p. 47*
9 *Knight Piésold (1995a) p. 27*
10 *Knight Piésold (1995a) p. 9*
11 *Knight Piésold (1995a) p. 10*
12 *Haile and Brouwer (1994)*
13 *Knight Piésold (1995a) Table 6.1*
14 *Knight Piésold (1995a) p. 33*
15 *Knight Piésold (1995a) p. 9*
16 *Knight Piésold (1995a) pp. 26-7*
17 *Knight Piésold (1995a) p. 11*
18 *Knight Piésold (1995a) p. 28*
19 *Knight Piésold (1995a) p. 29*
20 *Knight Piésold (1995a) p. 38*
21 *Knight Piésold (1995a) p. 39*
22 *Knight Piésold (1995a) p. 19*
23 *Knight Piésold (1995d) p. 16*
24 *Knight Piésold (1995a) p. 56*
25 *Knight Piésold (1995a) p. 26*
26 *Knight Piésold (1997b) p. 24*
27 *Knight Piésold (1995b) p. 9*
28 *Knight Piésold (1995a) p. 39*
29 *Knight Piésold (1995c)*
30 *Knight Piésold (1995c) p. 11*
31 *Knight Piésold (1996) pp. 6-7*
32 *Knight Piésold (1996) p. 2*

6 TSF CHRONOLOGY

This chapter provides a narrative summary of the history of the Mount Polley tailings storage facility (TSF) throughout its lifetime up to August 3, 2014. The chronology relies extensively on documentation provided to MEM by MPMC, in particular a series of Construction Manuals submitted in support of *Mines Act* permit amendment applications (*Mines Act* permit M-200), which were required at each stage in the facility's raises; and a corresponding series of as-built reports, required by MEM upon completion of each raise. The chapter is a summary of highlights of the TSF's history, not an exhaustive documentation of all activities and decisions surrounding the TSF.

TSF HISTORY

construction began in 1996 and continued until the moment the breach occurred in 2014

The chapter structure reflects the cyclical construction process used for the TSF. The TSF was built with a series of stages, each spanning one or more construction seasons, which raised the crest of the embankment high enough to meet the capacity requirements for each time period. Although each stage was designed and permitted discretely, the construction and operation of the TSF was an ongoing and continuous process.

The chronology is an important element in understanding the roles that the engineer, MPMC and MEM staff played over the life of the TSF. The chronology also highlights the dynamic nature of the construction process and the complexities involved in the evolution of the TSF's design, construction and management.

The chapter also addresses changes over time in TSF oversight, engineering consultants, economic conditions, and other elements during the life of the mine.

6.1. CONSTRUCTION STAGES

The TSF was designed and constructed in a series of lifts (stages), each of which was driven by a variety of variables, including mine plan, milling process water requirements, storage capacity for tailings, and storage capacity for mine-influenced water driven by current water balance constraints. In addition, the stages were dependent on a sufficient supply of construction materials (quarry or run-of-mill rock) as well as construction capacity, including adequate time in a construction season and logistics limitations such as equipment availability or weather constraints.

The chronology of construction stages, dam crest elevations, and engineering consultant responsibility is summarized in Figure 6.1.

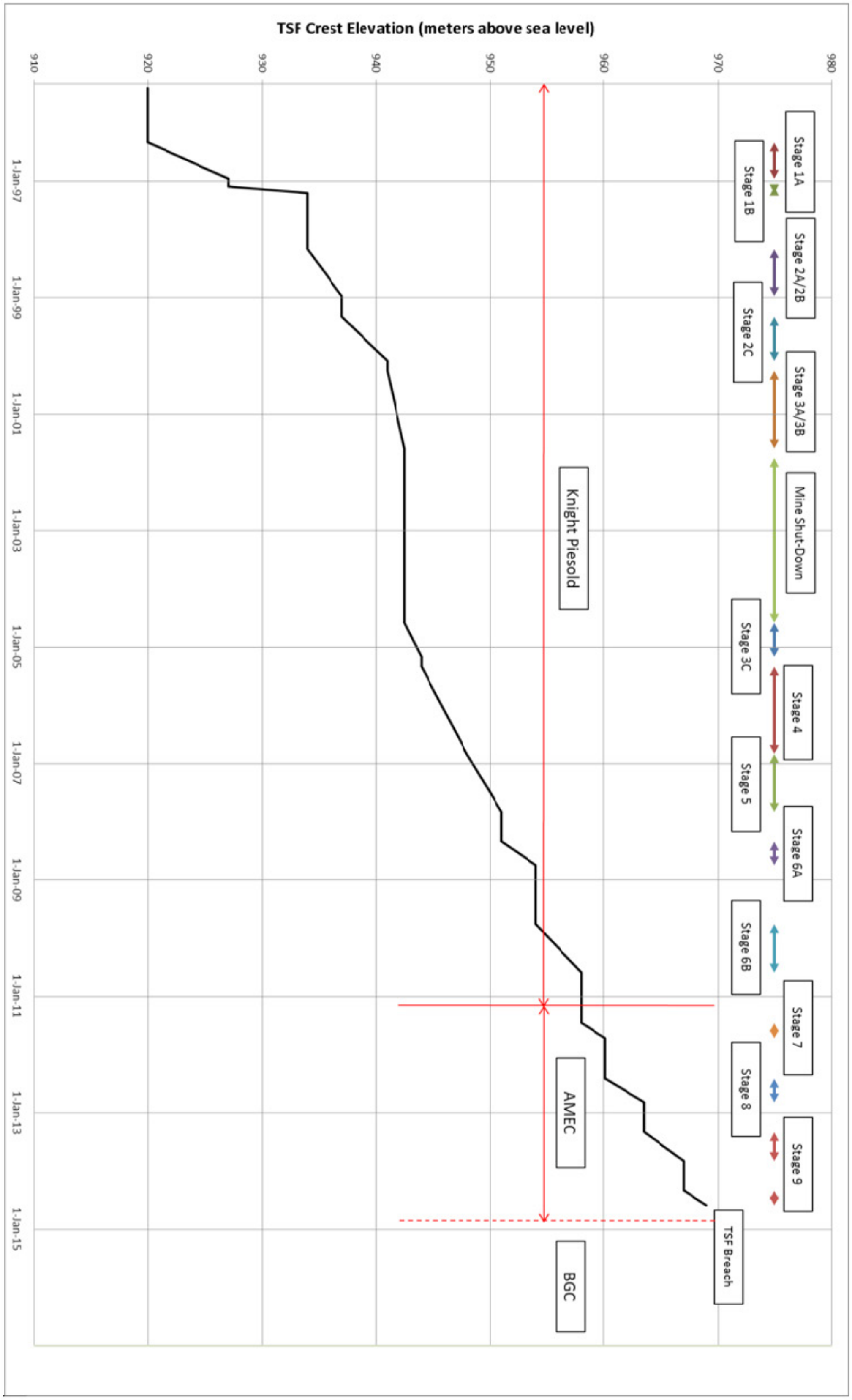

Figure 6.1 TSF Construction Stage Chronology with Crest Elevation and Engineering Consultant Appendix 3, p. 42

6.2. STAGE A TO 931M – 1995-1996

6.2.1. PERMITTING

The initial permit for Mount Polley Mine, issued August 3, 1995, approved the construction of a starter dam for the TSF to an elevation of 931 m. (For reference, the lowest point in the topography of the Main Embankment (ME) Set-Out Line (SOL) was approximately 920m.) Permission was granted for clearing, grubbing, and stripping of soils and overburden across the TSF site. The permit stipulated that freeboard for the pond include storage for a 24-hour PMP and one metre for wave run-up. It also required submission of an operating manual, including a "water management plan, which addresses normal and extreme operating conditions," and set forth the requirement for an annual tailings dam report, submitted by March 31 of each year.

Review and additional requirements relative to the initial design were addressed by a number of MEM staff and contract personnel. These contributions are addressed in Sections 6.2.5 and 6.3.5.

6.2.2. DESIGN

Design of the starter dam conformed to the initial design documents, as presented in Chapter 5.

6.2.3. CONSTRUCTION

Construction of the Stage Ia embankment at the ME was only intended to capture a full year of surface runoff, including the 1996 freshet, prior to mill start-up to ensure that adequate water reserves would be available for operations.

PE construction was limited to stripping and clearing of the footprint (to a design width adequate for the 931 m raise), installation of toe drain outlet pipework and toe drain to elevation of 931 m, and construction of the PE seepage pond.[1]

The stage included "excavation of exploration trenches to define the limits of the glaciofluvial sediments in the tailings basin and the Main Embankment foundation."[2] The purpose of determining areal extent of these soils was to ensure that the initial basin was adequately lined with locally-obtained glacial till, and was not focused on identifying foundation conditions.

6.2.4. OPERATION

An Operations, Maintenance and Surveillance manual (OMS) was prepared for the TSF by KP in 1997. The OMS is a guidance document required by the Code for all mine impoundments. The OMS contained an organizational chart of persons responsible for the facility, including the dam coordinator (the mill superintendent), the dam operator (the mill shift foreman), and technicians (maintenance crews, etc.). It required a daily visual inspection of the facility by the dam coordinator. The OMS also described an annual inspection by a suitably qualified Professional Engineer, with an annual refresher training course for all persons involved in the TSF.[3]

The OMS required the dam operator to monitor, log all observations, and ensure prompt reaction to unsafe or unusual situations to provide for "continuous surveillance of the facility."[4]

Milling of ore commenced June 13, 1997, with a design throughput of 13,500 tonnes per day (tpd).[5]

6.2.5. MEM INSPECTIONS AND OVERSIGHT

Throughout the initial design phase, MEM inspectors raised design concerns, requested additional description and explanation of plans, and proposed additional design verification for the TSF.[6]

An external, independent review of the TSF design was required by MEM on September 5, 1995, the terms of which were limited to the current Stage (ME). This review was carried out by Chuck BRAWNER, P.Eng.[7]

In his report, BRAWNER provided review comments on the KP design report for the Mount Polley project. He observed, "from environmental, volume storage and tailings dam height considerations it is recommended that Imperial Metals be requested to review in detail the potential to mine the pit sequentially and place tailings in them on completion of Pit 1 followed by Pit 2. The stability and environmental benefits are significant. There may also be a cost saving."[8] BRAWNER's review comments also included:

- site investigation
- glaciofluvial sediments in the tailings basin;
- underdrains;
- seepage collection pond;
- filter design;
- random fill;
- compaction;
- groundwater monitoring wells;
- compaction tests;
- seepage collection pond dam;
- stockpile stabilization materials for urgent use;
- modified centerline design; and
- winter operation.

Four geotechnical inspections of the TSF site were conducted during this stage to review site preparation activities for the starter dam. The inspections were carried out on September 20, October 11, and October 19 of 1995, and August 26, 2006. All were focused on the initial development of the starter dam, restricted to the ME and the TSF liner and borrows.

A geotechnical inspection was conducted by George HEADLEY on September 20, 1995. HEADLEY noted, "the site was being cleaned and grubbed. Test pit locations, sediment control measures, surface drainage trench locations … were discussed. The proposals are satisfactory." He ordered that "the company shall have its consultant [KP] excavate and log test pits as proposed in his letter report of September 25, 1995 to the company. These shall be completed in the 1995 field work."[9]

In response, MPMC reported to MEM that 34 test pits were excavated between October 3 and 5, 1995.[10]

Follow-up geotechnical inspections were conducted by HEADLEY on October 11 and 19, 1995. The inspections included review of surface and ground water conditions, soil conditions in test pits and surface drainage trenches and sediment control system. Test pit logs, photos and the site plan provided by KP were used during the second visit. The information was to assist in design review. Additional test pits were required to define permeable or soft foundation soils.[11]

In addition, a geotechnical inspection of the TSF site was conducted on October 19, 1995 by C.O. BRAWNER, a geotechnical engineer on contract to MEM, as an independent reviewer. His inspection was carried out with HEADLEY. The inspection noted that "the site has been cleared of vegetation and numerous surface drainage trenches have been developed. The organic overburden has not been removed. All test pits have been filled back in. The [KP] report adequately describes the site. A review of the test pits indicates a sand horizon exists near the surface over a portion of the west flank of the dam site area. This sand will have a moderate permeability and under moderate head could develop piping. It will be necessary to develop a seepage cutoff to prevent such an occurrence. All of the organic overburden must be removed. The excavation of the surface glacial till leaves a smooth surface. To tie the first layer of fill and disrupt the smooth surface, that surface must be scarified."[12] No other concerns with site preparation were noted.

BRAWNER followed up on the site inspections with a review of the KP initial design documents, and provided recommendations for construction practices.[13]

On July 23, 1996, HEADLEY informed MPMC "prior to [MEM] issuing Permit Amendments for construction above elevation 934 metres we require that you retain a qualified tailings dam expert, independent of your current consultant to review the foundation conditions for the dam site, your particular storage requirements, the design of the dam and make recommendations for the most efficient and safest dam design."[14] The independent review was conducted by one of the MEM-recommended engineers, Fred MATICH. The review was performed in accordance with the scope defined by MEM: "[the] initial terms of reference were for a water storage dam. Initial work and reporting was for impoundment foundation and starter dam. Next portion of review work was to be the upstream part of the design." [15]

The scope of the Matich review was limited to the ME, particularly with respect to the basin liner, underdrains and internal drainage of the embankment. The report considered geotechnical characteristics of the foundation soils, supplemented by additional data developed by KP during the review. Artesian groundwater conditions were observed. No significant concerns regarding embankment design, site conditions, or drainage were raised. The review concluded that the integrity of the initial basin liner, particularly in the ME area where till depths were minimal and underlying glaciolacustrine/glaciofluvial sequences were encountered, should be "checked for effectiveness," as should the potential for frost penetration at certain portions of the liner. A downstream berm of the ME was suggested to minimize potential piping, as was a more comprehensively implemented surveillance and monitoring program. Matich suggested several improvements to the toe drain design, including redundancy. [16]

A geotechnical inspection was conducted by HEADLEY on August 26, 1996. The TSF was undergoing site preparation. HEADLEY observed soil stripping at the ME foundation and discussed foundation drainage options with KP (EMBREE). He also noted that wet weather was contributing to slowed construction of the starter dam.[17]

6.3. STAGE I(B) TO 934M – 1996-1998

6.3.1. PERMITTING

This amendment was identified as "Stage I(b)" and authorized a raise to an elevation of 934m. The amendment was filed on September 5, 1996 and approved on September 23, 1996. The permit conditions stipulated that freeboard for the pond include storage for a 24-hour PMP and one metre for wave run-up. It also required that the "Permittee shall obtain permission from the Chief Inspector prior to storage of water, tailings, or supernatant within the impoundment."

6.3.2. DESIGN

Design of Stage I(b) conformed to the specifications in the initial design documents (see Chapter 5). The stage consisted primarily of continued construction of the starter dam at the ME, with an initial embankment along a portion of the PE to 934 m.

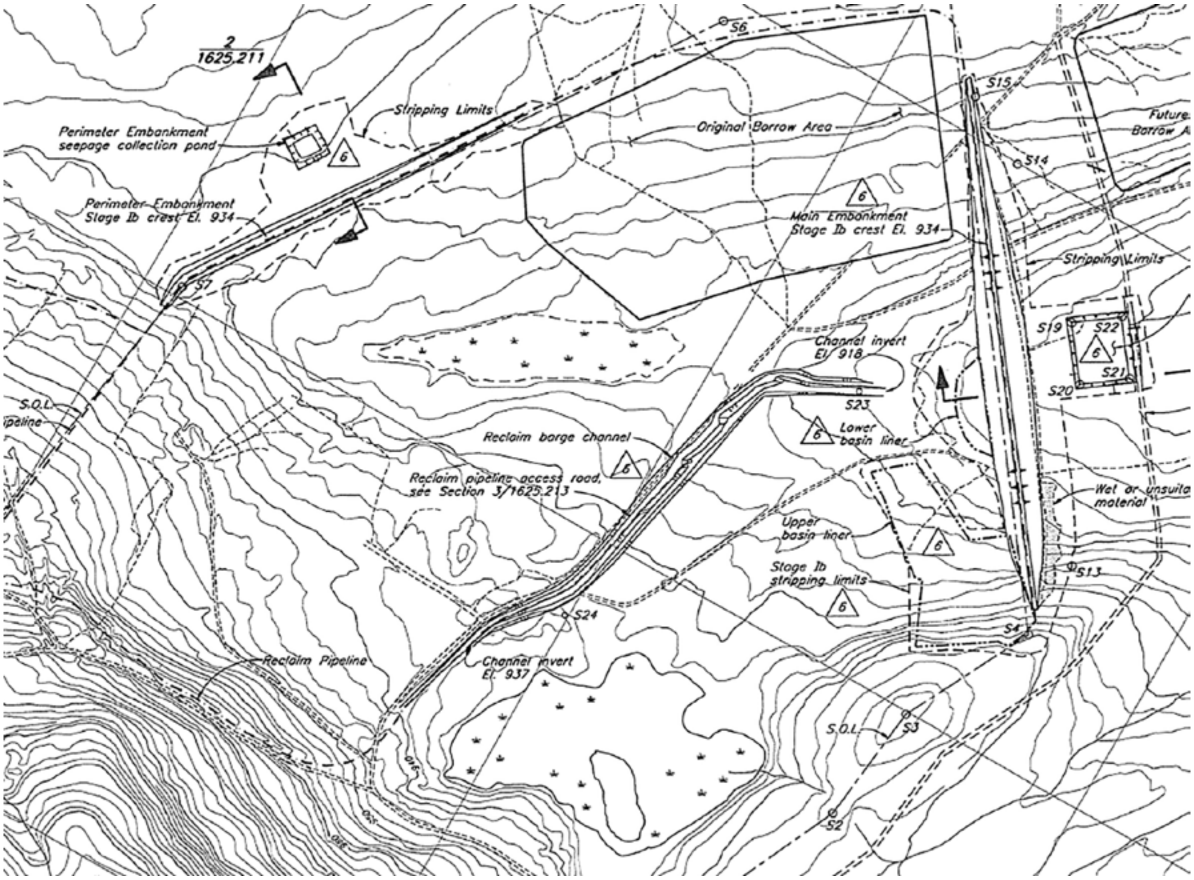

Figure 6.2 *PE Design, Stage I(b)*
Knight Piésold (1995d) Dwg. 1625.205

Investigation data collected in 1996 and early 1997 were presented in the KP *Updated Design Report* (KP 1997b). Drilling programs during 1996 and 1997 comprised the following (for additional detail, see Appendix 3, Section 3):

- 6 groundwater monitoring wells were installed around the perimeter of the TSF, downstream of the embankments. The holes were drilled through overburden with a tricone bit and standard penetration tests (SPTs) were performed at 3.1 m to 6.1 m intervals in most holes. GW96-1 and GW96-2 were drilled downstream of the PE at stations 4+020 and 3+260, respectively.
- Vibrating wire piezometers (VWPs) were installed in the foundation of the ME at 3 locations. The holes were drilled with a hollow stem auger. Continuous SPTs were performed in the top 10 m and samples were collected. Sample testing results, if any, were not reported.
- 4 pressure relief wells were drilled using a solid stem auger in the foundation of the ME. Two samples collected in the GLU were tested for moisture content.
- 5 seismic cone penetration test (CPT) soundings were performed in the foundation of the ME.
- 4 pressure relief trenches were excavated in the ME foundation. Data collected during the excavations were not reported.
- 25 shallow holes were drilled in Borrow Area No. 1 (original borrow area) within the TSF basin to determine the maximum depth of the glacial till. The holes were drilled with solid and hollow augers. Split spoon and auger flight grab samples were taken for laboratory testing; testing results were not reported.

A large number of test pits were excavated in 1996/early 1997 both inside and outside the TSF basin primarily to determine the required extent of the natural basin liner and to assess the suitability of construction fill borrow sources. The number of test pits excavated and their locations are summarized below:

- 19 east of the PE and 14 at the west end of the reclaim barge channel to locate a borrow source for filter sand;
- 28 in the upper natural basin liner area, upstream of the ME near the abutment with the SE;
- 14 in the lower natural basin liner area, upstream of the ME;
- 13 in Borrow Area No. 3 (Alternate Borrow Area) southeast of the TSF;
- 4 in the reclaim barge channel;
- 2 downstream of the ME toe; and
- 83 in Borrow Area No. 1. Twenty samples were collected from the excavations for index testing.

After the *Updated Design Report* was issued, additional test pits were excavated in 1997 to investigate borrow areas and to gather more information for the PE foundation conditions. The investigations included:

- 21 test pits in Borrow Area No. 4, within the TSF basin upstream of the PE. Moisture content samples were collected in each of the pits.
- 18 test pits in Borrow Area No. 2 (Future Borrow Area), located southeast of the TSF downstream of the ME. Moisture content samples were collected in each of the pits.
- 22 test pits in Borrow Area No. 3. Moisture content samples were collected in each of the pits.
- 4 test pits in the PE foundation. The pits were excavated to a depth of approximately 5 m and moisture content samples were taken. No GLU was encountered in these pits.

Prior to mill startup, the TSF stored 2.1 million m^3, including 670,000 m^3 pumped from Polley Lake and the captured 1997 freshet.[18]

6.3.3. CONSTRUCTION

Construction of the PE began with Stage 1b. Due to the elevation of the ground at the embankment site, only a small section of the embankment was required. The elevation of the PE Set-Out Line (SOL), the surveyed line that marked the eventual centerline of the dam crest was approximately 930 m at the general location of the breach. The PE raise to 934m was completed in March 1997.[19]

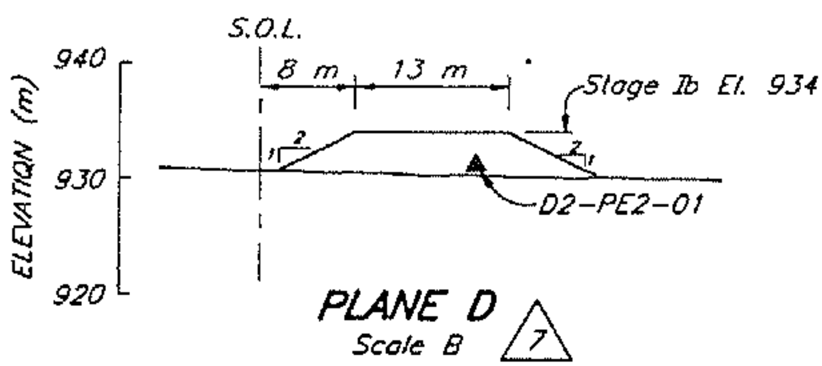

Figure 6.3 PE As-built (Instrumentation Section), Stage I(b)
Knight Piésold (1997a) Dwg. 1625.220

6.3.4. MEM INSPECTIONS AND OVERSIGHT

A geotechnical inspection was conducted by HEADLEY on September 27, 1996. With respect to the TSF preparation, the report noted, "design, site investigations at this stage, construction quality, and geotechnical engineering are satisfactory." [20]

On March 14, 1997, HEADLEY reviewed the OMS for Stage 1a, and authorized MPMC to fill the impoundment and operate the tailings facility for water storage.[21]

A geotechnical inspection was conducted by HEADLEY on July 21, 1997. The inspection "confirmed as built conditions and water impoundment performance for approval to deposit tailings. Conditions were very good." The inspection report identifies the areas inspected, which included the ME and PE.[22]

6.4. STAGE 2 – 1998-2000

6.4.1. PERMITTING

An application for a *Mines Act* permit amendment to raise the dam to 940 m was received on April 2, 1998 and approved on April 7, 1998. The raise was identified in the amendment as "Stages [2] A, B and C." The permit called for revised water balance work by the mine: "A revised water balance for the tailings facility, using recent precipitation data from the mine site and, if warranted, a contingency plan to handle excess water, shall be submitted as part of the 1998 annual tailings report." [23]

6.4.2. DESIGN

In Stage 2, the modified centerline design (see Section 5.3.1) was used. It included a raise of both core (Zone S) and chimney drain (Zone F), and initiated Zone C, the downstream toe rockfill. The raise for Stage 2 was based on an increased throughput of 17,808 tpd with a full production startup date of August 1, 1997. The stage was intended for three lift phases, each encompassing a raise of 2 m to a height of 940 m.[24]

Investigations in Stage 2A (1998) were focused on borrow area determination and delineation of the basin liner extent. The investigations (see Appendix 3) comprised:

- 12 drill holes in Borrow Area No. 4. Drill rig type and drilling logs were not reported by KP. Three samples were collected for index testing.
- Eleven drill holes in Borrow Area No 2. Drill rig type and drilling logs were not reported by KP. Four samples were collected for index testing.
- 19 drill holes upstream and within the footprint of the SE to delineate the basin liner area. Drill holes were advanced to a maximum depth of approximately 7.5 m; the drilling method was not reported. Three samples of glacial till were collected for index testing. One sample of GLU was collected for moisture content determination.

In 1999 (Stage 2C), site investigation included:

- 44 drill holes upstream of the SE near the right abutment to further delineate the natural basin liner extent. The depth of drilling varied but the maximum depth achieved was approximately 9 m. 14 samples of glacial till and 2 samples of GLU were collected for index testing.
- 91 shallow holes drilled around the perimeter of the TSF to "evaluate the potential for seepage infiltration into foundation materials during hydraulic placement of cycloned sand" [25] Drilling depth was variable but a maximum depth of 7.5m was achieved. Twenty-three of these holes were located just downstream or within the PE footprint with some within the future breach area. SPTs were performed in most holes; no laboratory testing data was reported.
- Twenty-three CPT soundings upstream of the PE and ME and downstream of the PE to assess the properties of the cycloned sand trial berms and the tailings beach.

Based on the *Mines Act* permit amendment condition, MPMC submitted a water management plan, received by MEM on April 8, 1998. Based on over 1,000 different meteorological scenarios, MPMC proposed a deficit water balance that would impound up to 2.5 million m^3 of water in the tailings impoundment prior to startup, ensuring that 1.9 - 2.5 million m^3 would be available in the impoundment during ongoing mine operations and allowing for contingency extraction of up to 1.0 million m^3 from Polley Lake during dry periods.[26]

6.4.3. CONSTRUCTION

Construction of Stage 2 was split into three segments: 2A, from January - May 1998, resulted in a raise to 936 m; a limited Stage 2B, from September - December 1998 (halted in October and November due to rainy conditions) raised Zone S to 936.7 m. The planned construction raise to 938 m was not warranted by production rates. The third segment, 2C, completed the raise to 941 m from April 1999 to February 2000.[27]

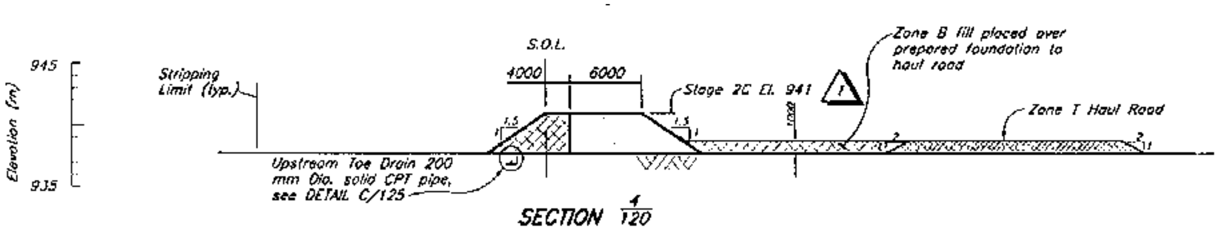

Figure 6.4 PE As-Built Section, Stage 2
Knight Piésold (2000) Dwg. 11162-10-121

6.4.4. OPERATION

A total of 45 piezometers were installed prior to Stage 2, with 16 in embankment foundations; an additional 10 instruments were planned for installation in Stage 2.[28]

6.4.5. MEM INSPECTIONS AND OVERSIGHT

A geotechnical inspection was conducted by George HEADLEY on June 11, 1998, to confirm the as-built conditions of Stage 2 construction for 1998. He observed minor tension cracking along the upstream crest side of the ME, which resulted from settlement of fine tailings between spigotting locations. KP stated there would be no effect on core stability or permeability performance.[29]

HEADLEY conducted a geotechnical inspection on July 12, 1999. He noted a "waste dump 20,000 tonne failure of the south side of the dump, which was caused by wet weak foundation soils and excess pore pressures in a swampy flat area. These conditions appear to exist over much of the area south of the dump. Therefore potential failure conditions will continue for the foreseeable future." HEADLEY recognized MPMC's failure to report a geotechnical incident, absence of dump failure procedures, and control measures taken by the mine, which he discussed with PARSONS.[30] While this event does not relate to the TSF, it suggests a lack of risk recognition by MPMC.

6.5. STAGE 3 – 2000-2001

6.5.1. PERMITTING

Stage 3 of the dam raise was developed over two separate *Mines Act* permit amendment applications. The first, received on June 2, 2000 and approved on June 13, 2000 approved a raise to 944m. The permit specifically did "not approve the use of sand fill for downstream shell construction," and focused on the geochemical characterization of rockfill used in shell construction (Zone C). The concern was around restricting the use of acid-generating rock — a condition that did not materialize in either mill tailings or rockfill used in dam construction.

An additional permit amendment application for Stage 3, to increase the raise by 1 m to 945 m, was submitted on May 16, 2001 and approved May 30, 2001. The amendment included an evaluation of using cyclone sand from tailings as dam fill. The amended permit highlighted the following areas of concern: "visual and instrumentation monitoring and reporting shall be carried out in accordance with the schedule provided by Knight Piésold Ltd. Two slope inclinometers shall be installed in the downstream slope of the main tailings embankment." [31]

6.5.2. DESIGN

In 2000, three holes were drilled downstream of the SE to install groundwater monitoring wells. The holes were advanced to a depth of 21 to 24 m. SPTs were performed in two of the holes. No soil samples were tested.

Holes were drilled in 2001 for instrumentation installation and borrow source determination (see Appendix 3):

- Two slope inclinometers were installed at the downstream toe of the ME to monitor foundation movements. The installations were drilled to a depth of 24.5 m and 30.5 m. SPTs were performed at regular intervals through the overburden. No soil samples were taken for laboratory testing.
- 66 shallow holes were drilled southeast of the TSF near Borrow Area No. 2 to assess the suitability of the till in the area for construction material. Hole depth ranged from approximately 1 to 12 m with moisture content samples collected in the majority of the holes.

While the design of Stage 3 represented a continuation of the previous stages, the mine undertook the evaluation of a major design change: to incorporate coarse sand sourced from cycloned tailings for use in construction of Zone C shell fill. This test phase, concluding in June 1999, validated the method and its suitability for stable embankment construction.[32] Modifications to the cycloned sand approach were made, largely for operational flexibility and construction scheduling.[33] These modifications included mechanical placement of cyclone sand in the downstream zone of the PE and placement of an upstream toe drain, among other changes. The eventual embankment would have an ultimate downstream slope of 3H:1V. Since a chimney drain is considered unwarranted when Zone C fill is cyclone sand, the updated design eliminated the chimney drain zone beyond Stage 2.[34] Ultimately the cyclone tailings design was not pursued. As indicated in the report on cyclone sand construction dated December 13, 1999, daily volume of tailings throughput was expanded to an estimate of 20,000 tonnes per day.[35]

6.5.3. CONSTRUCTION

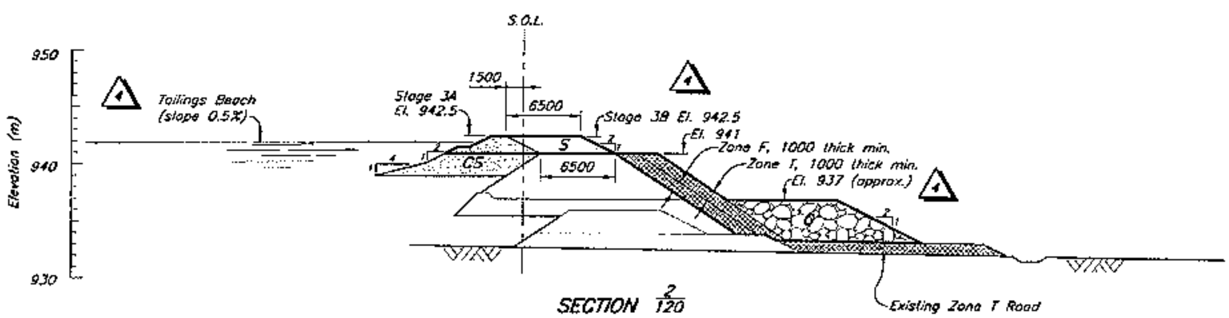

Figure 6.5 *Typical As-Built PE Section*
Knight Piésold (2001) Dwg. 11162-13-125

No section drawings of the Stage 3 as-built PE were made at the critical section (the location of the breach). Figure 6.5 depicts a section of the PE to the southeast of the breach area, similar to the area of interest, though somewhat lower in overall height. Documentation presented an embankment built in general accordance with the approved design.

6.5.4. OPERATION

Normal operations continued during this stage until the mine went into care and maintenance status in October 2001 (see section 6.6).

6.5.5. MEM INSPECTIONS AND OVERSIGHT

In a letter to MPMC (BROUWER) dated January 24, 2000, HEADLEY commented on the cyclone sand approach to embankment construction proposed for Stage 3. He specified aspects that required more detailed information, to be discussed at an upcoming meeting with the mine, including: operations, construction methodology, design, stability analysis, risk assessment, monitoring and operational controls. He referred to specific issues critical to a risk assessment: "risk minimization, detailed discussion of medium and high risk potential problems, vertical drainage, detailed risk assessment of operating problems and construction methodology with monitoring and operational controls and contingency controls in event of failures, and use of sensitivity analysis to set piezometric trigger levels for phreatic surface in active cycloning construction."[36] These comments were repeated in the meeting held February 13, 2000.[37]

In a letter to BRAWNER dated February 4, 2000, EATON requested a review of documents for MPMC, including the report on cycloned sand construction for Stage 3 and future stages of the TSF (Volumes 1 and 2). EATON noted, "MPMC is anxious to move to cyclone sand construction for their TSF dam. We are concerned that they may not have completed realistic cost estimates and recognized all the construction difficulties."[38]

Correspondence between MEM Inspectors Brian MCBRIDE and CARR dated May 1, 2001 identified MPMC risk management concerns: "the tailings line has sprung several leaks, all tails are held within containment structures. [MPMC recognized the problem] at the upper end of the tailings line, the back eddy caused from the inside bead at the joints has eroded the inside of the pipe causing the rupture; the lower end has flat spots in the line--the result of the raising of the tailings line--with the increasing level of the tailings impoundment; large air bubbles are trapped in the line reduce the cross-sectional flow area, increases pressure and causes leaks at the joints. Vacuum breaks will be installed when the line is reconstructed during the June shut-down to eliminate the air bubbles."

CARR was concerned about the location of the tailings line, given the higher risk of its location if the line breaks. MCBRIDE responded that he had not read inspection report, and that he would follow-up with MPMC and KP. He also noted another concern: "the lack of storage volume in the containment structure itself. If there was a major rupture, the sands would fill that narrow containment structure quickly and there are no dump ponds along the way." CARR responded, "you may want to stress on MPMC the importance of moving the tailings line, if they have not already done so, due to the added risk now that the pipeline is leaking."[39]

CARR conducted a geotechnical inspection on May 3, 2001 with MPMC and KP personnel. Following a review of construction and materials on the ME, CARR stated, "the Ministry would strongly support the installation of two slope inclinometers at the downstream toe buttress (ME) to monitor potential dam and/or foundation movement. The slope inclinometers should extend through the underlying glaciolacustrine sediments."[40]

MPMC Manager George WIGHT responded to CARR's comments on May 21, 2001. The manager reported submitting the documents as requested: construction drawings for the lift to 945 m and a letter of application to amend the M-200 permit were submitted May 15, 2001. Regarding installation of slope inclinometers at the downstream toe buttress [on the ME] to monitor potential dam and/or foundation movement, MPMC forwarded the matter to their geotechnical consultants (KP) for review. The manager confirmed the tailings pipeline was relocated onto the tailings beach on the upstream side of the PE during the week of May 8, 2001.[41]

6.6. SHUTDOWN– 2001- 2005

Mine operations were suspended on October 13, 2001. The mine was placed in care and maintenance status.

6.6.1. CARE AND MAINTENANCE

Over the course of the closure, substantial water accumulated in both the pits and the TSF. Additional accommodation for water management was made for the care and maintenance period. On February 7, 2002 MPMC received a *Mines Act* permit amendment for entering into care and maintenance for transfer of supernatant water from the TSF to the Cariboo Pit and release of effluent from the PE and ME seepage ponds to nearby surface water courses. This approach was requested noting that dam raises would not be feasible during shut down conditions. Upon re-starting the mine and milling operations, an additional amendment was issued. It included pumping of pit water to the tailings impoundment and removal of the PE settling pond discharge, which was now pumped back to the tailings impoundment. The mine had also requested discharge from the tailings impoundment to Polley Lake but this was not approved by MOE.[42]

During the care and maintenance period, all permit conditions attached to *Mines Act* Permit M-200 continued in force, including obligations for annual dam safety reviews and OMS compliance. A permit condition on temporary shutdown stated, "if this mine ceases operation for a period longer than one year, the Permitee shall either continue to carry out the conditions of the permit or apply for an amendment setting out a revised program for approval by the Chief Inspector."[43] No such amendment application was submitted during this period.

A limited number of personnel were present on site, primarily for maintenance and operation of pumps for water management and discharge, environmental monitoring, mine development planning, and security. No mining or milling operations were permitted. No construction activities were undertaken on the TSF. However, planning was undertaken by MPMC to expand operations to an additional ore body (the Wight Pit) as well as another source of high-grade ore in an underground operation. This increased footprint would also expand the amount of mine contact water that would be placed in the TSF.

With the suspension of operations, the experimentation with cyclone sand for Zone C fill purposes was suspended and was not revisited in the future. No cycloned sand, with the exception of a small area (east of the breach) used for cyclone testing, was placed on the Perimeter Embankment.

6.6.2. MEM INSPECTION AND OVERSIGHT

CARR informed MPMC in a letter dated April 22, 2002 that the annual Dam Safety Inspection report for the TSF had been due on March 31, 2002. He reiterated the requirement in the Code and requested notification of the expected date of report submission within 30 days. CARR provided a copy of the revised MEM document, *Guidelines for Annual Reports, Dam Safety Inspections* (updated February 2002).[44] A geotechnical inspection of the Mount Polley mine site was conducted on May 6, 2002, by Brian McBRIDE. The purpose of the inspection was to observe the effectiveness of the water diversion works during the peak of the spring run-off and to tour the mine site during the care and maintenance period.

The primary function of the diversion and pumping systems was to direct natural run-off and seepage away from the TSF and discharge into the environment, while collecting any mine seepage, or run-off from the mine site, the rock disposal sites and mill site sump and direct the flow either directly into the Cariboo Pit, or into the TSF and then pumped into the Cariboo Pit preventing any discharge of these flows into the environment.

The inspection noted that contact water was being pumped from the TSF to the Cariboo Pit for 15 days in May 2002, with a target volume of 400,000 m^3, which should have been sufficient to allow for the required freeboard of 1.27m.[45]

Water balance continued to be an issue of concern to MEM during the closure period. In a letter dated June 26, 2003, to Greg SMYTH (Environmental Coordinator, MPMC), CARR noted, "the water balance data indicates a projected temporary freeboard reduction to 0.9m during the 2003 freshet period and a more significant reduction of available flood storage and freeboard in 2004. Please provide details of the plan to remove water prior to the 2004 freshet." CARR also requested that MPMC follow-up regarding slope inclinometer displacement data and survey monument data from their 2002 Annual Inspection Report. CARR further noted that an Emergency Preparedness Plan is to be issued as part of a revised OMS, and requested a copy of the revised OMS. CARR also noted that a dam safety review shall be done by a qualified person in 2006.[46]

6.7. STAGE 4 – 2005-2006

6.7.1. PERMITTING

Stage 4 marked the restart of the mine following its period of care and maintenance. MPMC requested a *Mines Act* permit amendment for restart and milling ore, which was issued May 4, 2005.[47] An application to raise the dam to 948 m was received on March 17, 2005 and approved on May 25, 2005. The raise is identified as Stage 4, and the permit amendment highlighted the requirement for a minimum freeboard of 1.39 m, as well as the requirement for three additional slope inclinometers on the Main Embankment, and a reinforcement of the requirement for "monitoring of piezometers, slope inclinometers and survey monuments … in accordance with the OMS or as specified by the design consultant." Additionally, the amended permit required that "foundation drains, toe drains and associated water collection and recycle systems shall be extended or installed as specified by the design consultant."[48]

6.7.2. DESIGN

The cyclone sand program, with its attendant construction methods, downstream shell material, and downstream slope (3H:1V) were not pursued. An updated design using rock fill for Zone C – back to the original modified centerline design parameters – was used. An "ultimate design elevation" of 965 m was introduced. A buttress was designed for the Main Embankment; the PE was maintained at a slope of 2H:1V.[49]

The design included chimney, longitudinal, and outlet drains for the PE.[50]

The PE would continue to have a core (Zone S) width of 8 m, filter (Zone F) and transition (Zone T) zones of 1 m, and a downstream rockfill shell (Zone C) comprising waste quarry rock.

Stability analyses continued to be predicated on a FoS of 1.3 during operations and 1.5 at closure. The FoS calculated for the PE for static conditions without upstream toe drains was 1.9 (2.0 with a toe drain). However, no upstream toe drain was constructed during this phase.[51]

Three slope inclinometers were installed at the downstream toe of the ME. The instruments were installed in diamond drilled boreholes advanced to bedrock with depths ranging from 35 m to 42 m. SPTs were performed at regular intervals. Soil samples were collected using a Shelby tube sampler in two of the three holes, and disturbed samples were collected from the SPTs. Select samples were tested for index properties. One consolidation test was performed on a Shelby tube sample collected in SI06-02. It is unclear from the logs whether the soil samples would be described as glacial till or GLU (see Appendix 3).

6.7.3. CONSTRUCTION

The mine recommenced milling operations in March 2005, with a mill throughput rate of approximately 18,000 tpd.[52]

The Stage 4 construction program involving a 4 m cap raise using a modified centerline design commenced in May 2005 and was completed the first week of October 2006, with placement of the Zone C downstream shell planned for April 2006.[53] However, no Zone C shell rock was placed during Stage 4 (see Figure 6.6); expansion of Zone C was delayed until Stage 5 instead.

Construction proceeded without a break throughout the winter months. Fill included core till (Zone S), upstream shell (Zone U) comprised of random fill and coarse tailings sand cells, and a coarse rockfill base over the tailings beach (Zone CBL). Zone U required being "constantly worked with a dozer to ensure proper distribution within the cells, to compact the sand and to expedite the drainage of excess water through the culverts."[54]

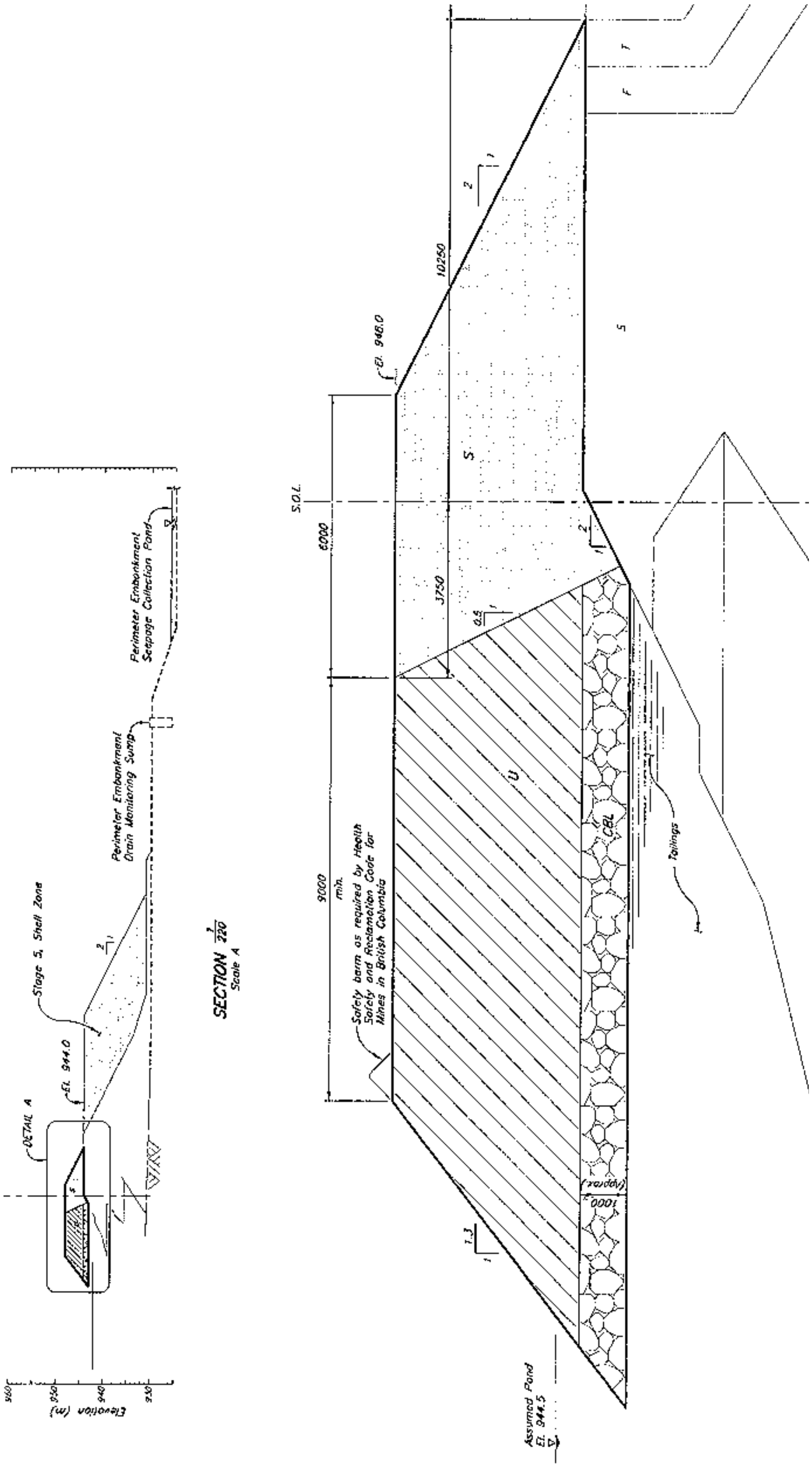

Figure 6.6 *Stage 4 PE Section, As-Built*
Knight Piésold (2007a) Dwg. 10-225 Rev. 1

6.7.4. OPERATION

Thirteen months of piezometer data are missing (July 30, 2003 – September 2, 2004), and no piezometer data were collected from September 22, 2005 through April 30, 2006. MPMC attributed the cause of the missing data to a malfunctioning readout box cable, and accidental destruction of instrument cables during construction.[55]

Twenty-two functioning piezometers were destroyed during this phase of construction. Once 5 were located and repaired, there was a total of 34 functioning piezometers.

As early as February 2004, MPMC was considering the implications of a surplus state of water balance as it designed a mine restart plan. In an email, Art FRYE conveyed Imperial Metals CEO Brian KYNOCH's recommendations: "[KYNOCH] wants a permit that will set discharge criteria for us to discharge water from the pond now and in the future so that we can discharge any time we like as long as we meet the criteria. This means that as long as we get the water to spec even if we have to treat it we can discharge it. He thinks that at some point in the future we will have to discharge water and getting the permit in place today is probably easier than it will be in the future." [56]

At restart in March of 2005, a geotechnical inspection by MEM came to the same conclusion. "There is currently no discharge to the environment from the tailings impoundment. Projected water balance indicates there will be a surplus water volume and a discharge permit will be required from the Ministry of Water, Land and Air Protection [now MOE]. Plans for discharge from the TSF shall be submitted to MEM for review." [57]

6.7.5. MEM INSPECTIONS AND OVERSIGHT

CHARACTERIZING A WEAK LAYER

MEM raised concerns about the possibility of a weaker glaciolacustrine clay unit

As part of the Stage 4 *Mines Act* permit amendment review, review of the 2005 KP report *Design of the TSF to Ultimate Elevation*, Senior Geotechnical Engineer Chris CARR raised a concern with borehole GW96-1A, located downstream of the breach location. He referred the following question through MPMC to KP: "Glaciolacustrine deposit is noted in GW96-1A on cross-sections 9 and 10 [*in Dwg. 1627.011*]. The material is described as firm. What are the characteristics and extent of this deposit and could it have an influence on dam stability locally?" The concern was discounted by KP as not being applicable to the dam footprint.[58]

The test holes located in the vicinity of the area of the breach included: MP89-231 (condemnation drill hole), and GW96-1A (groundwater monitoring well), which are shown in plan on Fig 6.7 and in section on Fig. 6.8. The highlighted section represents a lower-strength clay unit.

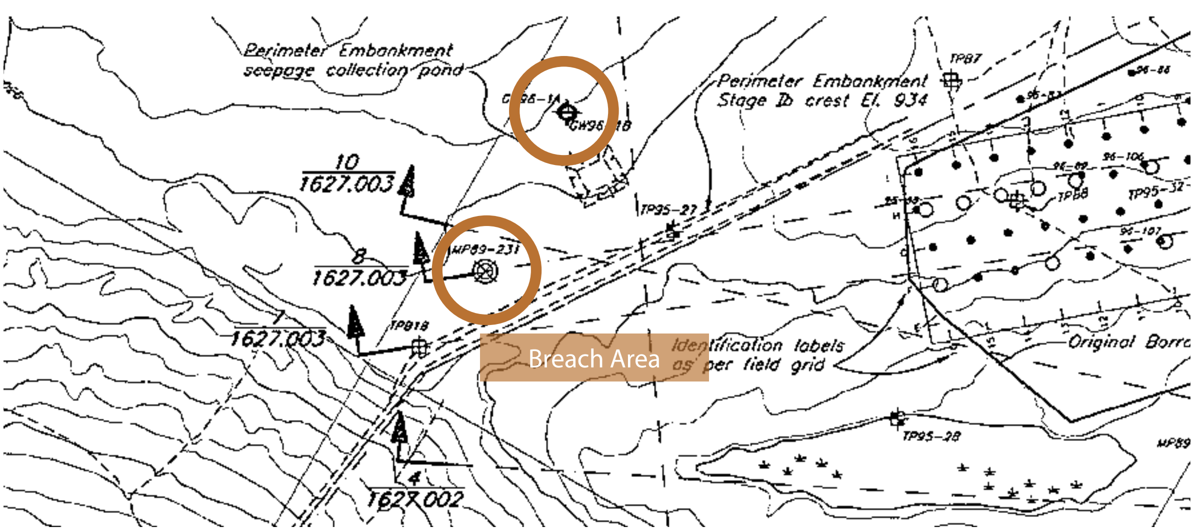

Figure 6.7 Location of Borehole MP89-231 and GW96-1A
Knight Piésold (1995d) Dwg.1627-001

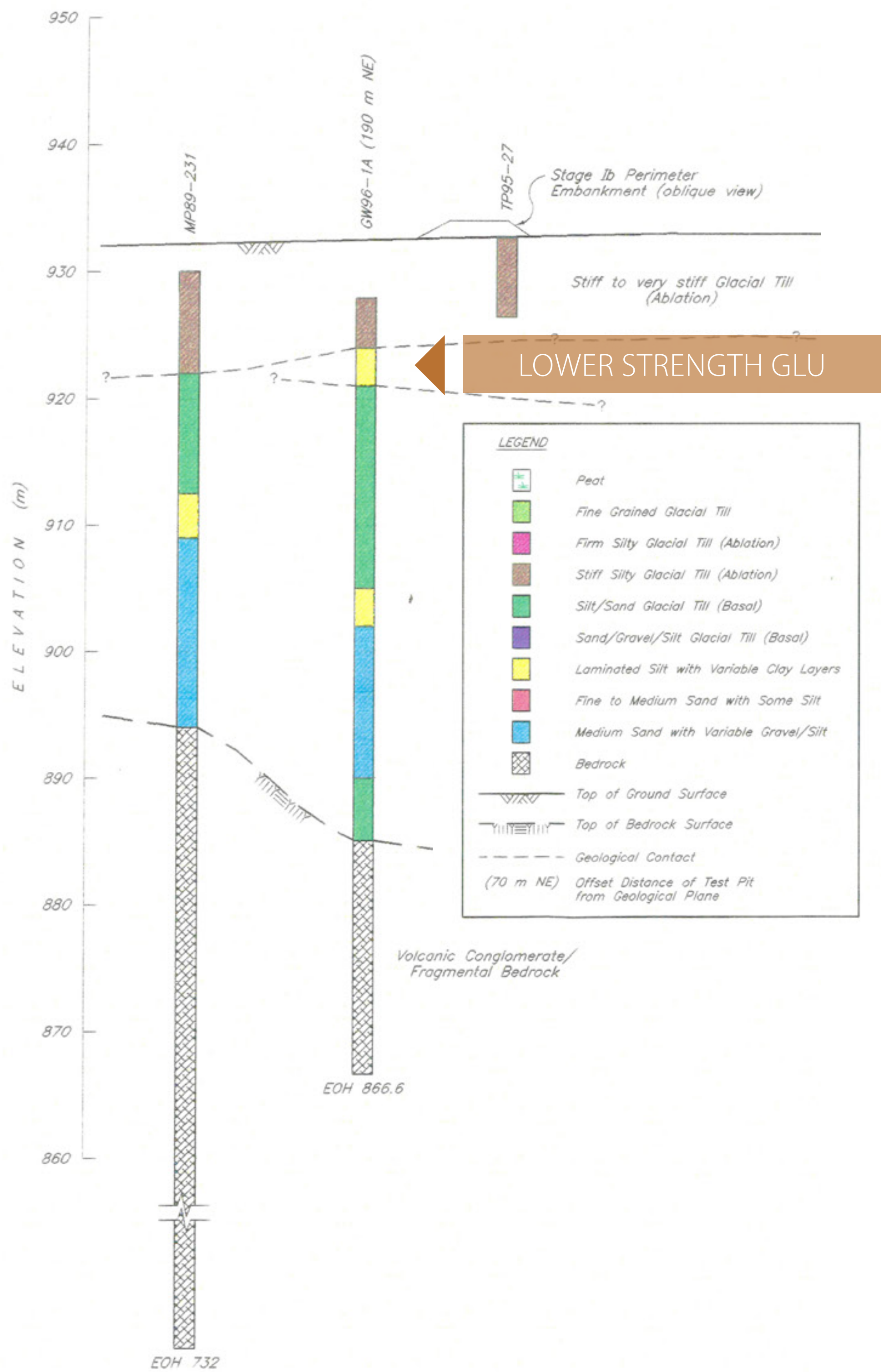

Figure 6.8 *Profile of Drillholes MP89-231 and GW96-1A Knight Piésold (1997d) Dwg 1627.011*

A response letter from Les GALBRAITH, P.Eng., and Ken BROUWER, P.Eng. stated, "the glaciolacustrine deposit encountered in GW96-1A and shown on cross-sections 9 and 10 consists of glaciolacustrine layers (silt, some clay) with lesser fine-grained glaciofluvial layers (sand). The material was described as firm based on an SPT N value of 6. The glaciolacustrine unit encountered within the TSF basin is a continuous unit near the Main Embankment, *but is only present as thin, discontinuous layers within the glacial till unit to the northeast near the Perimeter Embankment*. This was investigated during development of the original borrow area during the initial Stage 1 construction program which involved excavating approximately 50 testpits and drilling approximately 22 hollow and solid stem auger holes on a 50m grid pattern. The location of the original borrow area is illustrated on Drawing 1627.001. The borrow area was also inspected during Stage 2 construction. These investigations *confirm that the glaciolacustrine deposit encountered in GW96-1A is a discontinuous unit and will not adversely affect the dam stability* (italics added)." [59]

CARR conducted a geotechnical inspection of the TSF on March 3, 2005, as work on the interrupted Stage 3C was completing. CARR was accompanied by Ron MARTEL (MPMC), Ken BROUWER (KP) and John ERRINGTON (MEM). He noted, "the tailings facility embankment dams are planned to be constructed to a final crest elevation of 965 m by the year 2012."

"At the time of the inspection Zone C shell material was being placed. Due to the method of construction, segregation of the rock fill was noted with many large boulders rolling to the base of the slope. Better control is required to ensure the placement of a homogeneous well-graded dam shell that comprises material within the gradation specified. It is understood that construction of the downstream shell of the tailings dam with waste rock from Wight Pit is being considered. Details shall be submitted to the Ministry for review and permitting.

WATER BALANCE

managing surplus water through discharge first noted in Stage 4

"There is currently no discharge to the environment from the tailings impoundment. Projected water balance indicates there will be a surplus water volume and a discharge permit will be required from the Ministry of Water, Land and Air Protection. Plans for discharge from the TSF shall be submitted to MEM for review.

"The annual Dam Safety Inspection report for 2003 was due November 30, 2004 and has not yet been received. The last Dam Safety Review was carried out in 1999 and is required every 7 years for a high consequence dam based on Canadian Dam Association guidelines. The next DSR is therefore due to be carried out in 2006.

"Changes to seismic standards in the National Building Code are expected to be issued soon. It will therefore be necessary to check the tailings dam design (for mine operating period) to confirm adequate seismic stability under the revised standard.

"Reclamation of the final downstream dam slope with a soil cover is required. Rather than spreading the cover after completion of the dam embankment to final height it has been suggested that it may be more efficient to place and spread the soil as each lift of the downstream shell is placed, which would allow for progressive reclamation." [60]

Nick ROSE, P. Eng., conducted a geotechnical inspection of the TSF on October 13, 2005, accompanied by MARTEL of MPMC. The reduction in the raise from 2.5 m to 1.5 m was discussed, and the report noted, "this adjustment was made to reflect the changes in mill start-up date and has been stated by the design consultant that the reduced height will not impact storm water storage and freeboard requirements." [61]

The inspection did reveal a concern about adequacy of tailings beaches. The report stated, "the TSF pond level was at the 942.4 m elevation at the time of the inspection. The beach on the southwest side of the impoundment was noticeably narrow or submerged. It is understood that a tailings deposition plan is being developed to discharge tailings from the Perimeter, Main and South Embankments to help develop beaches and manage the location of the pond in accordance with recommendations from the design consultant." [62]

A response to the inspection report from Howard BRADLEY, MPMC mine manager, on February 16, 2006 indicated that the beach construction method used for Stage 4 "was completed under the supervision of Knight-Piésold and the constructed material met the design requirements."[63]

6.8. STAGE 5 – 2006-2007

6.8.1. PERMITTING

An application for a Stage 5 raise of the dam to 951 m was received June 12, 2006 and approved on August 2, 2006. The amended permit highlighted the requirements to maintain a minimum freeboard of 1.39 m, and reinforced the requirement to extend or install foundation drains, toe drains, and "associated water collection and recycle systems" as specified by the design consultant.

Additionally, monitoring systems as specified by the design consultant were reinforced in the *Mines Act* permit amendment. These monitoring requirements included the following:

"The inclinometers installed through the lacustrine unit downstream of the Main Embankment shall be monitored to determine possible deflection with respect to the baseline survey using a standard inclinometer probe.

"Monitoring of piezometers, slope inclinometers and survey monuments shall be carried out in accordance with the OMS manual or as specified by the design consultant.

"Any damage to piezometer cables from construction activities shall be repaired or replaced in a prompt fashion to allow ongoing assessment of piezometric levels as specified by the design consultant."[64]

DOWNSTREAM SLOPE

an "interim slope" of 1.4H:1V was introduced to the PE

6.8.2. DESIGN

Stage 5 commenced in October 2006 with a minimal break in construction following Stage 4 activities. The raise was to an elevation of 951 m, adding sufficient storage for one year of mine operations. An upstream toe drain was part of the perimeter embankment design in this stage.[65]

The raise design included a modified centerline construction with Zones C, S, F, T, and U. The downstream shell (Zone C) was designed to be constructed in two phases: the first, at an "interim slope" of 1.4H:1V "to allow the embankments to be raised using the modified centerline construction method in the timeline required to maintain the storage and free board requirements of the TSF." Once the design elevation was reached, the shell fill would be expanded to maintain the 2H:1V slope.[66]

Calculated static stability FoS for the PE design was reported at a minimum of 1.9 with the interim slope, and 2.0 for the final slope.[67]

Two brass tube samples were collected in the GLU at the ME at approximately 2.5 m to 3.0 m depth in a test pit downstream of the ME. Direct shear testing was performed on the samples, which indicated lower strengths than previously used for stability analysis. Index testing on the samples was limited to fines content.[68]

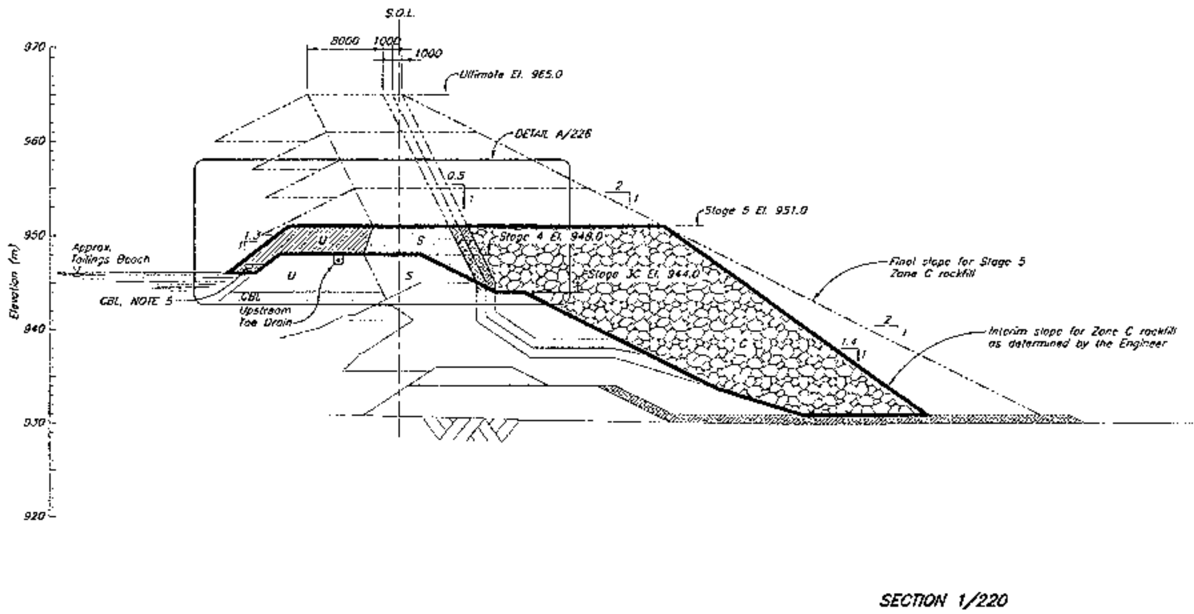

Figure 6.9 Stage 5 PE Section, Planned
Knight Piésold (2006a) Dwg. 12-225 Rev. 0

During this stage, a Dam Safety Review (DSR) was undertaken by Michael DAVIES of AMEC, then a third-party engineering consultant. The review did not bring to light any major concerns. Shortly after completing the DSR, AMEC was contracted by MPMC to produce an *Optimization Report*, which considered the potential for reducing the size of the buttress, reducing the width of the core zone, reducing freeboard requirements, and reducing the role of the EoR in the day-to-day QA/QC of construction.[69]

6.8.3. CONSTRUCTION

Construction of Stage 5 was an uninterrupted continuation of Stage 4 expansion, and was completed in November 2007. The crest of the PE was significantly widened (see Figure 6.9) resulting in a considerable expansion of the volume of Zone C rockfill. The planned upstream toe drain was added during this stage with an elevation of 946.3 m. The drain provided seepage control within the embankment, as well as draining and consolidating the tailings mass near the embankment.[70]

The as-built report (shown in Figure 6.10) indicates that the upper portion of the slope was an interim slope and the lower slope was 2H:1V. [71]

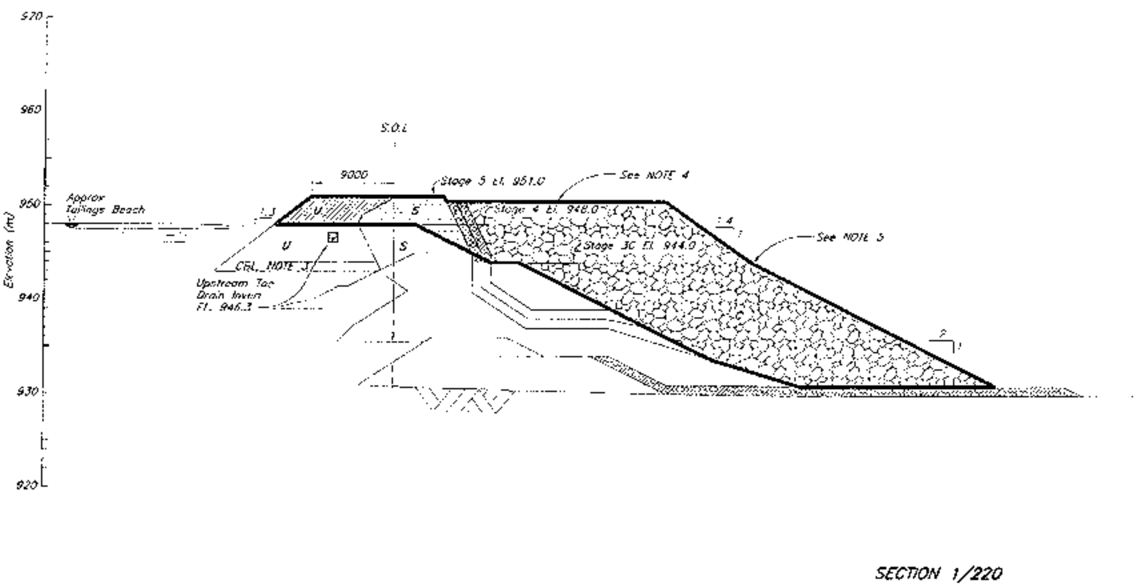

Figure 6.10 *Stage 5 PE Section, As-Built, with Interim Slope Knight Piésold (2008a) Dwg. 225*

6.8.4. MEM INSPECTIONS AND OVERSIGHT

On August 30, 2006, Nick ROSE, P. Eng. conducted a geotechnical inspection of the TSF, accompanied by MARTEL (MPMC) and Bruce MILLIGAN (MEM). The inspection was preceded by a request for an updated OMS and a review of a technical memorandum regarding geotechnical instabilities in the Bell Pit-West and East.

ROSE noted, "since the last geotechnical inspection, a wide tailings beach has been developed across the Perimeter, Main and South Embankments. Improvements in the beach development is understood to have been achieved following construction of a dyke to raise the tailings pipeline across a previous topographic low near the South Embankment, that was resulting in sag in the pipeline and associated flow losses. With respect to the tailings beach width, the Ministry requests specification of the minimum design beach width that is required for construction and operation."

ROLE OF BEACHES

the EoR stated that the minimum beach width requirement did not need to be continuously maintained

The inspection also noted monitoring of the GLU downstream of the ME. "The inclinometers installed in the toe of the Main Embankment are understood to have been recently monitored and show negligible displacement. As per the conditions of the M-200 Stage 5 construction *Mines Act* permit amendment, the inclinometers installed through the lacustrine unit downstream of the Main Embankment shall be monitored to determine possible deflection with respect to the baseline survey using a standard inclinometer probe."[72]

MPMC supplied a response regarding beach specifications prepared by KP. The response claimed that "the tailings embankments have been designed to remain stable for any condition and therefore there is not a 'requirement' for a minimum beach width in terms of embankment performance. The fundamental requirement of the tailings deposition plan is to ensure that a blanket of tailings solids are present immediately upstream of all embankments and along the abutments. Thus there is a fundamental objective to establish adjacent to the embankments, but it is not necessary to continuously maintain a minimum width of exposed beach adjacent to the embankment, and periodic temporary (less than 2 months duration) shallow flooding (less than 0.5 meters depth) of the beaches is anticipated."[73]

6.9. STAGE 6A – 2007-2008

6.9.1. PERMITTING

An application for a Stage 6 raise to 958 m was received July 4, 2007 and approved February 9, 2008. The design for Stage 6 included both the raise and addition of a downstream buttress on the ME to increase the FoS.

6.9.2. DESIGN

Design of Stage 6 was intended to accommodate a 7 m raise to an elevation of 958 m, sufficient to provide two years' storage to the TSF (see Figure 6.11). The design reflected the findings of the DSR conducted by AMEC (at that time, a third party firm) in October 2006. Additional design modifications included a reduction of the core width (Zone S) from 8 to 5 m based on improved performance of the dam's toe drains, and constructing a buttress at the ME. The design was also reflective of the mining plan that increased the total resource at the mine from 85 to 100 million tonnes, which would translate to an eventual height of 970 m for the TSF; and to an average daily throughput of 20,000 tonnes.[74]

The DSR questioned the level of preshearing in the GLU and its effect on strength. As highlighted in the DSR, KP reviewed the issue of foundation soils: "laboratory testwork on the foundation soils indicates that the materials have adequate shear strength to ensure foundation stability of the embankments. The lacustrine unit at the Main Embankment is being investigated further and samples have been collected for direct shear testing to confirm the shear strength of this material." [75] No concerns were registered regarding foundation soils on the perimeter.

During Stage 6 design, maximum rainfall parameters were revised to address stormwater runoff from a 72-hour PMP with wave freeboard. This runoff volume was estimated at 1,070,000 m^3, and would correspond to a 0.6m rise in the tailings pond elevation. Additionally, Stage 6 saw the first discussion of the need for some form of water treatment, acknowledging that at the very least water discharge at closure would be a necessity. The design engineers thought implementing appropriate water treatment and discharge would be "beneficial" well in advance of closure to validate the system.[76]

Four inclinometers were installed and operational in the ME. New piezometers were also recommended for the ME. A drilling program was undertaken to investigate a potential construction fill borrow source downstream of the PE. Eleven holes were drilled by the sonic method to depths ranging from 11 m to 24 m. SPTs were performed periodically in most of the holes. Samples were collected but laboratory test results were not identified in any documentation (see Appendix 3).

Stability analyses, conducted for the planned construction stage dam configuration, were also completed "to identify the buttress requirements at the Main Embankment *should a weak layer exist in the lacustrine material* (italics added)." [77] The stability analysis for the PE indicated a factor of safety of 1.7.

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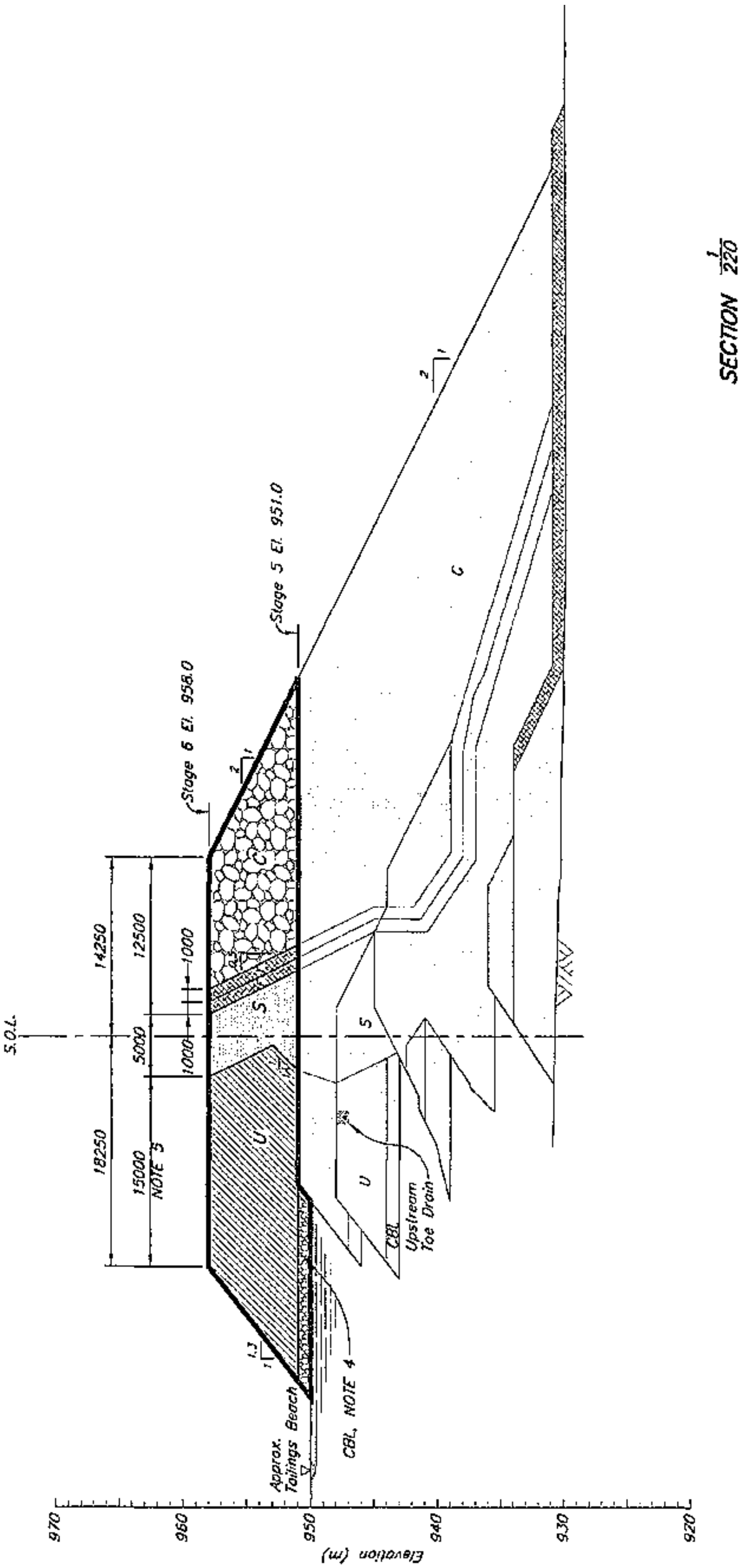

Figure 6.11 *Stage 6 PE Section, Planned, without Interim Slope Knight Piésold (2007b) Dwg. 18-225 rev. 0*

6.9.3. CONSTRUCTION

Stage 6a utilized the same construction methods as Stage 5, including the development of sand cells for Zone U.

Construction to an elevation of 954 m was completed in October 2008. Five new piezometers[78] were installed, for a total of 68 – 12 of which were foundation piezometers. Zones F, T, and C used screened, crushed waste rock from mine operations. At the request of MPMC, the design specifications for the slope of Zones S, F, and T were flattened to "facilitate the placement of the filter materials."[79] As in the previous stage the upper portion of the embankment slope was 1.4H:1V and the lower portion was 2.0H:1V (see Figure 6.12; the full embankment section is shown in Figure 6.13).

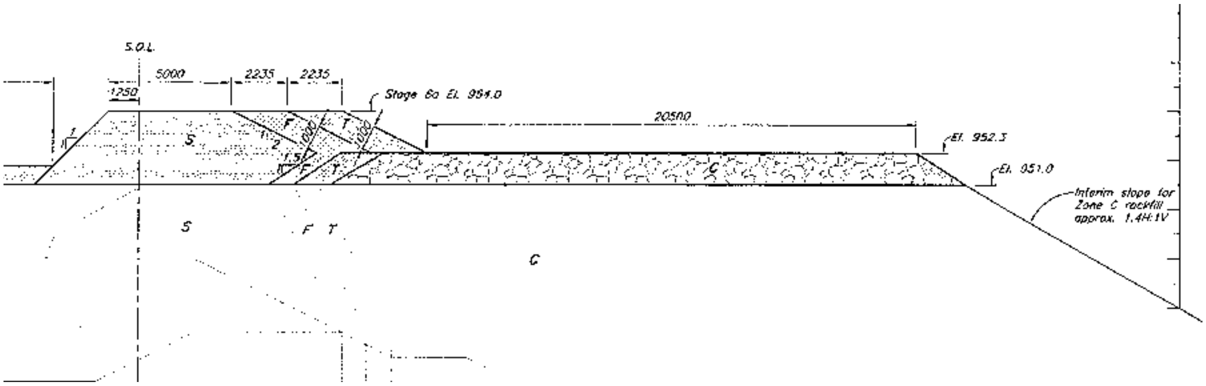

Figure 6.12 Stage 6A PE Section, As-Built: Detail Reflecting an Interim Slope of 1.4H:1V Knight Piésold (2009b) Dwg. 225

During the 2008 construction season, a series of 11 sonic boreholes were drilled into a potential borrow area downstream of the PE (southwest of the breach area). Drilling to depths of 11 - 24 m, the drillholes exposed some lacustrine sediments, which "typically occur as poorly sorted fine sands and silts with trace clay. They have low to moderate plasticity and are typically moist to wet, very dense and massive. The lacustrine sediments occurred as thin lenses within the till units, or as thick deposits underlying the till."[80] No laboratory testing results were reported on these samples.

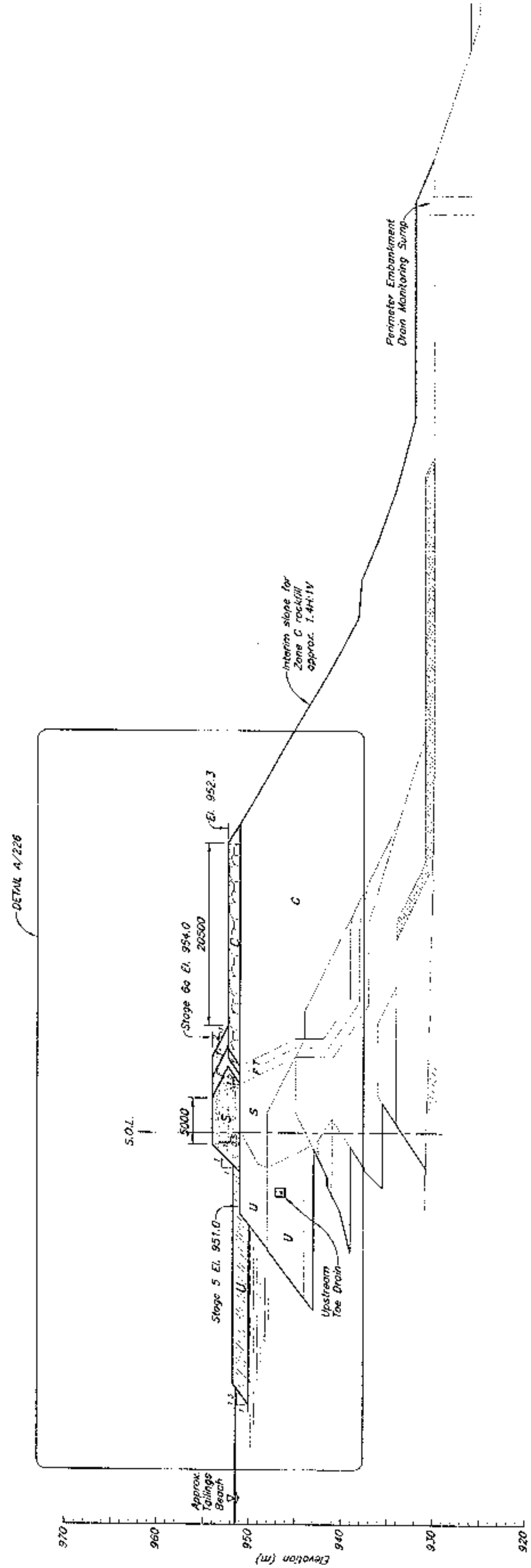

Figure 6.13 Stage 6A PE Section, As-Built
Knight Piésold (2009b)
Dwg. 225

6.9.4 OPERATION

Design documents stipulate that the "minimum recommended tailings beach width is at least 20 m along the abutments of the embankments (where the embankment contacts natural ground)."[81]

One inclinometer showed "slight deviations" at a depth of 10 m in lacustrine silts, which received closer monitoring. KP engineers recommended "increasing the monitoring frequency of the inclinometers and increasing the current buttress elevation at the Main Embankment."[82]

Freeboard maintenance requirements were unchanged, at a total of 1.4 m to accommodate storm runoff and wave run-up.[83]

6.9.5. MEM INSPECTIONS AND OVERSIGHT

A geotechnical inspection was conducted by Nick ROSE, P.Eng. on July 31, 2007, accompanied by MARTEL and MILLIGAN.

The report noted, "construction of the Stage 5 dam raise was in progress on the Perimeter and South embankments. The pond elevation was at 947.09 m on July 28, 2007. On the Main Embankment, dam construction had reached the 950 m elevation. No geotechnical concerns were identified with respect to the TSF.

"Monitoring of piezometers, slope inclinometers and survey monuments shall be carried out in accordance with the OMS manual or as specified by the design consultant."[84]

A geotechnical inspection was conducted by Derek APEL, P.Eng. and Chris CARR, P.Eng. on June 7 and 10, 2008.

APEL noted a dangerous occurrence had not been reported: "the recent tailings line break and release of tailings is considered to be a potential dangerous occurrence and incidents such as these should be reported to MEMPR. As a result of the incident, and review by the mine, new operating procedures shall be developed. We understand that this has been completed. The Operation, Maintenance and Surveillance manual shall be updated to reflect the current construction and monitoring requirements. Piezometers shall be installed during Stage 6 dam construction to replace those no longer functioning and for additional monitoring purposes."[85]

APEL also reported on a contravention of the Code by MPMC, citing Section 10.1.11, Departure from Approval: "the specification for till used in the construction of the dam core (Zone S) requires that rock inclusions larger than 4 inches be removed prior to compaction. Rock boulders over 12 inch in size were noted in the till core and shall be removed by machine or by hand."

APEL also cited an additional departure from approval in beach development: "the design requires that an above water beach be developed against the upstream face of the dam. There was no beach observed in the vicinity of the SE corner of the main embankment. A beach shall be re-established as soon as possible in this area to meet the design objectives. In the meantime regular monitoring of piezometers in the dam in this area shall be undertaken."[86]

A similar compliance issue regarding the October 23, 2007 tailings line rupture was raised in CARR's review of the 2007 Annual Dam Safety Inspection. The review also noted that additional piezometers were to be installed during Stage 6 construction to replace damaged or destroyed instrumentation on the embankments.[87]

6.10. STAGE 6B – 2009-2011

6.10.1. PERMITTING

An application for a Stage 6 raise to 958 m was received July 4, 2007 and approved February 9, 2008. The design for Stage 6 included both the raise and addition of a downstream buttress on the ME. This permit covered both phases of Stage 6 (a and b), and did not require amendment or alteration for Stage 6b.

6.10.2. DESIGN

Design of Stage 6 covered both phases; Stage 6b design was unchanged from the original.

6.10.3. CONSTRUCTION

Stage 6b, conducted from October 2009 to August 2010, completed the Stage 6 raise to 958 m. The construction followed essentially the same methods as Stage 6a, with the exception of a suspension of Zone U sand cell deposition in favour of "utilizing economical haulage of mine waste rockfill" from the mine pits, beginning in May 2010.[88]

The engineers' as-built report noted that: "The Zone C material on the downstream shell is constructed at a relatively steep grade of approximately 1.4H:1V. The buttress on the main embankment construction has not been completed as designed. It is recommended that a review of the embankment stability be completed prior to further embankment raises." [89]

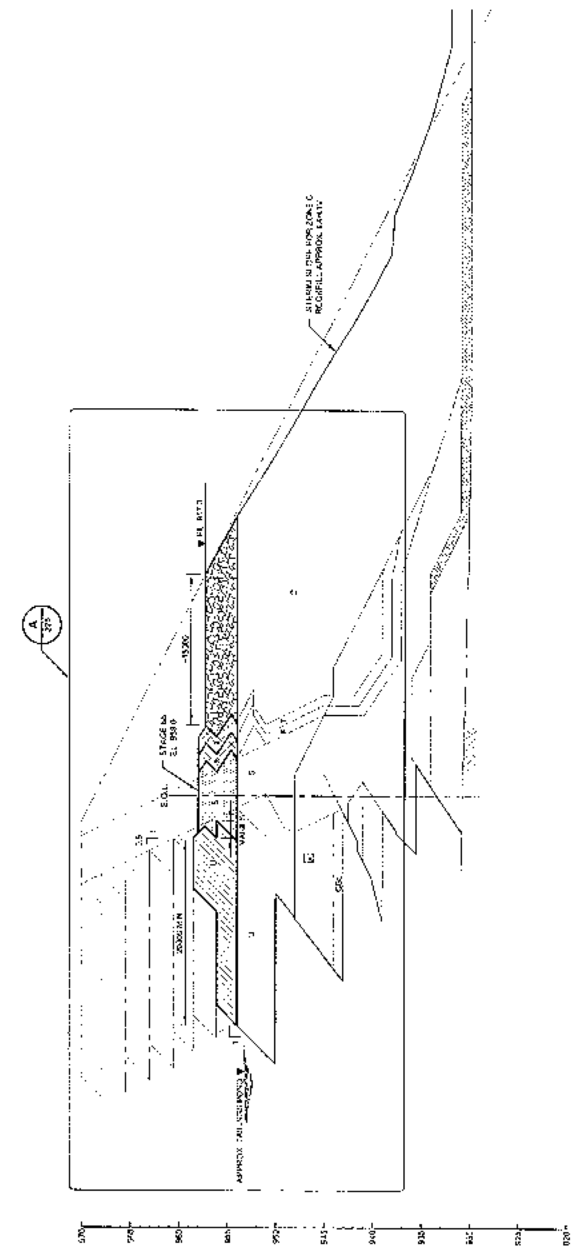

Figure 6.14 Stage 6b PE Section, As-Built, Reflecting an Interim Slope of 1.4H:1V Knight Piésold (2011a) Dwg. 225

6.10.4. OPERATION

The engineers' report submitted January of 2011 noted several operational inconsistencies. The instrumentation installation program, intended to replace damaged or malfunctioning piezometers, "is overdue and should be carried out prior to further embankment raises."[90] Recommendations for additional inclinometer placement had been made, but the placement had not been completed.[91] The report indicated that replacement of instrumentation "will increase understanding of the behavior and performance of the foundation soils under the dam and is an important aspect of the operational monitoring requirements."[92]

Another observation regarding operations was that "the seepage flows were monitored only once in the summer of 2010, which is inconsistent with the frequency specified in the OMS manual. It is recommended that the seepage flow monitoring be increased to the frequency recommended in the OMS manual (weekly)."[93]

In addition, the report brought to light an event on the PE involving a tension crack. It was brought up to the KP engineer conducting the annual inspection: "a tension crack was observed at the Perimeter Embankment at an approximate chainage of 3+400 [not in the area of the breach location]. The tension crack is in the Zone C material at the downstream edge of the embankment crest. The tension crack was apparently identified two months earlier by the grader operator and was approximately 10 to 15 m long. The area has since been graded over but portions of the tension crack are still visible. The location of the tension crack in relation to the downstream slope is not an uncommon occurrence in rock slopes as the outer edge of the material typically receives less compaction effort. A tension crack does not necessarily indicate a plane of weakness in fill materials but it can't be ignored either."

The report continued to recommend strongly that "a stability assessment be completed for this area to assess whether the borrow area configuration has any impact on the integrity of the current, and ultimate embankment section. It should also be noted that the identification of a tension crack, or any other abnormal observation at the tailings dam, should be reported to the design engineer immediately and prior to any remedial action being taken."[94]

The annual dam inspection was conducted by Knight-Piésold on October 7, 2010. The resultant report issued in January 2011 served as a handover document on the expiration of KP's term as Engineer of Record.[95]

6.10.5. MEM INSPECTIONS AND OVERSIGHT

No geotechnical inspections were conducted during Stage 6.

On August 12, 2009 John COX, Health and Safety Inspector, conducted an inspection of Mount Polley Mine. The report included a request for engineering reports for the TSF raise and ME buttress. Both of these structures were approved in the Stage 6 *Mines Act* permit amendment issued February 19, 2009. No further issues were reported at the TSF.[96]

6.11. STAGE 7 – 2011-2012

6.11.1. PERMITTING

An amendment application to raise the dam to 960.5m was received on November 9, 2010 and approved August 15, 2011. The *Mines Act* permit amendment reinforced the construction process, including potentially acid-generating (PAG) rock exclusion, selective removal of cobbles and boulders greater than 100 mm diameter from the till used in the central core, and "direct supervision by the design consultant during construction." The permit also required a minimum freeboard of 1.30 m at all times, and required appropriate updates to — and compliance with — the OMS. In addition, the amendment required that "damaged or inoperative geotechnical instrumentation including piezometers and slope inclinometers shall be repaired or replaced to ensure ongoing performance monitoring." The amendment also reinforced the requirement that MPMC submit an as-built report within six months of dam construction, and that an annual dam safety report be submitted.[97]

MEM geotechnical issues raised during permit application review produced the following commentary from MPMC: "water balance projects through 2012 (and will continue to be projected out each year), and is integral in managing material in the TSF. The water balance is updated with real figures every month (i.e. precipitation, evaporation, daily mill throughput, water flow and pumping rates), with projected inputs based on historical data and forecasted figures." MPMC concluded, "the current dam elevation is 958.0 m, and according to the water balance provides sufficient freeboard until June of 2011. Looking into later spring of 2012, the dam will need to be 961 m. The crest elevation will be adjusted to maintain freeboard requirements for storage of the probably maximum precipitation (PMP) event plus one metre for wave run-up as required by the current permit."[98]

6.11.2. DESIGN

Stage 7 was the first construction phase following the handover of Engineer of Record responsibilities from KP to AMEC Environment & Infrastructure (AMEC), which occurred January 28, 2011.

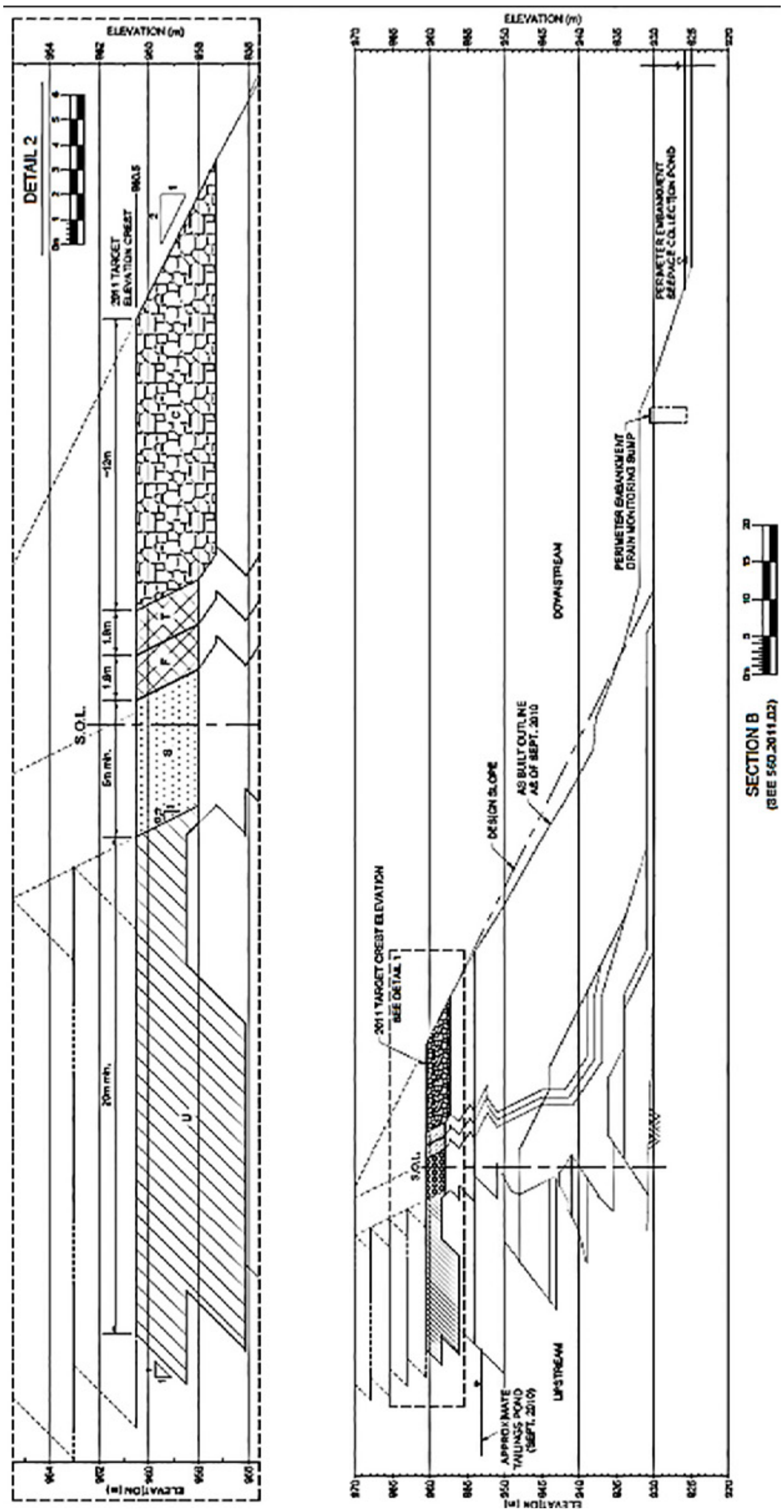

Figure 6.15 Stage 7 PE Section Plan, Reflecting a Downstream Slope of 2H:1V AMEC Earth & Environmental (2011a) Fig. 560.2011.05

Several changes accompanied this stage, including the following:

- Updated CDA Dam Safety Guidelines, implemented since the DSR in 2006, resulted in a change of consequence classification from "low" to "significant."
- Impoundment instrumentation was renumbered for data management purposes, and a program of instrument replacement and updating was implemented. Three additional slope inclinometers and 11 VWPs were installed around the TSF. A total of 81 functioning VWPs were in place as of 2011 (15 in the PE), and 7 functional inclinometers were installed (one in the PE).[99]

CHANGING THE EOR

Knight-Piesold transferred its engineering duties to AMEC at this stage

Eight holes were drilled in the ME foundation, 4 in the PE foundation (at 3 locations), and 2 in the SE foundation. The holes were drilled using the sonic coring method with soil grab samples taken at regular intervals for laboratory testing. Depth of drilling ranged from approximately 11 m at the SE to 49m in the ME; 23 piezometers and 3 inclinometers were installed.[100]

Construction drawings for the PE indicated the design slope of 2H:1V.

6.11.3. CONSTRUCTION

The 2.1 m raise in Stage 7 took place between June 13 and September 21, 2011.[101] Stage 7 fill placement was conducted by Peterson Contracting Ltd (Zones S and F) and by MPMC (Zones U, T and C). According to AMEC's overall assessment of Stage 7, the construction "achieved conformance with design intent."[102]

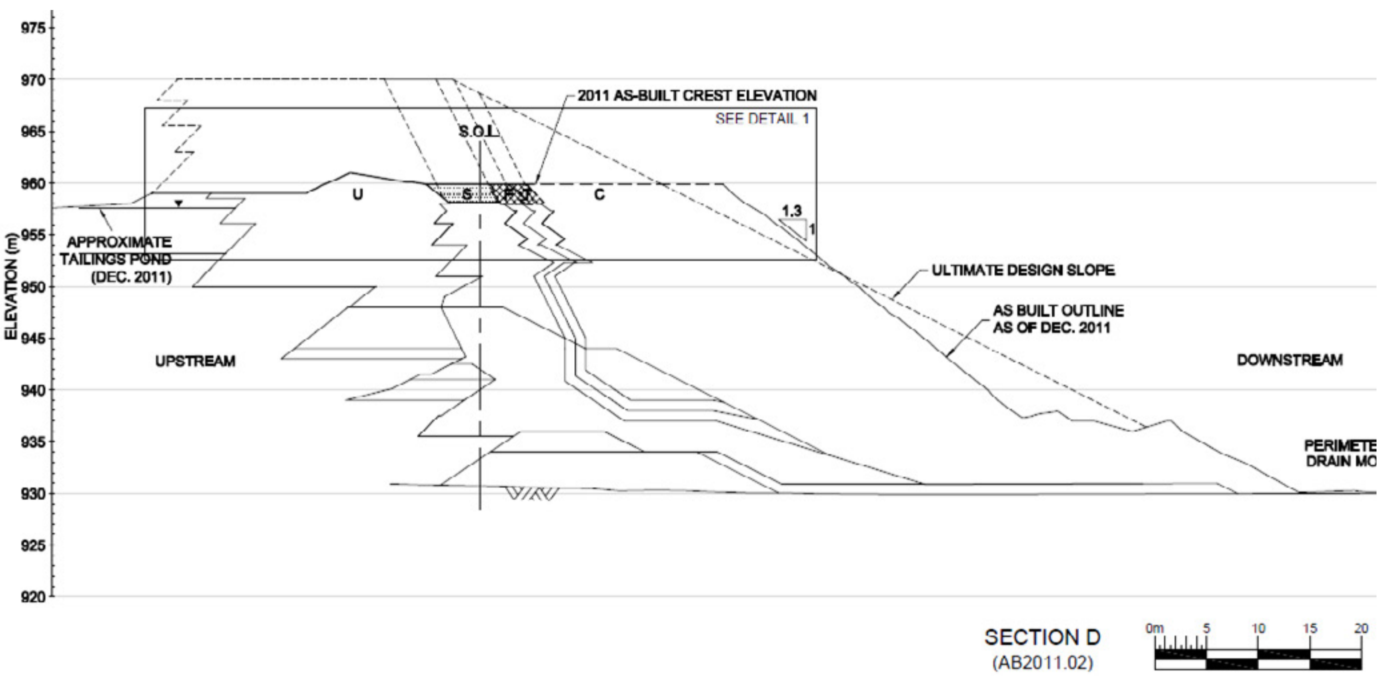

Figure 6.16 Stage 7 PE Section, As-Built, Reflecting an interim Slope of 1.3H:1V AMEC Earth & Environmental (2012) Fig. 2011AB.05

Prior to Stage 7, onsite engineering field presence under KP included daily engineering presence. For example, a report on Stage 2 reported that KP provided "day time supervision and quality assurance (QA) services for … construction of the [TSF]. MPMC provided technicians for night shift supervision and QA services … Key QA items addressed by KP included: foundation inspection and approval prior to fill placement; assessment of borrow material suitability; inspection of fill placement procedures; in-situ testing of the placed fill for moisture content and density; collection of control and record samples at the required frequencies; and installation and monitoring of instrumentation. Monitoring was conducted by MPMC staff." [103]

It was noted that construction monitoring and QA/QC were continued as in prior lifts; however, "in 2011, MPMC undertook a greater role and responsibility in this regard. Specifically, MPMC engaged its own engineers, technicians, and summer students to provide full-time construction monitoring and field inspection during the construction of the embankment." [104] MPMC's full-time inspection personnel did not include a registered Professional Engineer or Engineer in Training.

AMEC's support engineer's presence on site was intermittent during the construction period. AMEC reported that it "was present onsite for critical, non-routine aspects of foundation preparation and fill placement. During this period, AMEC verified that construction methods employed were consistent with design expectations, material specifications were adhered to, and monitoring and testing requirements were understood by MPMC personnel. AMEC's time on site was also used to verify that daily technical/progress reports were being completed properly, QA/QC and reporting responsibilities were thoroughly understood by all parties, and lines of communication between the site and AMEC office-based support were clearly established and functional. Once AMEC was satisfied that the MPMC's field inspectors were fully trained and prepared to undertake the construction monitoring and reporting role with remote support required by AMEC, AMEC reduced their monitoring presence to monthly visits, with monitoring of construction progress carried out via reports and photographs issued by MPMC. Actual timing of AMEC's support engineer site visits varied somewhat to align with key construction activities such as foundation preparation and approval, and till core trench approval." [105] AMEC senior engineers visited the TSF site on 4 days in 2011 (June 20/21 and July 25/26).[106]

AMEC maintained the steeper "interim slope" of the PE downstream shell as KP, its predecessor EoR, had initiated; however, AMEC changed the nomenclature of the slope in its as-built drawings to show an as-built slope of 1.3H:1V, and a dotted line for an "ultimate design slope" of 2H:1V (see Figure 6.15).

6.11.4. OPERATION

Freeboard requirements were specified as 1.3 m to accommodate a 72-hour PMP event.[107]

In response to MEM questions emerging from the *Mines Act* permit amendment application, MPMC stated that "effective water management at the site will ensure that the discharge of TSF water will be minimized and that the removal of water from Polley Lake will not be required. An optimum average volume of water to be stored in the TSF is 1,500,000 m^3." Water balance calculations provided by MPMC suggested TSF water volumes in the range of 1 to 2 million m^3. [108]

However, as of September 2011, an estimated 3.6 Mm^3 were stored in the TSF, an increase in 1 year of 2.6 Mm^3 above earlier reported volumes.[109]

6.11.5. MEM INSPECTIONS AND OVERSIGHT

No geotechnical inspections were carried out during Stage 7. There were no geotechnical inspectors on staff at MEM from December 2010 through November 2011 (although contract geotechnical engineers were employed at this time).

6.12. STAGE 8 – 2012-2013

6.12.1. PERMITTING

The application for the Stage 8 raise to 963.5 m was received April 3, 2012, and approved on June 29, 2012. The amended permit highlighted the requirement to measure toe drain flows in accordance with the current OMS. In the same construction season, an additional application amending the Stage 8 raise to 965 m was received on September 18, 2012 and approved October 15, 2012. This amended raise was labeled Stage 8A.

STEEPENED DESIGN SLOPE

the PE toe slope was maintained at 1.3H:1V

6.12.2. DESIGN

Design of Stage 8 generally continued the design from Stage 7, with a raise of 3.0 to 3.4m following the modified centerline method, resulting in a narrowing of the dam crest. The PE downstream slope was again acknowledged at 1.3H:1V, with an "ultimate design slope" of 2H:1V (see Figure 6.17).

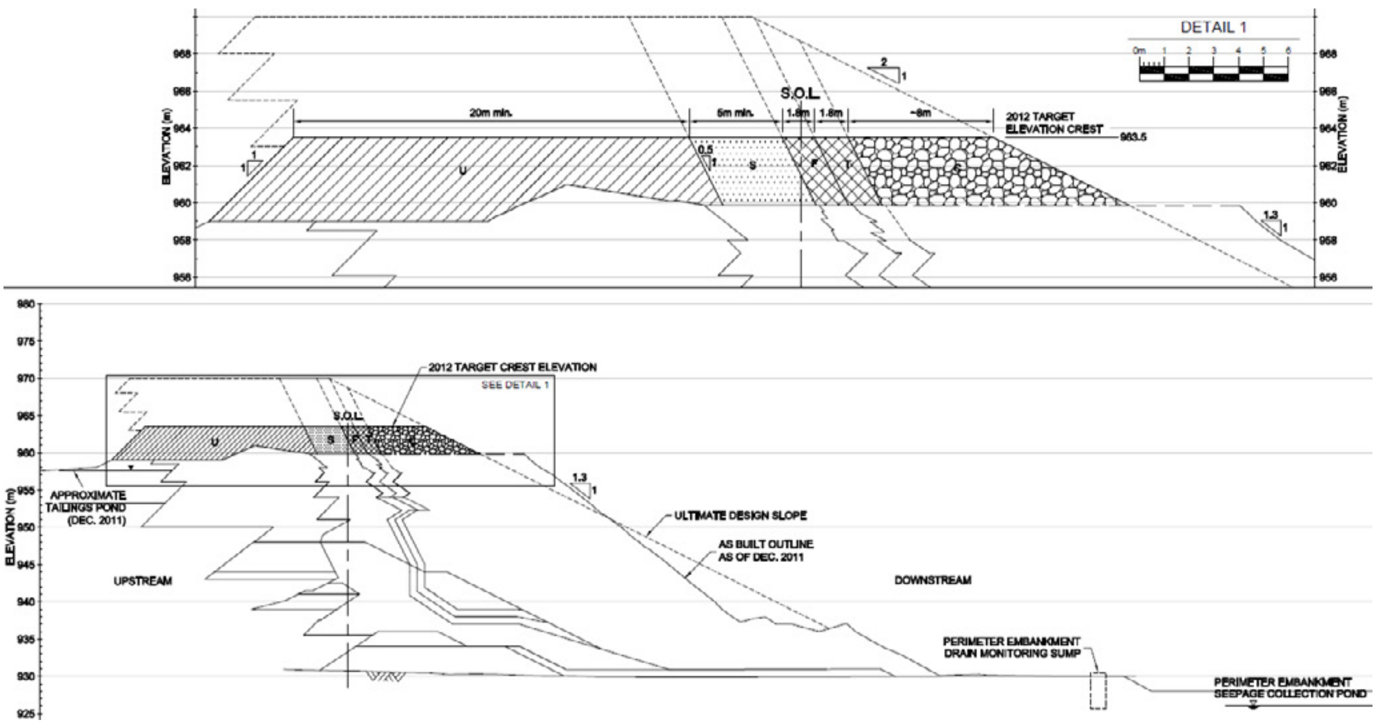

Figure 6.17 Stage 8 PE Section, Planned, Reflecting an Initial Slope of 1.3H:1V AMEC Environment and Infrastructure (2012a) Fig. 2012.05)

A total volume of 160,400 m^3 of Zone C fill rock was estimated for Stage 8, including 70,100 m^3 for the PE.[110]

Two slope inclinometers were installed downstream of the PE. One was positioned adjacent to the previously installed SI11-04 which was experiencing "compression failure deformation." The second was installed near Sta. 3+270, nearby VW11-09 (see Appendix 3, Section 3.3).

An adjustment to the design to accommodate a raise to 965m was requested by MPMC during the raise, and AMEC provided an amended design (Stage 8A) on September 10, 2012. The design shifted to a centerline approach (see Figure 6.18).

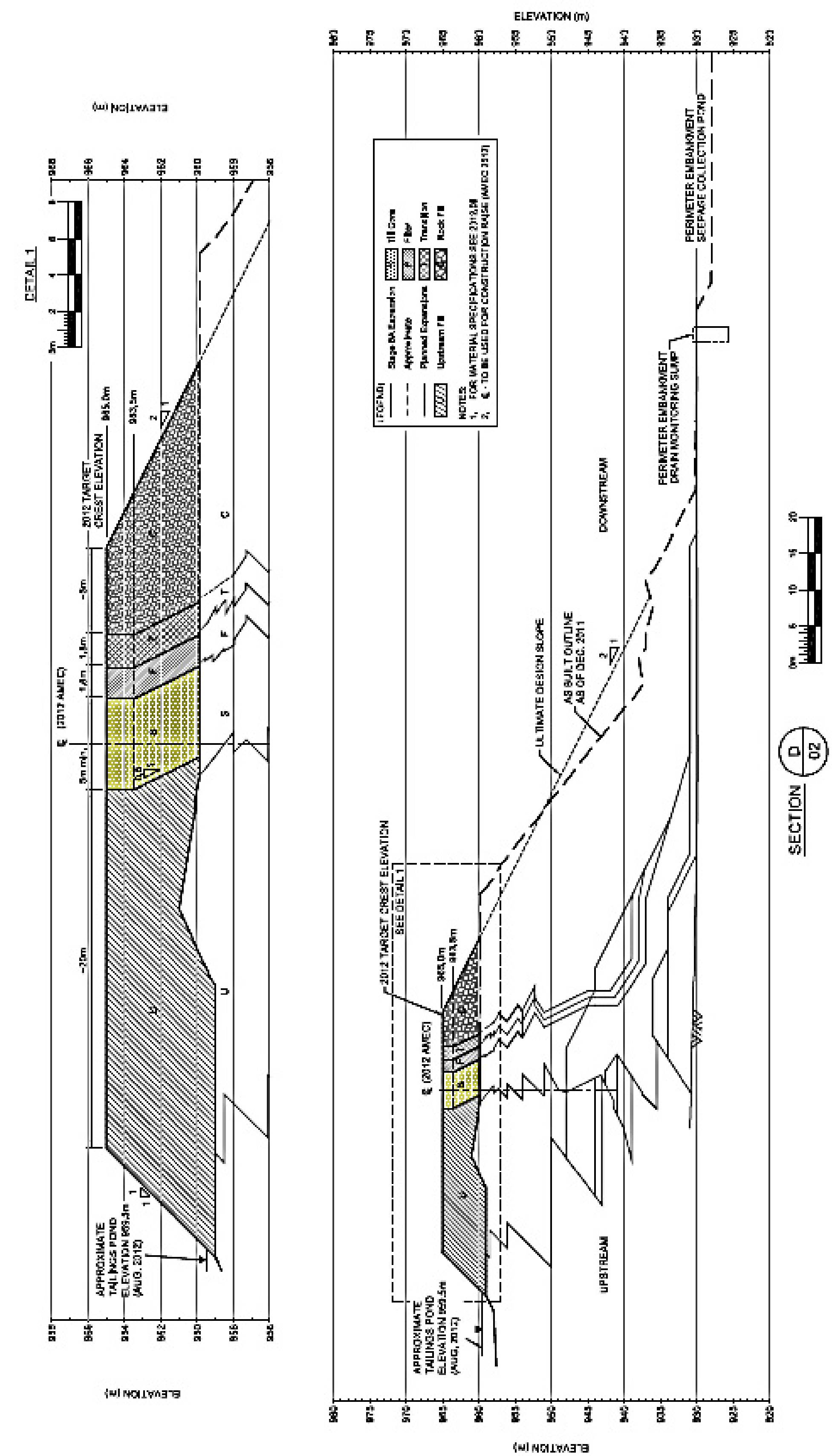

Figure 6.18 Stage 8A PE Section, Planned
AMEC Environment and Infrastructure (2012d) Fig. 2012.05

No other changes were made to the initial Stage 8 design.

6.12.3. CONSTRUCTION

The design document specified "Mr. Luke MOGER of MPMC will oversee the overall construction monitoring. The day-to-day monitoring, reporting and instrumentation reading tasks will be the responsibility of the MPMC Field Inspectors and mine technicians."[111] AMEC continued it roles of support engineers and senior engineering oversight.

MPMC contracted a third-party engineering firm, BGC Engineering Ltd. (BGC) to perform the annual Dam Safety Inspection (DSI). In the report, BGC noted that "construction monitoring and quality control during the 2012 construction season was mainly carried out by MPMC personnel, AMEC undertook regular site visits and carried out quality assurance activities."[112]

The construction of Stage 8A was completed on October 30, 2012, and the embankment reached a height of 963.5 m.

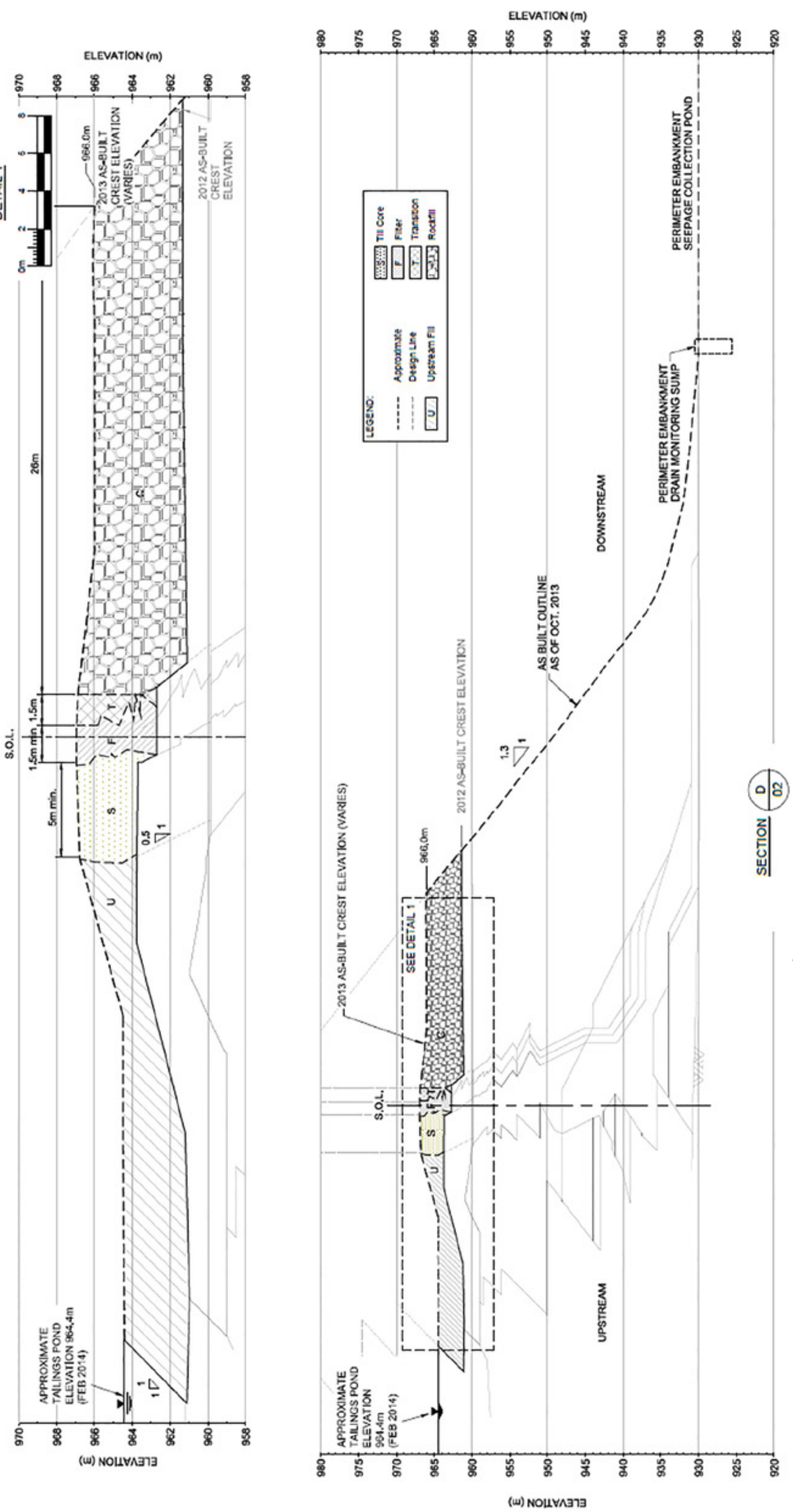

Figure 6.19 *Stage 8A PE Section, As-Built AMEC Environment and Infrastructure (2014a) Fig. 2013AB.04*

6.12.4. OPERATION

Freeboard requirements were reconfigured. According to the OMS, the effective definition of a PMP event changed from 72 hours to 24 hours, which led to a "normal operating level" of 1.3 m freeboard to a "maximum operating level" of 1.0 m freeboard, which "means the loss of storage capacity for a 24-hour PMP event." [113] In conflict with this value, AMEC maintained that its PMP event window remained at 72 hours.[114]

BGC's assessment noted, "given the orientation of the gravity-fed tailings line, insufficient tailings line pressure prevented cell [Zone U] construction along the central portion of the Main Embankment... The tailings delivery line is currently being redesigned with the expectation that the new alignment will allow for upstream tailings cell construction to take place along the Main Embankment in 2013." [115] The limited cell development (and lack of beaches) can be seen in Figure 6.20.

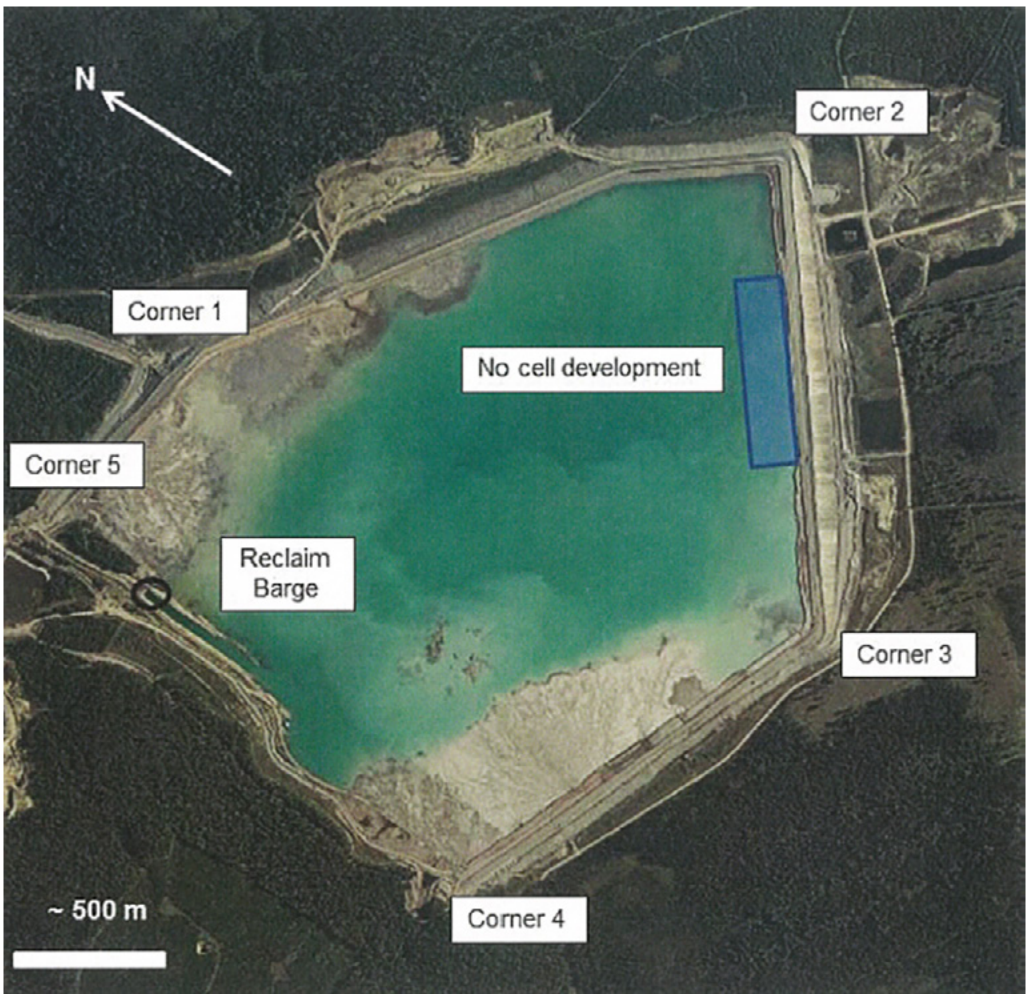

Figure 6.20 Sand Cell and Beach Development (commentary by BGC)
BGC Engineering Inc. (2013a) p. 6

A water discharge permit was issued in November of 2012 by MOE. The permit was issued with the opinion that "although Mount Polley has maximized water recycling the water balance is such that they now have an annual surplus of approximately 1.4 Mm^3 and a discharge is required." [116] Although the permit sought was for site-specific water quality objectives, allowing discharge directly into Polley Lake, MOE denied the site-specific objectives permit. Instead, a discharge permit for up to 1.4 Mm^3 annually was issued, with discharges dependent on water quality, flow rates of Hazeltine

Creek, and seasonality (for fisheries protection). Since only dam-filtered seepage water met water quality objectives, only approximately 100,000 m^3 of water was actually discharged annually. In addition, undisturbed runoff "must be diverted so that it does not flow into the tailings impoundment, or to the mine or mill areas." [117]

6.12.5. MEM INSPECTIONS AND OVERSIGHT

A geotechnical inspection was conducted on September 24, 2012 by Michael CULLEN, MEM. Sand cell development was raised: CULLEN noted, "we also observed sand cell construction on the upstream side of the west dam and discussed the problems and potential impacts of limited sand placement on the central dam due to gravity placement limitation, it is understood that the Mine's consultants (AMEC) will be reviewing."

CULLEN also raised the issue of water balance on the mine. He noted, "the Mine is reminded that the TSF and associated water management facilities are to be operated and monitored in accordance with the recommendations prepared by the design engineers."

A final observation was the currency and adequacy of the OMS: "we reviewed the Operation, Maintenance and Surveillance manual prepared for the TSF by Knight Piésold in March 2010. This document is considered satisfactory but somewhat out of date in light of the recent dam construction and change of EoR from KP to AMEC. It is understood that the Mine in consultation with AMEC are revising this document, and will submit to [MEM] in the near future."

No inspection orders were issued.[118]

In a follow-up geotechnical inspection on October 3, 2012, CULLEN stated, "the mine is reminded that the TSF and associated water management facilities are to be operated and monitored in accordance with the recommendations prepared by the design engineers." CULLEN's report reinforces the recommendations prepared by the design engineers.[119]

A site visit was conducted by MEM inspector George WARNOCK, accompanied by Steve ROTHMAN (MEM), on April 13, 2012. This site visit served as a familiarization tour for the MPMC operation. Comments relevant to the TSF included a note that the steepness of the PE downstream slope appeared to be at an angle of repose.[120]

6.13. STAGE 9 – 2013-2014

6.13.1. PERMITTING

The application for the Stage 9 raise to 970 m was received April 18, 2013 and approved August 9, 2013.The as-built report at the conclusion of the raise was to be stamped by a professional engineer and "shall include a statement indicating that the facility was constructed in 'general conformance with the design.'"

A follow-up email with MPMC was sent by Heather NARYNSKI (MEM) on May 8, 2013 regarding compliance with the mine's permit, including submission of the 2012 updated OMS and an updated site water balance. These deliverables, required as permit conditions, reflected engineering recommendations from the 2011 as-built report submitted to the Ministry.[121]

A further concern was raised by NARYNSKI on July 31, 2013, regarding TSF design in the Stage 9 *Mines Act* permit amendment application: "the stability analysis indicate that the FoS for the ME only marginally achieves the short term CDA design criteria of 1.3". MEM required a commitment from MPMC to work towards a FoS for the ME equal to that of 1.4. MOGER responded, "FoS is something we are working into our designs, we should be discussing this prior to our next raise submission (anticipated late 2013)." [122]

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6.13.2. DESIGN

Design parameters for Stage 9 essentially followed those for the pervious stage raise, with a centerline approach further narrowing the dam crest. Design documentation confirmed the previous as-built drawings showing a 1.3H:1V downstream slope, but maintained that the slope was "temporary given that the final dam downstream slope is currently planned to be flattened to 2H:1V. The final design for the downstream slope may be revised after the current target elevation of 970 m is reached." [123]

Independently of AMEC, MPMC retained BGC to conduct a study on TSF stability modeling to evaluate requirements for downstream shell footprint expansion. Included in this analysis was a review of stability requirements for crest elevations of 970 m, 975 m, 980 m, and 985 m. BGC personnel also visited the site on June 10-11, 2013, to evaluate potential raises to an elevation of 1000 m.[124]

PLANNED EOR TRANSITION

BGC would assume responsibility for TSF engineering after Stage 9

BGC presented a *Project Memorandu*m to MOGER on October 3, 2013.[125] BGC had also provided MPMC with additional documentation between June and October 2013. BGC's stability analyses indicated the need for expansion of the ME buttress and creation of a buttress on the PE.

The memorandum strongly suggested the need for an updated water balance, produced by a qualified professional. In addition, BGC urged MPMC to proceed with obtaining a reverse osmosis (RO) water treatment plant to enable water discharge under the existing MOE discharge permit.

The document was not provided to MEM prior to the TSF breach.

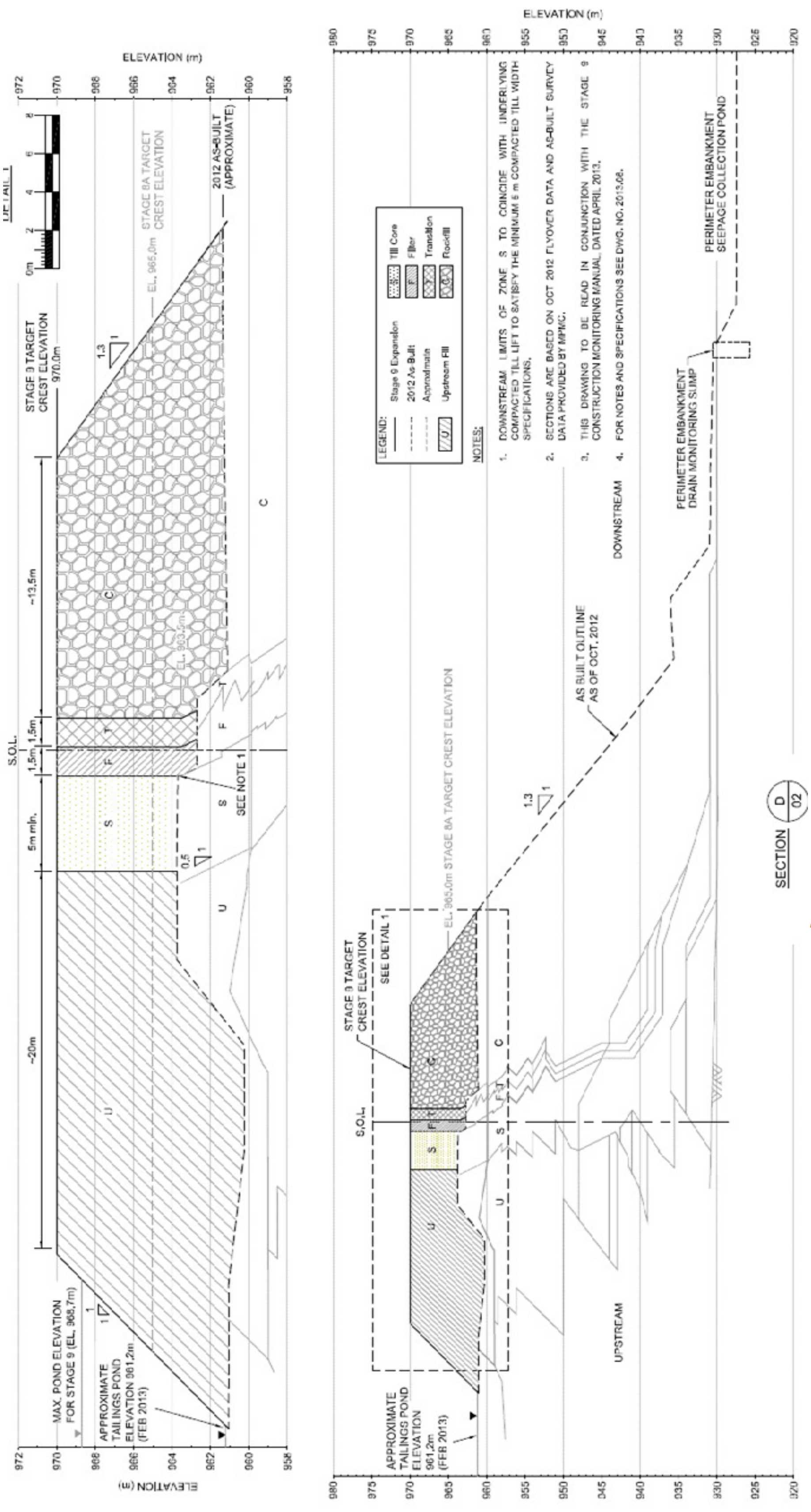

Figure 6.21 *Stage 9 PE Design Section AMEC Environment and Infrastructure (2014b) Fig. 2013.05.01*

6.13.3. CONSTRUCTION

Construction of Stage 9 was undertaken during summer and fall months of 2013 and into the spring and summer of 2014, toward a target permitted height of 970 m.

In January 2013, AMEC engineering personnel (Todd MARTIN and Daryl DUFAULT) transferred to BGC, the engineering firm that had produced the 2012 DSI.

ENGINEERING EXPERTISE

key personnel transferred from AMEC to BGC

At the end of the 2013 construction season, the PE was raised to 966 m (with a core elevation of approximately 966.5 m. The downstream slope of the PE remained at 1.3H:1V, and the maximum elevation of the dam was sketched in at 980 m (see Figure 6.22).

Neither the construction of an expanded ME buttress nor the subexcavation of a buttress foundation for the PE was included in the Stage 9 *Mines Act* permit amendment application. Neither was approved as a design for Stage 9.

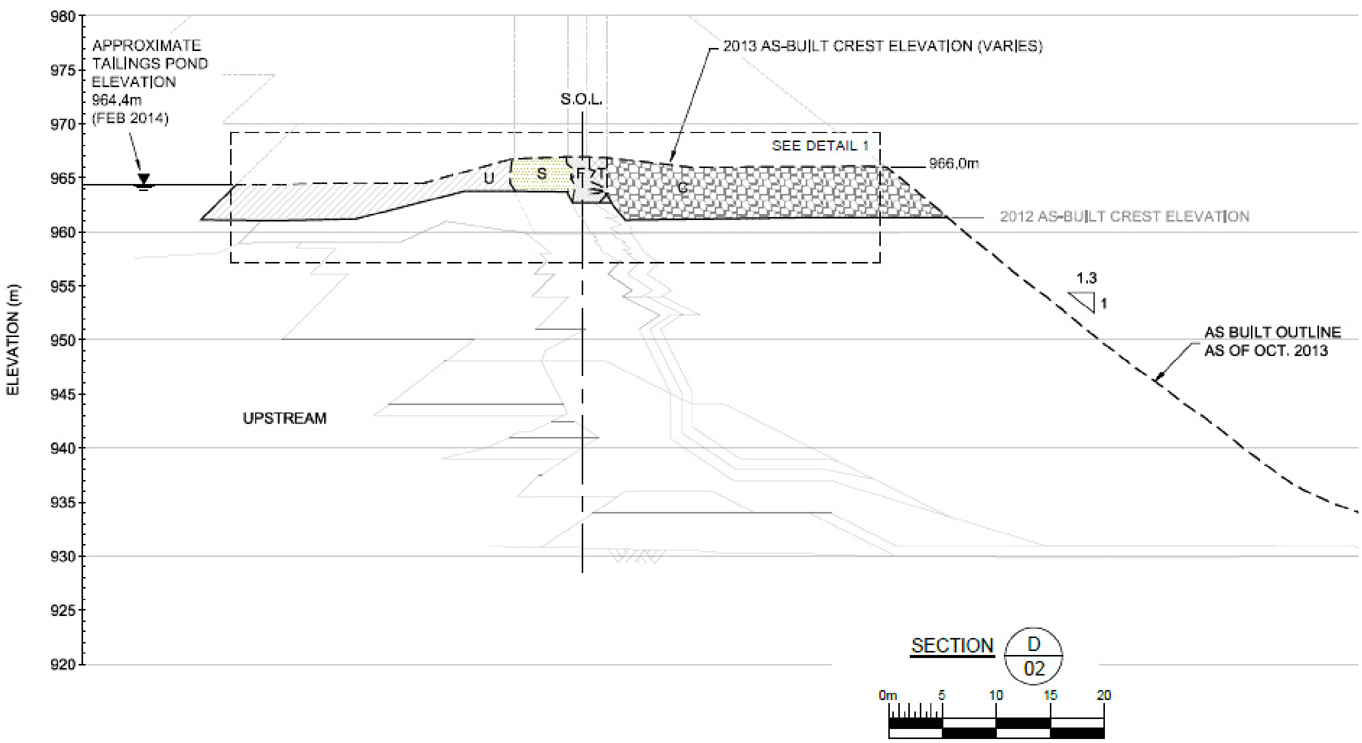

Figure 6.22 October 2013 PE Section, As-built, with Slope of 1.3H:1V AMEC Environment and Infrastructure (2014a) Fig. 2013.AB04

AMEC reported that its support engineer provided on-site supervision of construction during the following periods in 2013: April 23-26; May 1-3, 7-9, and 13; June 4-6, 17-19, and 26-28; July 3-5; and August 2 and 12-14.[126]

While the supervision and oversight roles of engineering consultants were consistent with previous stages, personnel changes resulted in different individuals filling these roles over time.

The Stage 9 raise continued in 2014 up to the time of failure. Stage 9 construction in 2014 included: the raise of the till core (Zone S) from approximately 967 m to 970 m , the raise of the upstream and downstream support materials from 966 to 969 m, and the re-location of the seepage recycle pipe located near Station 3+950. Further details on the construction sequencing for the PE are as follows:

- The till core (Zone S) was raised to 967m by October 2013. Till core placement resumed in June 2014 starting at Station 3+100. Daily construction reports indicated the till core was completed to 968.8m on July 31, 2014. However, surveyed elevations from drill holes and a CPT sounding at the embankment crest west and east of the breach area indicate the till core was likely closer to 970m.

- Raise of the downstream shell (Zone C) started in June 2014. AMEC's daily reports indicate that by August 1, 2014, Zone C placement reached the target elevation and was being graded to 969 m. On August 3, 2014, Zone C placement at the re-located seepage recycle pipe was completed.
- Hydraulic placement of tailings in the upstream shell (Zone U) started November 2013 and was last reported at 967.6 m in June 11, 2014 between Stations 4+286 and 4+396 m (AMEC's construction daily report TSF14-06-11). Post-failure survey contours to the east and west of the failure area showed that Zone U was likely between 968 m and 969 m.

Buttress Subexcavation - General. Following the delivery of an internal review report from BGC to MPMC, which outlined the requirement of buttressing to increase the FoS on the ME and PE, MPMC commenced a construction program to prepare foundations for the new buttress on the PE (as indicated in AMEC's *Construction Daily Reports* from that time).[127]

Although the permit for Stage 9 referred only to buttress preparation for the ME (and ME buttress construction only included raising the height of the existing buttress, without new foundation preparation), the construction activities included foundation subexcavation for over 1,700 m of buttress along nearly the entire length of the PE, beginning in September of 2013 and progressing until weather conditions deteriorated in late November/early December.

Although they were not referenced to specific locations along the embankment, daily construction reports referred to buttress subexcavation along the PE. Construction photos likewise depicted multiple instances (again not referenced by location) on the PE where a foundation was prepared in panels of unspecified length, filled with Zone C rock, and compacted by equipment traverses (see, for example, Figure 6.23). The excavations would require site engineer inspection prior to refilling.

Figure 6.23 C Zone Material Placed in PE Subexcavation, October 19, 2013
AMEC Environment and Infrastructure (2013b)

Although there seemed to be some local variance, the general dimensions of the buttress foundation preparation were 0.5-3 m in depth (removing organics down to a depth of competent soil) and 20-30 m in width. Excavated sections would be inspected by the site engineer, filled with Zone C rock, and compacted following the construction monitoring manual.

Because of the limited detail of the *construction daily reports*, it is not possible to trace either the timeline of construction or the specific location of panels. Location data were limited to "Perimeter Embankment," and specific dimensions were not included in the reports. Surveys of the construction activities were not available.

AT THE BREACH LOCATION

the excavation from Station 4+100 to 4+300 was left unfilled

Excavation in the Breach Area. The buttress subexcavation proceeded along the PE to include the area later breached. The as-built report for the 2013 portion of Stage 9, issued in March 2014, reported that over 1,700 m of buttress foundation preparation had been completed for the PE. "Foundation preparation was also conducted downstream of the Perimeter Embankment within the final dam footprint. The area was stripped of all organics and soft and over wet soils to expose dense inorganic native soils. The area was then approved by the AMEC Support Engineer and waste material hauled outside the proposed dam's footprint. The area was approximately 1,700 m in length, extending from Station 2+700 to 4+400," [128] which included the area of the breach.

It also reported, as an outstanding task whose completion is "important to the proper completion of the development of the tailings embankment," that a section of the foundation had not been filled: "inspection of the prepared foundation between Station 4+100 and 4+300 was attempted late in the season but was covered with snow. It should be noted that this section will require approval prior to any backfilling activities." [129] The Independent Expert Panel's report referenced an as-built survey of the toe excavation (datum manually adjusted to a logical location) though no source of the survey is given.[130] No survey of the buttress excavation was found in records provided to MEM.

It was not possible to discern the exact dimensions of the open excavation. A variety of dimensions were reported by various MPMC personnel.[131] Drill logs that record soft soils to a depth of 1.5 – 2 m near the breach area suggest that the depth of the excavation was at least 1.5 – 2 m.

Dimensions of the excavation reported in the Independent Expert Panel's report are consistent with the MEM's interpretation from available construction records and interviews.

It is evident from the Stage 9 construction manual (which does not refer at all to the foundation sub-excavation procedure) that any construction procedure, including paneling, inspection or backfilling procedures, was applied informally. While a detailed procedure for sub-excavation, inspecting, and tying in abutments–along the Set-Out Line (SOL) of the embankment, presumably at the extreme western ends of the SE and PE, where they rose into the hillside that formed the western end of the TSF–there was no mention of any buttress foundation preparation procedure or approval process in the construction manual.

It was not until the 2013 as-built report issued in March 2014 that any procedure for buttress foundation preparation was presented, and then only as a report of activities completed. There was no discussion of either excavating or backfilling the buttress foundation subexcavation.[132] The fact that the excavation was left open and untended for eight months suggests the documented guidance in the construction manual for excavations was not applied.

The open excavation initially filled with snow, and once snowmelt occurred it continually filled with water. The excavation was hydraulically linked to the perimeter seepage pond via a French drain connecting to the area of the dam toe. Since the foundation could not be inspected in that condition, the inspection was never conducted. Instead, MPMC left the excavation open, a condition that remained at the time of the failure and breach.

6.13.4. OPERATION

Due to the failure of the PE on August 4, 2014, no as-built report was issued for Stage 9 as construction had not yet completed.

TSF OVERTOPPING

An event ultimately determined by MEM as an overtopping occurred on May 24, 2014

Water Management. Water management, especially the maintenance of sufficient freeboard in the TSF, continued to be a challenge for MPMC. For example, Figure 6.23 shows construction of a sand cell with pond elevation higher than the cell. A case in point was an incident on May 24, 2014 in which the embankment core was overtopped by water in the TSF following a rainfall event of 24 mm in a 24-hour period. (Associated snowmelt also drained to the TSF.) The overtopping was characterized as "a low flow of water passing over the crest of the dam near Corner 3." [133]

Figure 6.24 Creation of sand cells 3+150 to 3+050, on May 18, 2014, indicating high water level 6 days before the overtopping event AMEC Environment and Infrastructure (2014c)

The overtopping is shown in Figure 6.25. The water flowed over the till core of the dam and into the filter/rockfill zones. There were three additional low spots in the embankments where standing water on the till core were also observed. The event illustrates the precariousness of the water balance for the site, the impacts of precipitation on freeboard, and the condition that MPMC was not maintaining required freeboard of 1.4 m. Although the freeboard reported just prior to the rainfall event was 0.7 m,[134] such a rainfall event would not be expected to raise the TSF pond level by this amount, which suggests that the reported freeboard was not correct.

The incident was described in AMEC's daily report as: "water is seeping through the U zone and ending up on top of our till which then flows into the filter due to the water elevation in the sand cell being 0.2 m higher than the top of the till at Corner 3." MPMC initiated response actions by constructing a temporary berm at Corner 3, consisting of random fill (Zone U) over the sand cell and glacial till. The berm was subsequently placed upstream of the core to contain the water. The pond water elevation at the time of this incident was 966.5 m.[135]

Figure 6.25 Water Overtopping Embankment Core and Entering Filter Zone, Station 1+530 on SE, May 24, 2014 AMEC (2014d) p. 5

AMEC Support Engineer Dmitri OSTRICHENKO assessed conditions on May 24, 2014. AMEC requested a survey of the embankments by MPMC, which revealed three low spots (around Corners 2, 3, and 5). Field review also discovered a low spot at the perimeter pipe crossing, with "standing water noted to be present on the core." AMEC recommended immediate lowering of the pond level through diversion of water, construction of temporary berms to protect the core at low points, and prioritization of raising the embankments at the low spots.[136]

The rainfall event (on the order of 25 mm) was not "significant" in that the original design of the TSF calculated a PMP of 203 mm in a 24-hour period, when the mine's footprint (and correspondingly, the amount of surface runoff water draining to the TSF) was smaller.[137]

Although the event was classified by the Code (1.7.3) as a dangerous occurrence, MPMC did not notify the Ministry of the event until three days later, on May 27, 2014. At that time, MPMC reported that freeboard was stable at 0.6 m, and water had been temporarily routed to the Cariboo Pit.[138] On May 27, MEM personnel conducted an aerial inspection of the site.

Based on MEM's understanding of the incident from discussions with MPMC during a May 27 teleconference, MPMC reported to have the situation under control. MEM indicated follow-up would be required to confirm whether an overtopping and possible unauthorized discharge occurred, as well as to discuss future dam design and operations.

MEM requested MPMC follow-up with an *Advice of Geotechnical Incident* form, which outlines the details of the event and MPMC's response; and in the future provide MEM with a report regarding similar incidents as the Code considers this to be a dangerous occurrence.[139]

Minimum operating freeboard of 1.3 m was re-established on July 4, 2014. MPMC, working with AMEC, requested a temporary freeboard of 1.1 m for a "limited exposure window" of two weeks while embankment construction addressed the low points in the TSF.[140] This temporary control measure (recommended by AMEC to MPMC) was recognized by the Ministry on July 18.[141]

MPMC classified the event not as an overtopping but a "loss of design operating freeboard allowance at tailings storage facility," according to the *Advice of Geotechnical Incident* form submitted. MEM did not have a record of receiving correspondence from MPMC during the incident to clarify whether a dam overtopping occurred or what the minimum freeboard was during the event. The first survey of freeboard was received by MEM on June 2, 2014 in AMEC's memo dated May 30 that indicated the pond elevation and the dam elevation at Corner 3 to be recorded as the same elevation (i.e., zero freeboard) on May 26. It was then, based on this information, MEM considered the event to be classified as a dam overtopping.

MEM follow-up on the incident included weekly updates from MPMC on the status of the site conditions (freeboard, construction activities, etc.), a memo issued by AMEC outlining the timeline and incident daily status, and a water management plan endorsed by AMEC.

In a formal report of the incident, AMEC indicated the overtopping was localized to a section of core stretching approximately 14 m. The after-action review noted, "due to poor weather conditions, construction activities for raising the core were very limited." [142] Despite multiple recommendations from the EoR (AMEC), "to date no extensive effort to lower the pond elevation was implemented." [143] It is unclear whether the mine took note of the causes of the event, implications for water management, or other lessons learned and their application to the water management issues facing the TSF.[144]

MEM inspectors concluded that the overtopping event indicated that MPMC:

- *did not adhere* to the OMS manual which indicates "the mine will implement emergency procedures when the pond level is less than 1.3 m below the dam crest;"
- *did not adequately monitor* the water levels to be aware of the incident in a timely manner;
- *did not produce sufficiently accurate* water balance calculations to predict the anticipated water levels.[145]

Ultimately, MPMC recognized that some form of water treatment was essential to achieve a realistic water balance on site. MPMC indicated that the company had "ordered" a reverse osmosis water treatment system with a treatment capacity of 3 million m^3/year that was scheduled to be implemented in late 2014 or early 2015.[146]

The estimated volume of supernatant water in the TSF as of August 2013 was approximately 6 million m^3. [147] Estimated supernatant water in the TSF as of August 3, 2014 was approximately 10 million m^3. [148]

6.13.5. MEM INSPECTIONS AND OVERSIGHT

A geotechnical Inspection was conducted on September 13, 2013 by Michael CULLEN, P.Eng., accompanied by Steve ROTHMAN (MEM). CULLEN reported "the Stage 9 dam raise to elevation 970m was underway at the time of this inspection. MEM has previously reviewed and accepted the designs for this lift. All construction work appears to be well done. A quality control and quality assurance program is in place and it is understood that there have been no significant issues. The Mine reports that instrumentation has responded as expected during construction.

"An inspection around the dams revealed no indictors of instability and no significant seepage on the face or toe of the dams.

"We reviewed the revised Operation, Maintenance and Surveillance Manual prepared by Mount Polley in July 2013. This document covers tailings and water management across the site and is considered well thought out.

"Based on our observations and information reviewed we consider that the TSF is being designed, constructed, and operated in general conformance with the requirements of the geotechnical components of the Code, Permit M-200, and accepted engineering practices." [149]

No inspection orders were issued.

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6.14. STAGE 10 (APPLICATION SUBMITTED) – 2015-

Although no Stage 10 raise was commenced due to the failure of the TSF, the Stage 10 design does have a place in the chronological narrative. A design was produced for Stage 10, and it appears that some construction work proposed in this design was started as early as October 2013.

The Stage 10 raise was planned to achieve a crest elevation of 972.5 m, and to accommodate further lifts to meet tailings storage requirements for the remainder of the life of the mine. The raise was anticipated to commence upon issuance of a *Mines Act* permit amendment, applied for on July 25, 2014, to be completed by spring of 2015. In addition to the raise to 972.5 m, Stage 10 proposed the following:

- Addition of Zone C buttresses along the main and perimeter embankments
- Additional shear strength testing of glaciolacustrine foundation layers

Commencement of Stage 10 would also mark the transition of Engineer of Record from AMEC to BGC Engineering Inc. (BGC). Key engineering staff, including Todd MARTIN and Darryl DUFAULT, had previously transferred from AMEC to BGC.

6.14.1. PERMITTING

The Stage 10 *Mines Act* permit amendment application, prepared on behalf of MPMC by BGC, was received by MEM on July 25, 2014, less than two weeks prior to the dam breach. Due to the breach event on August 4, the permit amendment application was not reviewed by MEM.

6.14.2. DESIGN

The crest raise to 972 m "is expected to provide sufficient tailings, water storage, and flood storage freeboard until the end of September, 2015." [150] Figure 6.26 shows both the construction lift at the dam crest and the development of a buttress to increase stability.

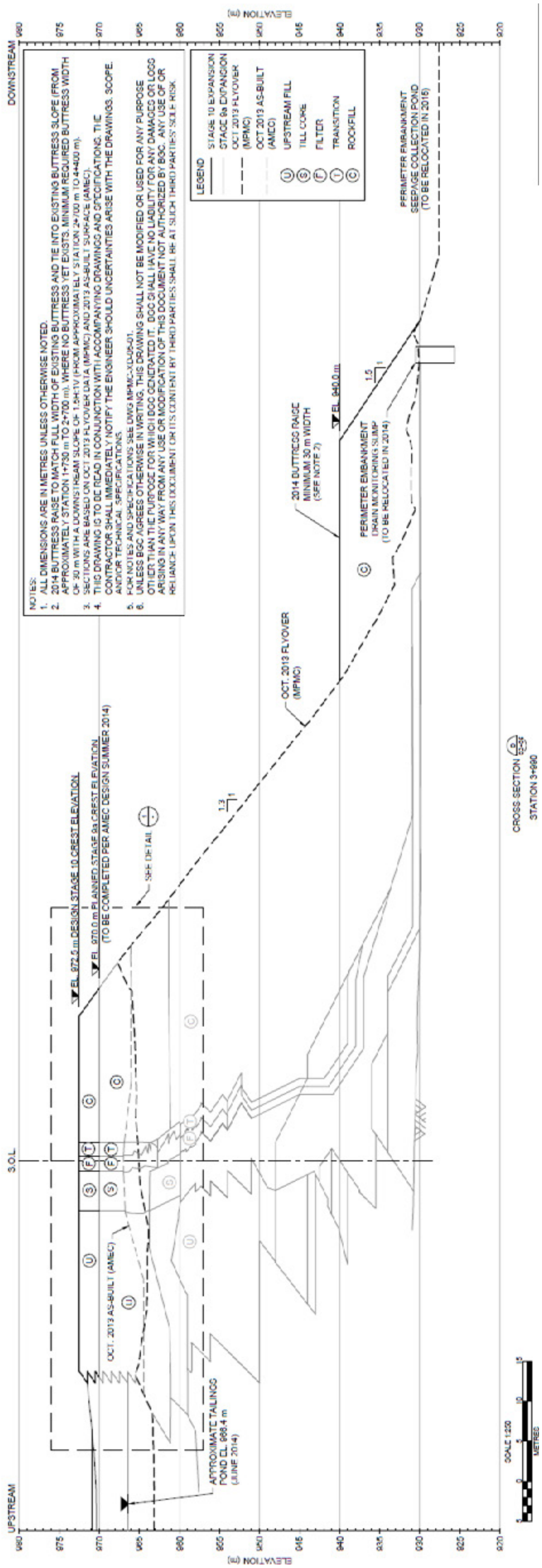

Figure 6.26 *Stage 10 PE Section Plan BGC Engineering Inc. (2014) Dwg. MPMC-XD-03-02*

"The currently permitted mine plan runs to 2016. MPMC is reviewing and updating the mine plan and as of issuance of this report, the mine life is projected to 2025. Extension of the mine life to 2025 would result in a projected final average tailings elevation (assuming flat deposition– neglecting beach slopes) in the TSF of 990 m.

"The intent therefore is to provide an interim dam configuration in the 2015 design report update. The design of the dam to its projected closure configuration will be completed once the water balance is better clarified, the efficacy of the water treatment plant (WTP) at its design throughput rate is confirmed, and the rate of decrease of the surplus pond volume, and coincident widening of the above water tailings beaches, can be incorporated into the design." [151]

The notion of the importance of wide tailings beaches was, for the first time, specifically mentioned in a design document. The report stated, "an above water tailings beach, separating the dams from the TSF operating pond, represents a fundamental structural element of the dams. Such a feature achieves the following key functions:

- Support for ongoing centerline raising of the dam
- Reduction of seepage from the TSF
- Reduction of hydraulic seepage gradients, of particular importance given the low core width/hydraulic head ratio for the core of the dams
- Reduction of pore pressures in the foundation soils underlying the dams
- Greatly restricts the supply of water to propagate a hydraulic fracture that could develop in a narrow core zone
- Limits the rate at which water can flow through any defects (e.g. cracks) in the core
- Where tailings are directly against the upstream side of the core, they could potential function as a crack-stopper." [152]

The Stage 10 design document goes on to propose, as an "interim target, *a minimum above-water beach width of 400 m is judged a reasonable criterion* for planning of tailings deposition operations once the volume of water within the TSF has been reduced. In the next phase of design for raising above 972.5 m, seepage analyses, calibrated to available seepage flow and piezometric data, will be used to guide refinement of these criteria, as wider beaches against the Main and Perimeter dams than against the South dam may be appropriate. The next phase of design should also include tailings deposition planning to provide operations with guidance for the tailings deposition locations and tonnages/durations necessary to establish and maintain wide above-water beaches for the entire length of the dams." (italics added)[153]

The document noted, "portions of the Mount Polley TSF dams are underlain by glaciolacustrine and glaciofluvial soils. There is evidence of a varved structure within the glaciolacustrine unit, which raises the potential of brittle behavior (i.e. significant reduction in shear strength) upon straining… In the worst case, foundation straining (in response to staged dam construction) could result in a reduction of the shear strength to its residual (minimum) value… there is to date no evidence, based on borehole and test pit data, site geology reports, or inclinometer monitoring, of any such degradation in foundation shear strength. Nonetheless, in keeping with the tenets of the observational approach, it is necessary to incorporate designs and/or viable plans of action to 'deal with every unfavourable situation that might be disclosed by the observations.' In the case of a reduction of shear strength from peak to residual in potentially brittle soils within the foundation, there is likely to be insufficient time available to recognize and respond to such a condition. Accordingly, as a contingency measure, the following FoS criterion is applied for the staged raising of the Mount Polley TSF: FoS ≥1.1 based on a reasonable worst case scenario for residual shear strength within the glaciolacustrine foundation soils." [154]

"It is important to note that the residual strength case is not the design basis – it is the basis for contingency planning consistent with the observational method. If ongoing monitoring and investigations indicate that the operative shear strength of the glaciolacustrine unit, where present, is significantly lower than currently estimated, then the FoS ≥ 1.5 criterion would apply for that lower shear strength."[155]

BGC concluded with the observation that "the Stage 10 crest raising will precede the downstream slope buttress raising, to take advantage of summer weather conditions for till core construction. For the Stage 10 crest raising, addition of fill prior to fill placement against the downstream slope of the dam is acceptable as the FoS values were evaluated for the El. 972.5m crest without buttress raising, and were *found to be adequate although below target factor of safety criteria in some instances*… FoS design criteria are expected to be achieved or exceeded along the entire length of the dam prior to commencement of crest raising above El. 972.5m in the spring of 2015." (italics added)[156]

6.14.3. WATER BALANCE

As in all recent (post-2005) design documents, water balance was performed by the mine, not the engineer; the design document, however, recognized that the expanded disturbed area footprint, coupled with the loss of water storage capacity in open pits due to mining operations, contributed to demands on the TSF for site water storage.

"In recent years, the TSF has been operating with a significant annual water balance surplus, with the result that the volume of water stored within the TSF has increased on a year over year basis. MPMC has a permit to discharge up to 1.4 Mm^3 of water per year to Hazeltine Creek, but has generally been unable to discharge more than about 10% of this amount owing to water quality constraining allowable discharge volumes. As of the end of May 2014, following what is understood to have been an abnormally high snowpack runoff and a significant multi-day rainfall event, the pond volume was estimated to be between 8 and 9 Mm^3. This is significantly more water than is required to maintain a viable process water reclaim pond – in 2010, for example, the estimated volume of water in the TSF was only about 900,000 m^3.

"The ongoing accumulation of a water surplus within the TSF causes the following challenges:

- For a given dam crest elevation, tailings storage capacity is displaced by water storage.
- Wide, above-water, tailings beaches that separate the dam from the reclaim water pond, a fundamental component of the dam design … can be neither established nor maintained.
- The conceptual closure configuration for the TSF incorporates reclaimed (covered and vegetated), wide, above-water beaches against the dam from abutment to abutment, and a minimal water pond with an overflow spillway for pond level control. TSF pond volume that increases year over year is incompatible with operating to achieve that closure configuration.
- The dam crest raising schedule has to be accelerated.

"The volume of water stored in the TSF is controlled by hydrologic conditions beyond MPMC's control. The ability of MPMC to store water in open pits, a previous practice, is at odds with current mine plans and on-going pit development. These circumstances have increased the potential for flood storage and freeboard requirements to be infringed upon as a result of larger than anticipated water accumulation within the TSF. To resolve this and the issues noted above, MPMC is advancing the permitting and design for the construction of a reverse osmosis water treatment plant (WTP), capable of treating and discharging up to 3 Mm^3 per year on a year-round basis. MPMC anticipates commissioning of the WTP, and initiation of discharge to Polley Lake, in October 2014.

"MPMC has developed a site-wide water balance model that can be used to predict the site wide surplus or deficit for average, wet, and dry year scenarios. The model accounts for the expanded mine footprint of recent years and for the flows captured by recently constructed runoff and seepage collection ditches. The model also allows MPMC to project TSF pond volume changes for various water treatment and discharge scenarios. MPMC has used the model to project various water management scenarios for the coming year, prior to the 2015 dam crest raise, in order to determine the appropriate target crest elevation for the TSF dams for the 2014 construction season."[157]

6.15. SUMMARY

The chronology of the TSF reveals a history of gradual changes. The embankment design and construction was staged over the course of nearly two decades.

Certain parameters and operational protocols changed over time, especially the management of water balance over the site, the oversight of construction activities, and the frequency of surveillance activities.

The design profile of the PE at the close of Stage 9 (at the time of the failure) is shown in Figure 6.27. The elevation of the crest is 970 m; the height of the embankment at its highest point (where the breach occurred) is approximately 40 m, and the downstream slope is at 1.3H:1.0V.

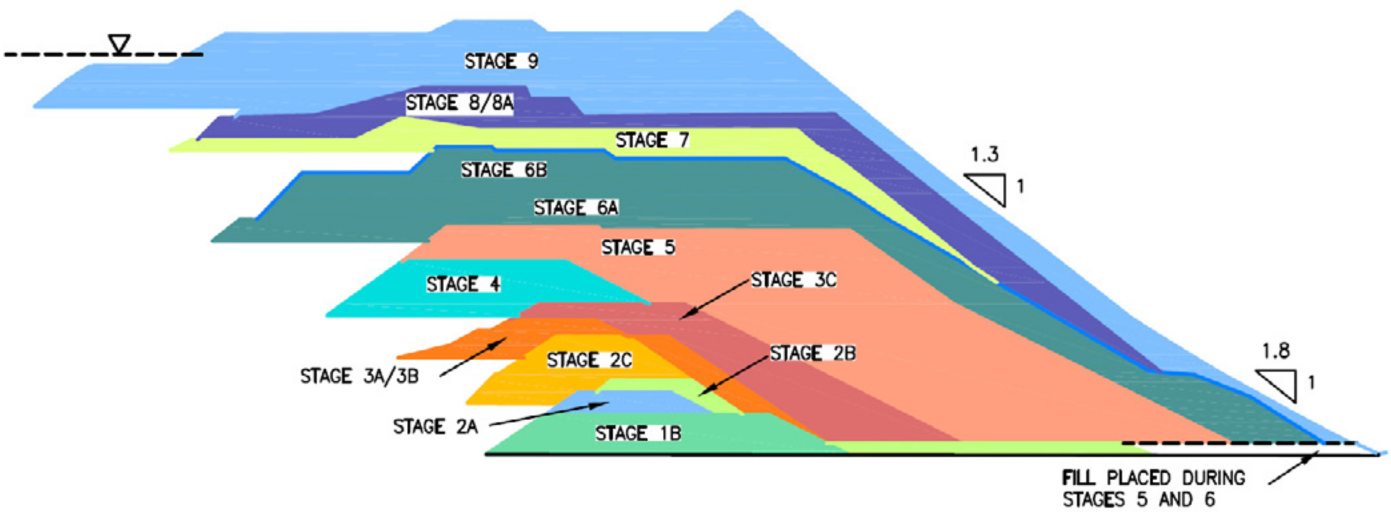

Figure 6.27 Embankment Stages Appendix 3, Fig. 2.6

Design changes proposed by BGC were aiming the TSF toward increased stability and an increased focus on water reduction, particularly by obtaining relief through treatment and discharge. Stability increases were to be accomplished with construction of a new buttress on the PE and enhancement of existing buttress on ME. This chronology represents the history of the TSF up until the PE failure and breach that took place on August 4, 2014.

FOOTNOTES

1 *Knight Piésold (1995a) p. 24*

2 *Knight Piésold (1995a) p. 23*

3 *Knight Piésold (1997a) p. 6*

4 *Knight Piésold (1997a) p. 18*

5 *Knight Piésold (1998) p. 3*

6 *Headley (1996b); Headley (1996c); Headley (1996d)*

7 *Headley (1995a)*

8 *Brawner (1995a)*

9 *Headley (1995b)*

10 *Embree (1995)*

11 *Headley (1995c)*

12 *Brawner (1995b)*

13 *Brawner (1995b)*

14 *Headley (1996c)*

15 *Headley (1998b)*

16 *MAJM Corporation (1997)*

17 *Headley (1996a); Headley (1996e)*

18 *Mount Polley Mine Engineering Department (1998) p. 2*

19 *Knight Piésold (1997b) p. 22*

20 *Headley (1996f)*

21 *Headley (1997a)*

22 *Headley (1997b)*

23 *Ministry of Energy and Mines (1995)*

24 *Knight Piésold (1997b) p. 42*

25 *Klohn Crippen Berger (2015b) p. 7*

26 *Mount Polley Mine Engineering Department (1998) p. 2*

27 *Knight Piésold (1998) p. 5*

28 *Knight Piésold (1999c) p. 58*

29 *Headley (1998a)*

30 *Headley (1999)*

31 *Knight Piésold (1999b)*

32 *Knight Piésold (1999b)*

33 *Knight Piésold (2000b)*

34 *Knight Piésold (1999c) p. 60*

35 *Knight Piésold (1999c) p. 7*

36 *Headley (2000)*

37 *Knight Piésold (2000a)*

38 *Eaton (2000)*

39 *Carr (2001b)*

40 *Carr (2001a)*

41 *Mount Polley Mining Corporation (2001)*

42 *Ministry of Environment (2012a) p. 3*

43 *Ministry of Energy and Mines (1995) p. 13*

44 *Carr (2002)*

45 *McBride (2002)*

46 *Carr (2003)*

47 *Ministry of Environment (2012a) p. 3*

48 *Ministry of Energy and Mines (2005)*

49 *Knight Piésold (2005) p. 6*

50 *Knight Piésold (2005) p. 9*

51 *Knight Piésold (2006) p. 6*

52 *Knight Piésold (2006) p. 1*

53 *Knight Piésold (2007a) p. i*

54 *Knight Piésold (2007a) p. 5*

55 *Knight Piésold (2007a) p. 6*

56 *Frye (2004)*

57 *Carr (2005a)*

58 *Carr (2005b)*

59 *Galbraith and Brouwer (2005) p. 1*

60 *Carr (2005a)*

61 *Rose (2005)*

62 *Rose (2005)*

63 *Mount Polley Mining Corporation (2006a)*

64 *Ministry of Energy and Mines (1995)*

65 *Knight Piésold (2007a) p. 2*

66 *Knight Piésold (2006) p. 9*

67 *Knight Piésold (2006) Table 3.2*

68 *Galbraith and Brouwer (2007)*

69 *AMEC Earth & Environmental (2007)*

70 *Knight Piésold (2008) p. 10*

71 *Knight Piésold (2008) p. 7*

72 Rose (2006)

73 Mount Polley Mining Corporation (2006b)

74 Knight Piésold (2007b) p. 1

75 Knight Piésold (2007b) p. 4

76 Knight Piésold (2007b) p. 7

77 Knight Piésold (2007b) p. 9

78 Knight Piésold (2009b) p. 8

79 Knight Piésold (2009b) p. 10

80 Knight Piésold (2009b) p. 11

81 Knight Piésold (2007b) p. 5

82 Knight Piésold (2007b) p. 9

83 Knight Piésold (2007b) p. 12

84 Rose (2007)

85 Apel (2008)

86 Apel (2008)

87 Carr (2008)

88 Knight Piésold (2011a) p. 4

89 Knight Piésold (2011a) p. i

90 Knight Piésold (2011a) p. 7

91 Knight Piésold (2011a) p. 9

92 Knight Piésold (2011a) p. 11

93 Knight Piésold (2011a) p. 9

94 Knight Piésold (2011b) p. 6

95 Knight Piésold (2011b)

96 Cox (2009)

97 Ministry of Energy and Mines (1995)

98 Mount Polley Mining Corporation (2011)

99 AMEC Environment & Infrastructure (2012b) pp. 1-4

100 AMEC Environment & Infrastructure (2012b) p. 3

101 AMEC Environment & Infrastructure (2012b) p. 13

102 AMEC Environment & Infrastructure (2012b) p. 17

103 Knight Piésold (1999a) pp. 9-10

104 AMEC Environment & Infrastructure (2012c) p. 2

105 AMEC Environment & Infrastructure (2012b) p. 4

106 AMEC Environment & Infrastructure (2012b) p. 12

107 AMEC Environment & Infrastructure (2012b) p. 8

108 Mount Polley Mining Corporation (2011)

109 Independent Expert Engineering Investigation and Review Panel (2015) p. 85

110 AMEC Environment & Infrastructure (2012c) p. 9

111 AMEC Environment & Infrastructure (2012b) p. 2

112 BGC Engineering Inc. (2013a) p. 11

113 BGC Engineering Inc. (2013a) p. 7

114 AMEC Environment & Infrastructure (2014a) p. 10

115 BGC Engineering Inc. (2013a) p. 5

116 Ministry of Environment (2012a) p. 3

117 Ministry of Environment (2012c) p. 4

118 Cullen (2012)

119 Cullen (2012)

120 Warnock (2012)

121 Moger (2013a)

122 Narynski (2013)

123 AMEC Environment & Infrastructure (2014a) p. 12

124 Klohn Crippen Berger (2015b) p. 142

125 BGC Engineering Inc. (2013b)

126 AMEC Environment & Infrastructure (2014a) p. 13

127 Mount Polley Mining Corporation (2014a)

128 AMEC Environment & Infrastructure (2014a) p. 18

129 AMEC Environment & Infrastructure (2014a) pp. 18-19

130 Independent Expert Engineering Investigation and Review Panel (2015) Appendix H

131 Klohn Crippen Berger (2015b) p. 13

132 AMEC Environment & Infrastructure (2014a) p. 18

133 Narynski (2015)

134 Narynski (2014a)

135 Klohn Crippen Berger (2015a) p. 15

136 Ostrichenko (2014) pp. 2-4

137 Knight Piésold (1995a)

138 Moger (2014a)

139 Ministry of Energy and Mines (2008) Section 1.7.2 (2)

140 Moger (2014b)

141 Narynski (2014b)

142 Ostrichenko (2014) p. 2

143 Ostrichenko (2014) p. 3

144 Warnock (2014a)

145 Narynski (2015)

146 Klohn Crippen Berger (2015b) p. 133

147 Independent Expert Engineering Investigation and Review Panel (2015)

148 Independent Expert Engineering Investigation and Review Panel (2015)

149 Cullen (2013) p. 5

150 BGC Engineering Inc. (2014) p. 6

151 BGC Engineering Inc. (2014) p. 24

152 BGC Engineering Inc. (2014) p. 18

153 BGC Engineering Inc. (2014) p. 19

154 BGC Engineering Inc. (2014) pp. 20-1

155 BGC Engineering Inc. (2014) p. 21

156 BGC Engineering Inc. (2014) p. 63

157 BGC Engineering Inc. (2014) pp. 22-3

GEOTECHNICAL CONDITIONS 7

Given the importance of understanding the geotechnical conditions in the dam's foundation soils, the investigation included the collection and analysis of geotechnical information to determine the actual geotechnical conditions in the area of the breach.

To accomplish this investigation, the Chief Inspector engaged the engineering firm of Klohn Crippen Berger (KCB) to review the level of knowledge of the engineering consultants who advised MPMC over the lifetime of the TSF, and to compare this knowledge at the location of the failure with the findings of the post-failure site investigation.

KCB noted differences in the interpreted foundation conditions, which focused on the understanding of the upper glacioacustrine unit (UGLU), which was either characterized as discontinuous and thin (and therefore dismissed), erroneously conflated with the lower glaciolacustrine unit (LGLU) that was accurately identified and characterized, or missed altogether. This chapter outlines the actual structure of the foundation in the area of the breach, with a focus on understanding the UGLU and its characteristics.

7.1. GENERALIZED SOIL UNITS

One area of focus of the investigation has been the weak layer of clay in the immediate vicinity of the breach. This layer, known as the UGLU, was deposited in the period between glaciations of the region in a glacial lake. The history of the UGLU, the amount of consolidation it received (by pressure caused by a glacier advancing above the UGLU), and the level of attention it received from engineering consultants all play significant roles in the dam failure event.

The Chief Inspector engaged KCB to collect pertinent geotechnical information to support an evaluation of the mechanism of failure of the embankment. A summary of the previous site characterization information at the embankment failure area is presented in Section 7.2. The soil profile encountered in the vicinity of the embankment failure consists of interlayered glacial till, lacustrine, and glaciofluvial deposits. A review of the knowledge prior to the dam failure suggests that the glaciolacustrine and glaciofluvial layers within the upper tills throughout the tailings embankment footprint were variable in consistency and were distributed across the site, both spatially and in elevation.

UGLU

the upper glaciolacustrine unit is a weak clay layer resting 10 metres below the site of the TSF failure

However, the post-failure site investigation identified a clay layer of glaciolacustrine origin underlying glacial till approximately 10 m below the base of the embankment. This clay layer, termed the UGLU, is a moderate to high plastic, clay-rich varved lacustrine deposit ranging up to 2 m thick and, to the extent the foundation conditions were revealed by post-breach site investigations, largely confined to the area of the failed embankment. As glaciolacustrine sediments are deposited sub-aqueously, horizontally, and often contain high percentages of silt and clay, they typically represent weak units within the foundation and are therefore of particular geotechnical concern.

The glaciolacustrine foundation soils were classified by KCB based on the following:

- Glaciolacustrine/glaciofluvial units above approximately el. 917 m were classified as units within the "upper tills" (referred to herein as the "upper glaciolacustrine units").
- Glaciolacustrine units below approximately el. 917 m and below the ME were assumed to be part of the main glaciolacustrine/glaciofluvial unit (referred to herein as the "lower glaciolacustrine unit").
- Till below the main glaciolacustrine/glaciofluvial unit was classified as "lower till."

A simplified schematic illustrating the generalized soils units is presented in Figure 7.1. The left soil profile is the generalized summary of the foundation soils as known prior to the breach; the right side shows the additional detail gained from investigations following the breach.

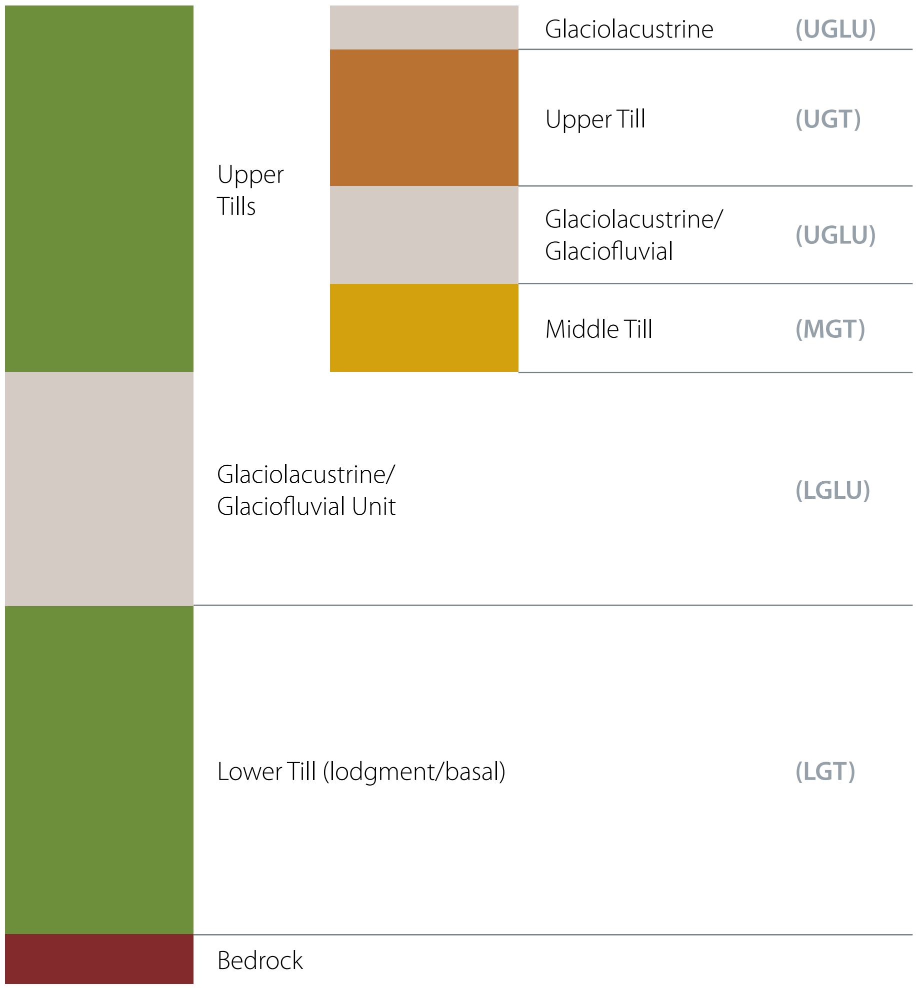

Figure 7.1 Schematic of Generalized Soil Units Appendix 3, p. 79

The appropriateness of the geologic models developed by the engineering consultants and presented in Appendix 3 (Section 3.4) was reviewed within the context of the relatively complex geological setting and history described in the previous sections of this report. Some of the challenges and key observations that can be made in trying to support or modify the previously proposed geologic models include the following:

- The PE is approximately 2 km in length, with a current maximum dam height of approximately 40 m, which is a relatively long stretch of soil conditions that need to be quantified.
- The majority of the previous site investigations within the PE footprint were shallow drill holes and test pits. Prior to 2011, only one drill hole extended to bedrock (MP89-231), and the tricone rotary drilling method only employed sampling of the drill cuttings as the hole progressed. This type of sampling is not adequate to quantify the soil properties or to identify thin layers.
- The 2011 drilling program included three locations near the downstream toe of the PE. Drilling included continuous core sampling into bedrock. However, the spacing on the drilling was approximately 500 m apart, a large spacing considering the glacial geology. A lower-strength UGLU was not encountered in the drilling.

- While there is evidence of UGLU downstream of the PE, there was no quantitative data that they were present beneath the dam footprint. The glaciolacustrine units identified near the surface in the breach area were reported to have been excavated as part of the dam foundation preparation.[1]

7.2. PREVIOUS SITE INVESTIGATIONS

Various site investigations were conducted from 1989 to 2012 at the TSF. Figure 7.2 presents the plan of pre-failure site investigations conducted at or near the failed embankment. The deep condemnation drillhole, MP89-231, is indicated with the arrow.

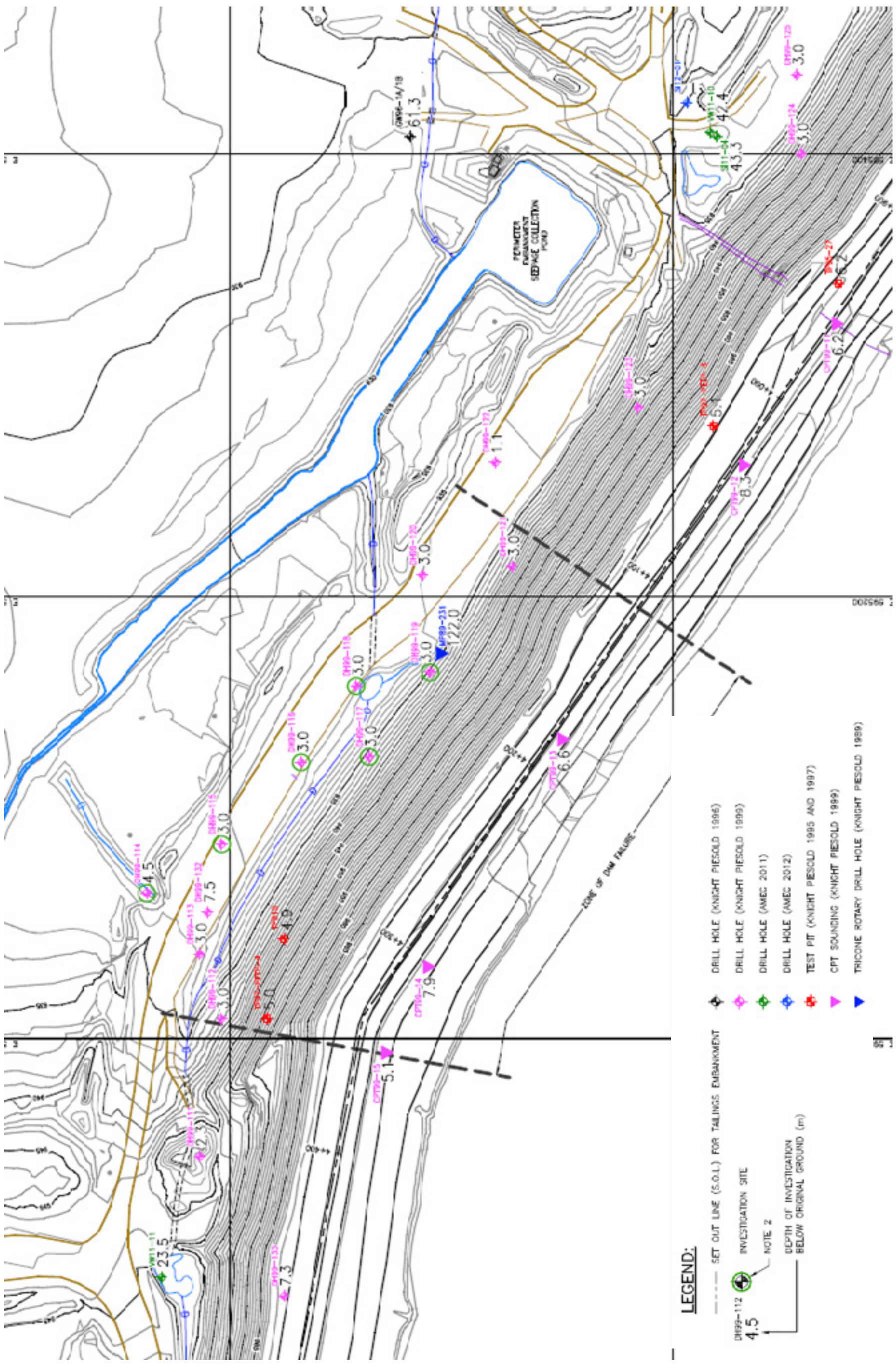

Figure 7.2 Site Investigations Near the Breach Appendix 2, Fig 2.9

The investigations conducted in the area of the failed embankment and the PE comprised the following:

- In 1989, MP89-231 was drilled below the failed embankment to 122 m depth by tricone rotary drilling. The overburden was characterized from drill cuttings, which is usually imprecise in quantifying soil properties or identifying thin layers. No glaciolacustrine deposits were identified in MP89-231. The water table was at the surface.
- From 1995 and 1999, a total of 4 test pits and 17 drill holes were completed in the vicinity, with 2 test pits and 11 drill holes below the failed embankment. These investigations were restricted to 5 m depth, except for DH99-132 which was 7.5 m deep. A clay layer, up to 2 m thickness, was encountered near the surface overlying stiff to very stiff glacial till. The areal extent of this layer was confined to the center of the failed embankment area, at DH99-114 to DH99-119 as shown in Appendix 2, Figure 2.9. This correlates with the shallow clay deposit excavated during the foundation preparation.
- In 1996, a 61 m deep groundwater monitoring well (GW96-1A/1B) was installed downstream of the Perimeter Embankment Seepage Collection Pond, approximately 150 m downstream and east of the failed embankment. A soft glaciolacustrine deposit was encountered from 919 m to 923 m, with a Standard Penetration Test (SPT) blow count of 6 blows per foot. Artesian conditions were also encountered in a permeable glaciofluvial unit from 896 m to 885 m.
- As discussed earlier, 5 Cone Penetration Tests (CPTs) were completed in 1999 through the upstream tailings beach to 8 m below tailings level. Three CPTs are upstream of the failure area. CPT99-14 reached 7.9 m below the tailings surface and encountered soils classified as silty clay. Tailings thickness in the area was about 5 m, indicating this CPT sounding reached about 3 m into the underlying foundation.
- In 2011, two sonic core holes (VW11-10 and VW11-11) were drilled at the embankment toe. VW11-11, located west of the failed dam, encountered a stiff glaciolacustrine deposit at 933 m to 929 m and VW11-10, located east, encountered a thin layer of glaciolacustrine at 917 m. Vibrating wire piezometers were installed in foundation soils in both holes.
- Also in 2011, one inclinometer (SI11-04) was installed downstream of the embankment toe, approximately 150 m east of the failed embankment. A stiff to hard glaciolacustrine layer was encountered at 914.9 m. In 2012, a replacement inclinometer (SI12-01) was installed adjacent to SI11-04 due to a suspected malfunction in SI11-04. Instrumentation records and readings from instruments on the PE are presented in Appendix 2.

In summary, detailed information on the soil profile below the failed embankment was restricted to a 7.5 m depth. The investigations encountered glacial till overlain in local areas by a deposit of glaciolacustrine clay. Deeper investigations outside the failure area revealed the presence of three other glaciolacustrine deposits at different elevations and depths, and the occurrence of artesian pressures within glaciofluvial deposits at depth.[2]

7.3. INFORMED QUATERNARY GEOLOGY

The soil stratigraphy was studied by KCB as part of the failure investigation and this information was used to update and confirm the quaternary geologic model discussed in Appendix 3 of this report (Section 4.3). Some key observations from the failure investigation are summarized below:

- The preservation of laminations and layering within the lightly overconsolidated UGLU indicates that the overlying upper glacial till (UGT) was deposited under relatively thin ice, likely less than 50 m in thickness based on the level of overconsolidation measured in free-field (outside of breach area) samples. Conversely, the LGLU appears to have undergone much greater glacial loading as evidenced by its overconsolidation ratio and wavy and distorted laminations that may be indicators of glacial drag.

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- The gradation and texture of the UGT are typical of basal till. The lower relative strength and higher moisture content of the UGT compared with the underlying MGT, however, indicates that the UGT was deposited under much thinner ice than the MGT. The preservation of structure and light overconsolidation of the underlying UGLU also indicate the ice that deposited the UGT was relatively thin.
- When the UGLU was not present, the UGT and MGT were often differentiated in the field based on colour. The UGT was generally brown/grey, whereas the MGT was green/grey. This, and the differences in the properties described above, indicates the two units are of different age and origin.
- Organic samples collected from the LGF indicated an age of approximately 34,000 years before present (bp).

KCB's interpretation of the history of glaciation within the breach area is summarized below:

1. The LGT was deposited during the penultimate glaciation. Both the degree of consolidation and high strength of this deposit suggest it was deposited subglacially under heavy glacial loading.
2. The LGF sediments were deposited as glacial outwash following the penultimate glaciation.
3. A second glacial advance deposited the basal MGT, and loaded the LGF unit.
4. A period of glacial advance and retreat during, or after, the second glaciation deposited ice-proximal glaciofluvial (UGF) and glaciolacustrine sediments (UGLU) found within the breach area.
5. A final glacial advance overrode the UGLU and deposited the UGT subglacially. The "bowl shaped" bedrock topography in the breach area may have created a stress shadow during the final glacial advance that limited glacial loading of the UGT and UGLU.[3]

7.4. GLACIOLACUSTRINE UNITS

As a result of the investigation carried out on site and in the laboratory by KCB, an understanding of the structure of the foundation in the breach area emerged. As part of the KCB site investigation, disturbed and undisturbed soil samples were collected to characterize the foundation soil units and dam core. Drill holes were located so that observations of soil structure and differences in soil strength could be assessed within the breach and in the "free field."

KCB compared the index properties of the two glaciolacustrine units encountered within the breach area: the ULGU and the LGLU. A summary of the index properties is shown in in the table below.

SUMMARY OF INDEX PROPERTIES FOR UGLU AND LGLU (KCB 2015A)

Parameter	Upper Glaciolacustrine (UGLU)	Lower Glaciolacustrine (LGLU)
Soil classification	CI-CH	CI
Specific gravity	2.77	-
Gravel content (%)	0 to 4 (2)	0
Sand content (%)	0 to 15 (8)	1 to 4 (3)
Fines content (%)	81 to 100 (90)	96 to 99 (97)
Clay content (%)	39 to 67 (50) [59]	23 to 32 (26) [31]
In situ water content (%)	13 to 54 (36)	15 to 29 (23)
Liquid limit (%)	33 to 69 (50) [61]	31 to 42 (35) [41]
Plastic limit (%)	15 to 26 (20)	11 to 23 (18)

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Plasticity index (%)	18 to 49 (30) [39]	11 to 27 (17) [24]
Liquidity index	(0.5)	(0.2)
Activity	(0.6)	(0.6)
XRD clay speciation (Note 3)	47% illite, 29% chlorite, 22% smectite, and 11% kaolinite	43% illite, 27% chlorite, 24% smectite, and 10% kaolinite

Notes:

1. Values presented are minimum and maximum range of tested data. The median of this range is included in brackets.
2. Square brackets shows mean + standard deviation value representing the upper 2/3 bounds of data.
3. Median values for semi-quantitative amount of clay minerals reported for the < 2 microns fraction.

Generally, the UGLU was shown to have a higher moisture content, higher plasticity, higher clay content and higher liquidity index (indicating less overconsolidation) than the LGLU.

Drained peak and residual strength parameters for the UGLU were measured by KCB through direct shear and triaxial compression testing. Consolidation tests indicate a mean preconsolidation pressure of approximately 400 kPa, meaning that under significant portions of the dam the UGLU would have been loaded beyond its preconsolidation pressure and into a normally consolidated state. Accordingly, the undrained strength of the UGLU was assessed under direct simple shear.

Compared to the UGLU, the LGLU is very stiff to hard and overconsolidated. Oedometer testing on one sample of LGLU indicates a preconsolidation pressure in excess of 750 kPa. This means that under the dam the LGLU would have remained in an overconsolidated state and ultimate strength of the soil would be governed by the drained frictional strength. One direct shear test was performed on the LGLU which was understood to represent the "average" drained strength. To approximate the strength of high plasticity, clay rich horizons in the LGLU unit, the fully softened and residual drained friction angles were estimated using liquid limit and clay content.

Glaciolacustrine units' strength parameters used for the KCB failure assessment are summarized in the table below.

SUMMARY OF STRENGTH PARAMETERS FOR FAILURE ANALYSIS – GLACIOLACUSTRINE UNITS (KCB 2015A)

Parameter	Upper Glaciolacustrine (UGLU)	Lower Glaciolacustrine (LGLU)
Peak effective friction angle	22°	28°
Residual effective friction angle	14°	23° (free field) 18° (below embankment)
Undrained shear strength	Su = 50 + 0.13 σvo' (peak) Su = 36 +0.11 σvo' (20% strain) Su = 22 +0.03 σvo' (remolded)	

None of the stability analyses conducted prior to the TSF failure incorporated the weaker UGLU layer. As the PE became steeper and higher, the forces exerted by the embankment penetrated deeper into the foundation soils, eventually incorporating the UGLU. See also Figure 9.2 for additional data on strength of the LGLU.

7.5. INSTRUMENTATION RECORDS

Figure 7.3 presents the pre-failure instrumentation plan at Corner 1 of the PE. Instrumentation includes: 17 vibrating wire piezometers, 2 slope inclinometers and flow measurements from the upstream toe drain. Reference information for the instrumentation is included in the *Failure Assessment*, Appendix 2.

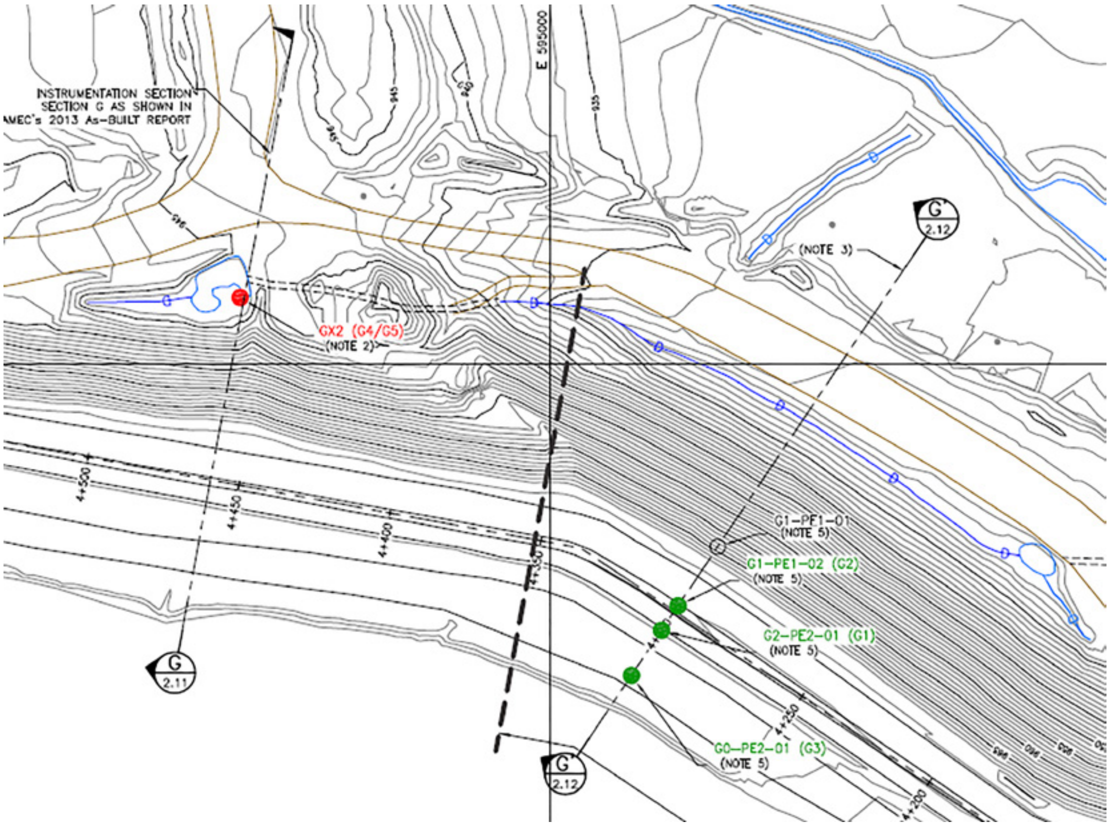


Figure 7.3 Instrumentation Plan at Section G and G' at Breach Site Appendix 2, Fig 2.10

Monitoring frequency varied throughout the operation of the TSF. Frequency was initially every two weeks for inclinometers and piezometers, and was reduced to once a month after 2012.[4] Seepage measurements from the upstream toe drain were typically recorded 3 to 8 times per year starting in 2007.

7.5.1. PIEZOMETERS

The piezometers were either installed during construction within the tailings impoundment and fill materials, or installed in foundation soils during site investigations. In the area of the breach, piezometers were installed in the dam structure, but not in the foundation. 12 of the 17 vibrating wire piezometers at the PE were functioning in 2014. The functioning piezometers are located along three sections (2 are shown in Fig. 7.2; Section D is shown in Appendix 2, Figure 2.10:

- Section G (AMEC) – west of breach area: 2 in foundation soils (glacial till and glaciolacustrine);
- Sections G' (KP) – in breach area: One installed in the upstream tailings, one in the upstream fill (Zone U), and one in the till core (Zone S); and
- Section D (KP and AMEC) – east of breach area: Three in foundation soils (glacial till, glaciolacustrine, and glaciofluvial), 2 in the filter materials, one in the till core, and one in the upstream tailings.

Salient observations from the piezometers are as follows:

- Piezometers G2 and D04 were installed in the till core (Zone S) at a nominal elevation of 948 m. Pore pressures in G2 began to increase as the pond elevation rose above about 960 m, indicating saturation of the core. No pore pressure response was observed in D04 in response to the pond rise. However, the pore pressure in piezometer D03 located downstream in Filter Zone F increased as the pond level rose above 955 m, an indicator of high seepage through the core. Other explanations are that the readings for D04 and D03 are interchanged and misreported or D03 is actually in the core.
- Piezometers installed in the upstream tailings (G3 and D05) and in Zone U (G1) all responded as the upstream pond level rose above the elevation of the piezometer tips. However, the piezometric levels were typically 5 m to 10 m below the adjacent pond level, reflecting the influence of the upstream toe drain.
- Piezometers installed in drain and fill materials downstream of the core showed no response to embankment raising or pond level rise. The exception is the anomalous response in D03 noted above.
- Only 2 piezometers at Section D outside the failure area, D01 and D02, are installed below the embankment. Both were installed in the upper glacial till deposits. Neither piezometer showed any transient increases in pore pressures caused by loading during periods of embankment raising. D01 gradually increased by about 5 m over time, likely in response to seepage pressures increasing with the rise in the upstream tailings pond.
- Piezometers D6, D7, G4 and G5 are located outside the failure zone and beyond the downstream toe of the embankment. G4 and G5 indicate a water table near the ground surface and a downward gradient. Piezometric elevations at D6 and D7 are about 12 m below the ground surface and also indicate a downward gradient.

7.5.2. INCLINOMETERS

Only one inclinometer (SI11-04) was installed in 2011 at the PE. It is located approximately 150 m southeast of the dam failure and 20 m downstream of the embankment toe. As such, this inclinometer would not have given prior warning of the dam failure.

There were no inclinometers installed in the area of the breach.

The 2012 as-built report indicated the following: "In late 2012, readings from an inclinometer located downstream of the Perimeter embankment (SI11-04) showed compression failure deformation consistent with settlement at depths from ground surface to 15 m below ground surface. AMEC recommended that additional instrumentation be installed, as the SI11-04 would likely cease functioning due to the deformation."[5] Based on the soil profile at SI11-04, this deformation occurred in the upper glacial till unit. No significant displacements were observed in the glaciolacustrine layer encountered at 914.9 m, which is described as very stiff to hard. The elevation and characteristics of this unit are similar to the lower glaciolacustrine layer (LGLU).

An inclinometer casing with compression fittings (SI12-01) was subsequently installed to replace SI11 04 and set 42 m below ground surface. Readings for SI12-01 began on March 12, 2013 and continued until August 13, 2014. No preferential displacement trends or shear planes were observed in SI12-01. Cumulative displacement was in the order of 5 mm for a period of 10 months. Installation details and readings from SI11-04 and SI12-01 are included in Appendix 2.

7.5.3. SEEPAGE FLOWS

The flow rates from the upstream toe drain were measured in the ditch downstream of the pipe outlet. Flow records extracted from as-built reports are included in Appendix 2. Relevant observations include:

- Seepage rates from the upstream toe drain increased with time as the tailings pond rose. The seepage rate on July 2014 just prior to the dam failure was 23.4 L/s at a tailings pond elevation of 966.3 m.
- A temporary "spike" in seepage rate to 91 L/s was reported for April 2013. The tailings pond during the spike was rising to 962 m, when the embankment crest was at 965 m. The seepage rate diminished after the pond surpassed 962 m. The increased seepage may be related to the higher permeability of the Zone U fills placed in Stages 6B and 7, which comprised mainly rockfill. The seepage dropped as this rockfill was covered by deposited tailings.

Flow measurements from the outlet drains located just east of the breach (see Appendix 2, Fig. 2.4) were reported from July 2000 to November 2006 and yielded flow rate of less than 1 L/s.

7.6. SUMMARY

Limited site investigation, first during the initial design and subsequently at each progressive lift stage, did not reveal a layer of weaker glaciolacustrine clays, roughly 10 m beneath the ground surface. This layer, the upper glaciolacustrine unit (UGLU), rested under the site of the breach. Neither its potential presence nor its strength was taken into account in any stability analyses conducted pre-breach, so the FoS calculated by these analyses were intrinsically in error. As the dam height increased, the forces exerted by the dam reached this weaker layer. The following chapters assess the role this weak clay layer had in the chain of events and additional conditions that led to the failure of the dam and release of the TSF contents into the environment.

FOOTNOTES

1 *Klohn Crippen Berger (2015b) pp. 81-3*

2 *Klohn Crippen Berger (2015a) pp. 9-10*

3 *Klohn Crippen Berger (2015b) p. 114*

4 *AMEC Environment & Infrastructure (2013a)*

5 *AMEC Environment & Infrastructure (2013a)*

EVENT NARRATIVE 8

The Perimeter Embankment (PE) of the tailings storage facility (TSF) at Mount Polley Mine failed during the night of August 3-4, 2014 between Stations 4+110 and 4+350 of the TSF (see Figure 5.11). The timeline of events during the failure and breach are summarized in Section 8.3. The initial dam slump (failure) occurred at approximately 11:40 pm, August 3, 2014. Subsequently, the crest of the dam was eroded, with the flow of materials from the TSF starting at approximately 12:50 am August 4. Major flow and power loss occurred at approximately 1:08 am August 4. The dam continued to erode throughout the night until approximately noon on August 4; outflow largely abated by approximately 4:00 pm.

TIMELINE

the breach opened within just two hours of the initial dam failure

The rapidity of the failure and breach events prevented possible remedial actions to repair the dam or breach before the PE failed completely. The rapidity of the failure supports the conclusion that a "brittle" failure mechanism was activated during the failure, as no prior evidence of distress in the dam was visually evident to mine staff.

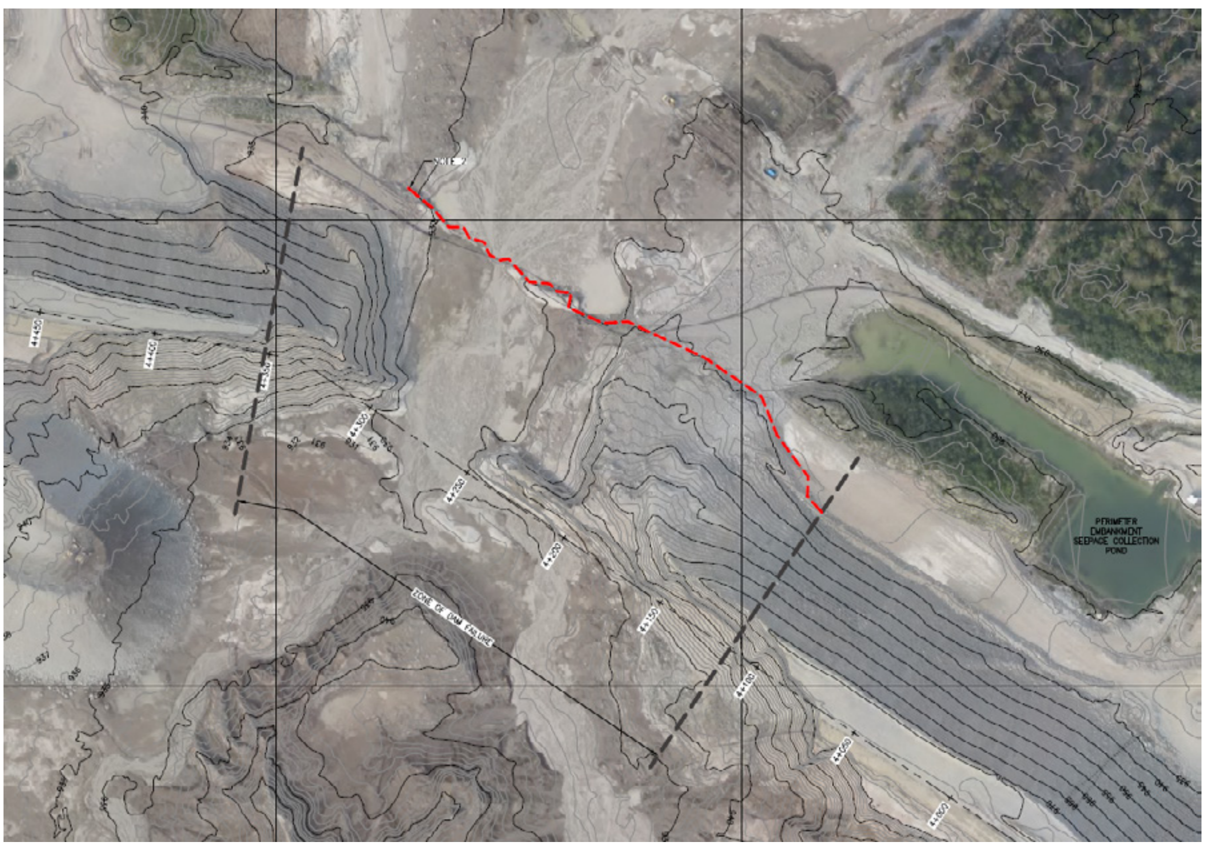


Figure 8.1 Aerial View of Dam Breach
Red line is limit of cracking and upthrust ground at toe. Appendix 2, Fig 3.2

Greater detail of the failure mechanism and process can be found in Chapter 9. Additional information on interviews and other data collected to reconstruct the narrative of the event can be found in Appendix 3.

8.1. CONDITIONS PRIOR TO FAILURE

Construction activities on the TSF continued up to the time of the breach. Figure 8.2 shows placement of Zone C rockfill on the PE a week before the failure. The night of the event, sand cell construction was under way until the breach was in full progress.

The event occurred early in the morning hours of BC Day, a statutory holiday in British Columbia. This is important as many staff, including managerial staff, were away during the long weekend. Operations during the night shift included a sand cat operating on the sand cells of the TSF near Corner 4, across the TSF, approximately 1.5 km from the site of the breach.[1]

Figure 8.2 Placement of Zone C Rock on PE, July 28, 2014
AMEC Environment and Infrastructure (2014e)

8.2. EMERGENCY RESPONSE

At Mount Polley Mine, guidance for emergency actions was provided in multiple documents, maintained at varying levels of currency, and with varying levels of access. Multiple emergency plans across the site were developed in isolation and not integrated. This section briefly reviews the state of two key emergency response documents, the *Mine Emergency Response Plan* (MERP) and the *Operation, Maintenance and Surveillance Manual* (OMS) and the role these documents played in the immediate response to the event. It includes some analysis and evaluation of the emergency response.

8.2.1. MINE EMERGENCY RESPONSE PLAN

The MERP is a requirement under Part 3.7.1 of the Code. The MERP must be current, accessible, and effective in providing emergency guidance. In the case of MPMC, the MERP fell short on all of these requirements. It did not include any reference to emergency management at the TSF. Although the MERP's deficiencies have not been linked to any cause of the failure, they significantly impacted the ability of MPMC senior staff to respond and could have severely impacted the safety of persons downstream had any been present.

The MERP available on site was not current. Prepared in 2005, the MERP appeared to have been updated only in a cursory manner in 2010 and 2014. MEM inspectors recognized non-compliance of the MERP with the Code and follow-up actions have been taken to rectify this finding, as detailed in Appendix 1, Section 1.5.

8.2.2. OPERATION, MAINTENANCE AND SURVEILLANCE MANUAL

As an operator of a TSF, MPMC is required by part 10.5.2 of the Code to have onsite a current OMS for the TSF. According to the OMS in force at the time of the event, the OMS "describes the roles and responsibilities of Mount Polley site personnel for the management of the TSF and associated facilities; describes in detail the facility; describes engineering and design of the components; establishes the procedures and processes for operation, surveillance and maintenance of the facility; explains documentation associated with the OMS; and, outlines emergency procedures."[2] In addition to setting out requirements for the tailings facility, the OMS provides operating procedures for managing water balance on site.

EMERGENCY RESPONSE

site personnel had to improvise a reactive emergency response

The MPMC OMS contained the emergency response plan for the TSF. The failure and breach events were classified by the OMS as a Level 3 Situation, the most serious event, which called for the following:

"The first actions in the event of any Level 3 Emergency Condition are:

- Check that all persons who could possibly be affected are safe; and
- Initiate the appropriate chain of communications.

"The person who initiated the communication should then stand-by at a safe location near the problem area and await further instructions or decisions. All those involved in emergency response, after first having communicated with the appropriate parties, should consider two types of actions as first steps in the emergency response, with respect to the protection of human life and health, environment and property:

- What can be done to prevent the situation from worsening?
- What can be done to reduce the consequences of the impending or actual failure?

"Any such action must be presented to the Mine Manager who will decide on its implementation in consultation with the MEMRH [regional MEM office].

"The notification procedure for a Level 3 Emergency Condition is as follows:

- The person noticing a Level 3 Emergency Condition shall notify the General Manager and initiate corrective actions and/or intensified monitoring, as appropriate.
- The General Manager shall notify Mount Polley Corporate office, Mount Polley Tailings Project Manager, and the Engineer of Record.

"In the event of an emergency situation that will result in an actual or potentially imminent dam failure, or release of untreated water, the General Manager shall also notify the MEMRH [MEM regional headquarters]. Names and telephone numbers for the key contacts are given in Table 2.1."[3]

A separate document, *Appendix E-13 Emergency Levels*, provided a somewhat more comprehensive action list. For "Failure or suspected imminent failure of a dam (any reason)," the list included:

1. "Initiate chain of communications and ensure safety of people.
2. Stop tailings discharge into the TSF.
3. Monitor water levels every 3 hours if safe to do so.
4. Lower pond by any practical means approved by the Design Engineer.
5. Mobilize pumps and earthmoving equipment.
6. Contact the Design Engineer.
7. Construct confinement berms downstream of the embankment and ponds where feasible.
8. Contact the Ministry of Energy and Mines."[4]

The MPMC employees on duty at the time of the TSF breach did not access the OMS or the MERP. They only referred to a list of telephone numbers, and many of the key staff on the sheet were unavailable on the holiday weekend. Emergency response actions taken in reaction to the failure were not guided by the MERP, the OMS, or the *Emergency Levels* documents; and that these plans were not developed to prepare the mine for a disaster of this magnitude. The events of the early morning hours of August 4, 2014 challenged the mine personnel to improvise a response despite the lack of preparedness or existing tools at hand to guide their response.

8.3. TIMELINE OF THE FAILURE AND BREACH EVENTS

The timeline, reconstructed from interviews and statements of individuals on site at the time, indicates the dam failed within a period of less than one hour between 10:35 pm on August 3, 2014 and 12:10 am August 4, 2014. The breach was under way with sufficient force by approximately 1:08 am to demolish the power line downstream from the breach site, triggering an initial response by site personnel to investigate the loss of power. Water level records obtained from the mill control room were also instrumental in tagging specific events to time of occurrence. Reviewed and summarized time records reflect local Pacific Daylight Time.

8.3.1. EVENT TIMELINE & MPMC RESPONSE

The following timeline has been reconstructed from physical logs of pumping station activity (with relative times registered to clock time), statements of MPMC personnel, shift logs, and other sources. Approximate times are noted as such; events for which no time was recorded are reported in sequential order. Pump station logs supply a quantitative record of events; times reported in personnel interviews may vary significantly.

SUNDAY, AUGUST 3 2014	
10:35 pm PDT	*[Mine Personnel]* drives along the toe of the PE and goes up to the dam crest, near the breach site, to turn on the No. 2 pump in the PE Seepage Collection Pond sump (a normal procedure). *[Mine Personnel]* notes that the sump pipeline discharging into the TSF is "turbulent."
11:30 pm	*[Mine Personnel]* is operating the sand cell cat on the South Embankment, on the opposite side of the TSF from the breach site. *[Mine Personnel]*, back in the mill's control room, notices that the water level in the Perimeter sump is increasing., and by 11:40pm has leveled out or "flatlined;" that is, water is flowing into the sump at a rate equal to the pumping, which is well above normal rates. 70l/sec was flowing into the Perimeter pond.

11:40 pm	*[Mine Personnel]* observes that the water level in the Perimeter sump is "increasing rapidly."
12:00 midnight	*[Mine Personnel]* had turned the sand cell water line on, but still could "hear some water flowing" elsewhere on the TSF.
MONDAY, AUGUST 4 2014	
12:10 am PDT	Water level starts to modestly increase – suggesting that failure has occurred and water is overflowing the crest of the dam. 300 l/sec to Perimeter pond *[Mine Personnel]* calls *[Mine Personnel]* [estimated between 12:00 to 12:30 am]
12:50 am	3m^3/sec into Perimeter pond
12:30 - 1:00 am	*[Mine Personnel]* observes that the water level is dropping in the TSF. He drives to Corner 1 and could hear "roaring like a 50-foot waterfall." [estimated time]
01:00 to 1:06 am	**Water level rapidly rises in the Perimeter Sump; a short interim spike within that time suggests there may have been a surge of water, before the sump water level was exceeded. The rapid rise suggests that the dam has breached further.**
01:08 am	**Time reported by a number of staff as to when the power went out at the mill, which is near the time of the rapid rise in the sump water level**. The power going out appears to be the result of the dam failure inundating the power lines approximately 300 m downstream of the breach.
1:10 am	*[Mine Personnel]* reports that the power has gone out, so he resets breakers and uses temporary lights in the mill. He attempts to restore power until *[Mine Personnel]* returns at 2:10 am with news of the failure. *[Mine Personnel]* reports that "the power died in the mill/shack and emergency backup lights activated. Light throughout the upper buildings started turning off slowly one by one. … *[Mine Personnel]* called the shift electrician and is informed that there was a power loss at the mill." [estimated time]
1:30 am	*[Mine Personnel]* notes, "I called *[Mine Personnel]* three times on the radio before the PE burst and the dam flowed into Polley Lake."[estimated time]
01:40 to 2:20 am	Staff go to the TSF to check the power lines and reclaim water lines and realize that failure of the dam is in progress.
2:00 am	*[Mine Personnel]*, calls and says, "better get down here." *[Mine Personnel]* drives to Corner 5 and meets *[Mine Personnel]*.[estimated time]
2:05 am	*[Mine Personnel]* reports that "*[Mine Personnel]* contacts *[Mine Personnel]* asking him to switch to channel 1. Operator informs *[Mine Personnel]* that he was asked on the radio if the water level in the dam has been dropping. He said he looked over and noticed it had, and promptly called *[Mine Personnel]* down to tailings. I drove with the lead hand from the warehouse down to the tailings immediately. We intercepted a mill pickup that stopped us and told us he believed the dam had let go and was not willing to drive any further towards 1 corner [just above the breach location] due to the rumbling noise and fear of what was going on in the darkness. *[Mine Personnel]* made it to 1 corner, also not moving beyond the safe upper level. Sand cell operator was evacuated immediately and *[Mine Personnel]* returned to the shack to begin making emergency response calls. I advised our lead hand that we begin securing access point into the tailings dam with 'Do Not Enter' signs and delineators to prevent people from entering the incident scene until we had a proper visual of what had taken place. This took approximately 30 minutes, in which time *[Mine Personnel]* were sent to evacuate the underground."

2:20 am	*[Mine Personnel]* calls Mill Maintenance Superintendent Don IBEY, the MPMC manager on call; no answer.
2:25 am	*[Mine Personnel]* locks access to the site and notifies the underground operations to evacuate.
2:30 am	Marcel HABSBURG, Acting General Foreman, is called and attends the mine sometime after 3:00am.
2:45 am	*[Mine Personnel]* "began assisting *[Mine Personnel]* with emergency response phone calls 1. Tried calling IBEY at home/cell, no answers. Multiple calls. 2. Tried calling Dave CARPENTER at home/cell, no answers. Multiple calls. 3. Tried calling *[Mine Personnel]* to try and retrieve alternate contact information for Nicholas *[Mine Personnel]* and Dave CARPENTER, no answer. Multiple calls. 4. Tried calling *[Mine Personnel]* to try and retrieve alternate contact information for *[Mine Personnel]* and CARPENTER, no answer. Multiple calls. Left message. 5. Tried calling *[Mine Personnel]* to try and retrieve alternate contact information for *[Mine Personnel]* and CARPENTER, no answer. 6. Tried calling *[Mine Personnel]* to try and retrieve alternate contact information for *[Mine Personnel]* and CARPENTER, no answer. 7. Answered phone call from Ministry of Environment. *[Mine Personnel]* was tied up speaking to another department, informed Ministry of such and put on hold until *[Mine Personnel]* was free to speak to him.
3:20 am	"*[Mine Personnel]* goes back into the pit to remove 05-005 from the 928 and shut down the Springer pumps. *[Mine Personnel]* stays behind to assist *[Mine Personnel]* with the phones and multiple calls potentially rolling in and handle the radio in the event himself or the lead hand were busy."
3:54 am	**Start of Nautical Twilight** (at which time the horizon is distinguishable):
3:55 am	"*[Mine Personnel]* calls *[Mine Personnel]* back. *[Mine Personnel]* makes him aware of the current situation and tells us that he will go wake up CARPENTER who was in Likely and inform him as well.
4:00 am	"Per Art FRYE's request, *[Mine Personnel]* began to monitor the level of the water in Polley Lake. With no easy access in the dark to see clearly from the Tower pad in the Wight pit - we opted to use the access before the bridge to the lake shore where we could drive right in.
4:25 am	1. "Before entering the access road - with daylight now on our side, *[Mine Personnel]* drove towards Corner 1 at tailings to ensure the flow of water we could only judge by sound was not going to impose a direct threat to us entering the access at lake level given the situation. We were the first to arrive and get a visual of exactly what had taken place. A large 'V' cut was visible towards the Perimeter as we got close to the bridge. It was approximately 250-300 feet at the top and had chiseled its way down to about a 100 foot section. Water was flowing at a very rapid rate of speed below the Corner 1 ramp level from the area above what used to be the road to the Perimeter Seepage Pond. This area had been washed completely out and a very large mouthed accumulated mass of tailings and debris was headed towards Polley Lake. We checked the level at Polley Lake and noticed it was three feet above fresh vegetation and informed *[Mine Personnel]*.

4:25 am	2. "HABSBURG, [Mine Personnel]and a few more people I did not recognize arrived at the scene to take pictures. HABSBURG asked me if it would be possible to get haul trucks to dump short above the breach and push the loads in with a dozer. I advised him against it due to the danger imposed on the operators and drivers and explained that the rate of flow would likely just remove anything put in its path. He asked me about freeboard in the Cariboo Pit, which I figured was about 4 metres. He then asked about the possibility of reversing the flow of water from the barge to the Cariboo and I informed him that checking to see if the barge was still actually in water would be the best course of action before giving the idea any more thought given the amount of tailings and water already dispersed. He left the scene with *[Mine Personnel]* to inspect the dam from above Corner 1 and check the barge."
4:30 am	CARPENTER visits the failure zone, which "sounded like Hells Gate;" waves and flow could be –3 to 7 metres.
4:50 am	**Start of Civil Twilight** (at which time terrestrial objects become distinguishable) *[Mine Personnel]* attends site and documents grounded barge and breach flow photographically.
5:00 am	"*[Mine Personnel]* return to check the water level [in Polley Lake] again and notice it had dropped eight inches and inform *[Mine Personnel]*. *[Mine Personnel]* notes that Polley Lake, which had been up one m, had dropped approximately 200mm [from the heightened level]. HABSBURG visits the breach, and sees "lots of muddy water" flowing out, debris 200 yards up, water cascading over the uplifted till bulge, large boulders, and no water in the TSF , and reports that "the TSF sounded like the Fraser River Canyon" from the location of the barge.
5:15 am	*[Mine Personnel]* began making our way up to the shack. We got a better vantage point at the top of the SERD dump and noticed the water was no longer headed towards Polley Lake but had diverted and was plowing its way past Gavin Lake road headed East [reporting to Hazeltine Creek]. BROWN arrives on site. **MPMC attempts to contact MEM**, MOE, IM, and additional MPMC personnel. There is difficulty encountered in contacting most people; successfully contact Don PARSONS and MOE Emergency Response Line (MOE headquarters and Prince George office had already been faxed by EMBC at 4:19am).
5:30 am	*[Mine Personnel]* "informed all parties of the water level, where we checked it at, and the direction the water was now headed in." The reclaim barge is reported resting on tailings. *[Mine Personnel]* attends at the TSF and witnesses water "roaring" out of the TSF.
5:31 am	**Sunrise**
6:00 am	Helicopter on site at request of MPMC: breach flow is observed as "going over the displaced block of soil on the downstream side of the dam."
6:30 am	HABSBURG notes smaller flows at the breach, about 60 feet wide.
7:45 am	Aerial reconnaissance from TSF to Quesnel Lake conducted by CARPENTER, *[Mine Personnel]*, and BROWN. Aerial photographic record.
11:30 am	FRYE arrives on site.
12:00 noon	**Flow is reduced but still "significant."**
4:00 pm	**Flow has abated.**

8.3.2. MEM RESPONSE TO THE EVENT

The following outlines the response of the Chief Inspector and key personnel including MEM's notification of the event. Initial actions are highlighted with respect to notification timelines, inspector site presence, and the initiation of the investigation.

The first notification of the event to MEM was not from MPMC, but from Emergency Management BC (EMBC). MPMC did not attempt to notify MEM until 5:15 am on August 4.

MONDAY, AUGUST 4 2014	
3:20 am PDT	Emergency Management BC (EMBC) receives notification from an anonymous caller that the Mount Polley dam had breached.
4:19 am	EMBC sends an email to the On-call Mines Inspector (OCI). The EMBC protocol is to contact the on-call inspector by phone rather than send an email notification, but a new operator receiving the notification at EMBC does not recognize the event as sufficiently severe to elevate to a call.
6:04 am	Dam breach email notification from EMBC is read by Jerrold JEWSBURY, OCI.
6:19 am	JEWSBURY activates the internal Ministry Emergency Management Plan (MEMP) and OCI Action Plan: JEWSBURY attempts to contact Steve ROTHMAN.
06:23 am	JEWSBURY notifies George WARNOCK.
07:20 am	JEWSBURY succeeds in contacting ROTHMAN by phone.
07:30 am	ROTHMAN contacts Chief Inspector Al HOFFMAN by telephone at home.
07:51 am	JEWSBURY notifies HOFFMAN.
12:09 pm	WARNOCK conducts helicopter reconnaissance to evaluate the scope of the breach event.
12:26 pm	WARNOCK conducts an overflight of Quesnel River (outlet to Quesnel Lake); notes that the river is still flowing clear at the time.
1:00 pm	WARNOCK meets with MPMC personnel BROWN, *[Mine Personnel]*, PARSONS, and FRYE [approximate time].
Afternoon	WARNOCK inspects the TSF from the top of the TSF with BROWN. ROTHMAN arrives on site. HOFFMAN and key personnel attend Victoria headquarters to support inspectors on site. HOFFMAN and key personnel initiate a conference call with EMBC.
TUESDAY, AUGUST 5 2014	
11:20 am PDT	Heather NARYNSKI and Chris CARR respond on site.
12:15 pm	NARYNSKI, CARR and ROTHMAN fly over the site. Photographic record is taken, but no ground inspection is carried out.
1:00 pm	HOFFMAN and MEM staff conduct a conference call with provincial Government agencies including EMBC, the ministries of Environment, Forests, Lands & Natural Resource Operations and Jobs, Tourism & Skills Training; as well as the Interior Health Authority and Cariboo Regional District to discuss the current state of the site.
8:00 pm	HOFFMAN and personnel conference call, updates and planning for the investigation.

WEDNESDAY, AUGUST 6 2014	
	Continued site presence from MEM geotechnical inspectors WARNOCK and NARYNSKI, and health and safety inspector ROTHMAN.
WEDNESDAY, AUGUST 6 2014	
10:00 am PDT	Haley KUPPERS and Rolly THORPE arrive on-site to initiate the investigation into the TSF breach, pursuant to section 7 of the *Mines Act*; briefing by on-site inspector ROTHMAN.
5:30 pm	Investigative team conduct a conference call with on-site inspectors, establishing daily briefings. HOFFMAN determines to increase health and safety oversight with two MEM inspectors to provide a continuous site presence until further notice.

Additional actions taken by MEM are detailed within the reference documentation. Extensive cross-agency consultation continued for several weeks to ensure all parties were briefed as to the status of the tailings storage facility and the early remediation efforts to protect the environment and any public or workers downstream of the at-risk area.

FOOTNOTES

1 *Mount Polley Mining Corporation (2014e) p. 39*

2 *Mount Polley Mining Corporation (2013) p. 1*

3 *Mount Polley Mining Corporation (2013) pp. 77-8*

4 *Mount Polley Mining Corporation (nd)*

MECHANISM OF FAILURE 9

This chapter is a summary of the Chief Inspector's investigation of the mechanism of failure of the Mount Polley TSF. The detailed forensic assessment included site investigations, laboratory testing and technical analysis conducted for the Chief Inspector by the geotechnical engineering firm of Klohn Crippen Berger Ltd., under contract to MEM. The full report, *Mount Polley Tailings Dam Failure: Assessment of Failure Mechanism*, May 1, 2015, can be found in Appendix 2 of this report, and is incorporated by reference into this investigation report in its entirety.

An analysis of the events leading to the failure and determination of root causes is explored in Chapter 10.

9.1. PROPERTIES OF THE UGLU

The dam failed by sliding on a foundation clay layer of glaciolacustrine origin, which lies approximately 10 m below the base of the PE. This clay layer, termed the upper glaciolacustrine unit (UGLU), is a moderate to high plastic, clay-rich varved lacustrine deposit ranging up to 2 m thick. To the extent the foundation conditions were revealed by post-breach site investigations, the areal extent of the UGLU is largely confined to the immediate area of the failed dam.

The native UGLU is a "lightly over-consolidated" clay with a pre-consolidation pressure between 380 kPa and 420 kPa. In its native state prior to dam construction, the UGLU would have exhibited dilative response to shearing and its ultimate strength would be governed by the drained frictional strength. The weight of the 40 m high tailings dam subjected the UGLU to vertical stresses up to 800 kPa and substantial portions of the UGLU beneath the dam were loaded to stresses well above the pre-consolidation pressure. These loaded portions of the UGLU became "normally consolidated" and would have displayed a contractive response to shearing. The ultimate strength of normally consolidated clay is its undrained strength, which accounts for pore pressures developed during shearing. This change from lightly over-consolidated behavior to normally consolidated behavior occurred incrementally over time as the dam was raised. At the time of failure, the demarcation point between "lightly over-consolidated" and "normally consolidated" behavior occurred below the lower third of the dam slope.

The shear strength of the UGLU is controlled by the higher plastic zones within the clay layer. Accordingly, the estimated peak drained strength of the UGLU was estimated as c' = 0 kPa and φp' = 22°, and the residual drained strength as φr' = 12° - 14°. The similarity of these parameters to the shear strength of other clay soils [see Appendix 2] indicates that the UGLU is not a unique or special soil.

Under rapid loading and straining, the undrained strength of the UGLU is represented by Su = 0.22 (OCR)0.8 σvo', where σvo' is the effective vertical confining stress and OCR is the overconsolidation ratio. This relationship is identical to the average relationship for homogeneous sedimentary clays recommended in the engineering literature [see Appendix 2] and again indicates the UGLU is not unique.

The UGLU is also a strain-weakening material which loses appreciable strength when deformed past its peak strength, in both drained and undrained loading conditions. The strain-weakening nature of the UGLU was observed in direct shear tests, direct simple shear tests and undrained triaxial compression tests.

The piezometers installed in the UGLU after the failure found no evidence of high excess pore pressures related to the loading of the dam during construction. However, unloading and deformations in the UGLU during the failure and breach would have substantially changed the pore pressure regime in the clay from that of the pre-failure state. Pore pressure analyses using the consolidation properties of the clay and rate of dam construction predicts that excess pore pressures up to 158 kPa may have existed at the time of dam failure.

On the other hand, evidence of "artesian" water pressures was encountered during post-failure site investigations in the permeable glaciofluvial deposits present about 5 m below the UGLU. These artesian water pressures were also predicted by pre-failure seepage analyses of the dam by KCB. These pressures reduce the consolidation stress and strength of the UGLU by about 5% to 15%.

9.2. ANALYSIS OF FAILURE

At the time of failure, the Factor of Safety (FoS) of the dam was calculated using limit equilibrium methods to be 1.27 using the peak drained strength of the UGLU and the pre-failure pore pressures estimated by seepage analyses. The FoS reduces to 1.19 with an allowance for construction-induced pore pressures.

Numerical stress analyses of the dam show that, at these low FoSs, the shear stresses induced in the UGLU below the steep outer dam slope would have exceeded the available peak drained strength, thereby initiating a progressive undrained failure mechanism in the UGLU. Using the peak undrained strength of the UGLU, the calculated FoS of the tailings dam reduces to unity.

Because of the strain-weakening behavior of the UGLU, the displacement of the dam probably accelerated once failure was initiated (FoS less than 1) as described above. This acceleration of movement subjected the UGLU to progressively larger strains and greater strength loss, with calculated FoS ultimately reducing to as low as 0.80 at the fully remolded strength of the UGLU. At this stage, rapid movement of the dam continued until the geometry of the failed mass re-stabilized at a FoS of unity.

Forensic drilling and excavations in the failed dam and breach area identified a distinctive shear plane and down-drop in the upstream till core and upthrust of the foundation soils at the dam toe. Movements interpreted from these and other features indicate net dam displacements in the order of 5 to 10 m along the sliding plane in the UGLU. Numerical deformation analysis of the dam by KCB shows that the down-drop of the dam crest during the failure would have been sufficient for the tailings pond water to overtop the crest of the till core and initiate the subsequent dam breach.

A sliding plane in the UGLU is also consistent with the small movements in the UGLU recorded by inclinometers installed post-failure, the heavily de-structured and folded varves of the UGLU in the failure zone below the dam, and the weakened state of the UGLU in the failure zone consistent with the remolding of the clay during the dam displacements.

9.2.1. FAILURE PROGRESSION

Dam failure would have been initiated by local yielding of the UGLU clay whereby the static shear stresses in the UGLU exceeded the available drained strength defined by the peak effective friction angle, ϕ'. This induced yielding of the clay would have led to rapid straining such that shear-induced pore pressures in the contractive clay would have insufficient time to dissipate, reducing the strength of the clay to its undrained resistance, Su. If the embankment was not stable with the available undrained shear strength, it would continue to deform until a stable configuration was attained. Such displacements would have strained the clay beyond its peak undrained shear strength and, if displacements were large enough, reduced the undrained strength to its remolded value.

A) UGLU - UNDISTURBED CLAY VARVES	B) UGLU - SHEARED CLAY VARVES
	
SH14-10 (Middle/Top UGLU Layer) Approx. 921.1 - 919.5m Sub-horizontal varved bedding. Water content = 35.77%; Liquid limit = 60%; Plastic index = 20%; clay fraction = 58%	SH14-03 (Bottom UGLU Layer) Approx. 920.9-918.8m Folded laminations/soft consistency. Water content = 37%; Liquid limit = 44%; Plastic index = 17%

Figure. 9.1 Buckling of Varved Clay Laminations in UGLU
Appendix 3, Fig. 5-10

Evidence for the failure process described above includes:

- Buckling and de-structuring of varved clay laminations in the UGLU below the failed embankment (see Figure 9.1).
- The reduced undrained strength of the UGLU measured below the failed embankment as a result of shearing. This reduced strength approaches the remolded strength of the clay as determined by in situ vane shear testing.
- The upthrust UGLU observed in TP14-01 at the toe of the failed embankment.
- The post-failure movements measured by inclinometers in the UGLU.

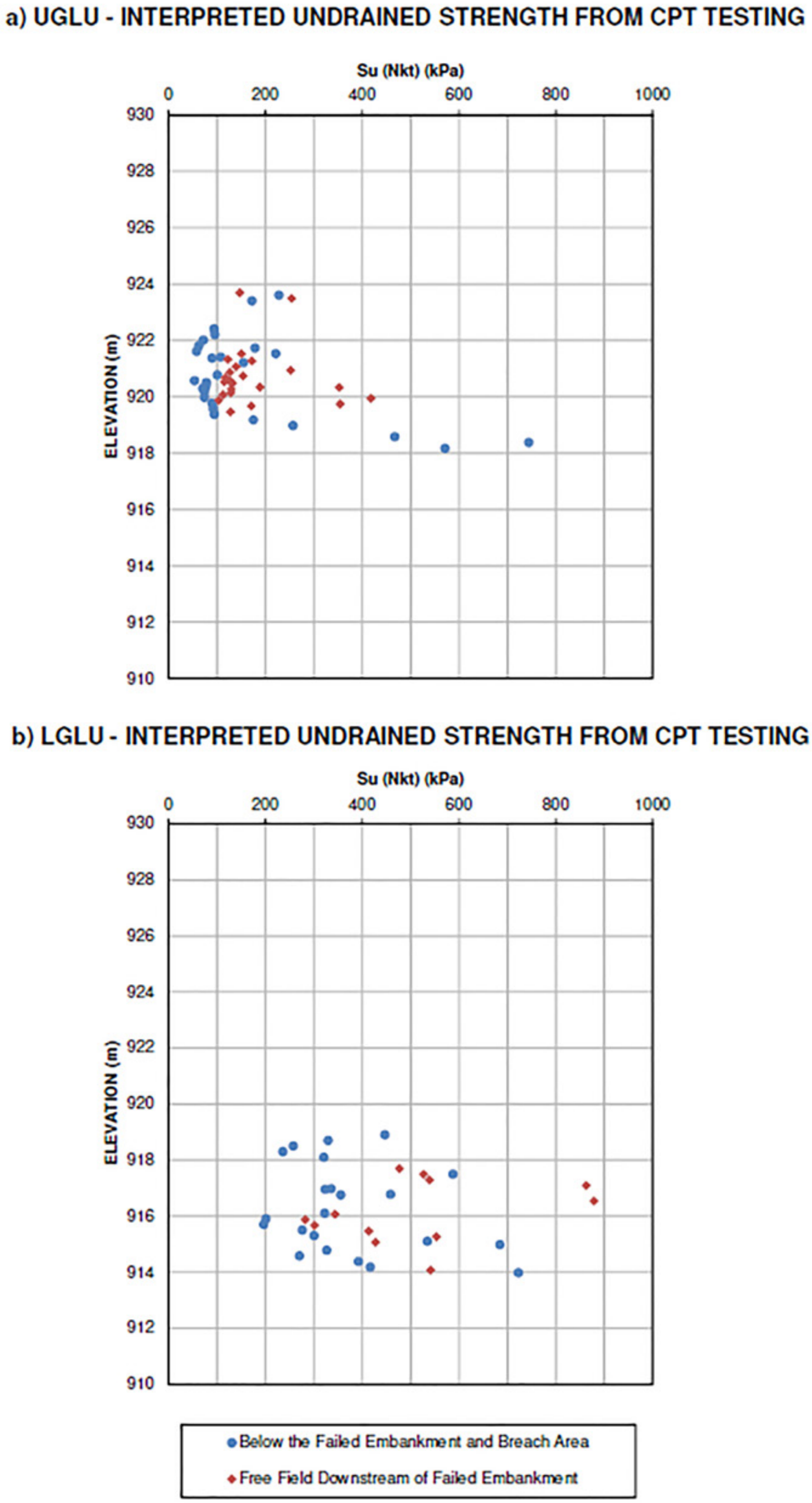


Figure. 9.2 Undrained Shear Strength in GLUs
Appendix 3, Fig. 5-16, 5-17

Figure 9.2 demonstrates the difference in undrained shear strength between the well-understood LGLU and the UGLU. The typical value of 100 kPa of the LGLU is three times stronger than the typical value of 300 kPa for the UGLU. Following from the above, KCB developed a conceptual sequence of dam failure as a framework to evaluate the failure process of the embankment. This hypothesized failure sequence is set out in five stages as listed in the table below. Each stage corresponds to the strength state of the UGLU and considers the influence of other contractive clayey soils and fills on the failure process. The progressional failure occurred in five stages:

- Failure Stage 1 considers the static stability of the embankment under fully drained conditions, using the peak effective friction angle of the UGLU. Local yielding of the foundation clay could occur if the limit equilibrium Factor of Safety (FoS) is low, typically less than 1.3, using the drained strength of the clay.
- Failure Stage 2 considers the embankment stability assuming that local yielding triggers the undrained strength of clay. If the FoS is less than or close to unity, then failure of the embankment would occur. Mobilization of the peak undrained shear strength occurs at shear strains of 5% based on laboratory testing. For a 2 m maximum thickness of the UGLU, movements in the UGLU would be in the order of 0.1 m or less. Such movements would not be detectable by observation at the crest of the embankment.
- Failure Stage 3 considers failure of the embankment is occurring and the undrained shear strength of the UGLU is reduced to a post-peak strength due to the accumulation of strain within the clay. At 20% shear strain in the UGLU, maximum movements in the UGLU would now be in the order of 0.4 m. At these larger displacements, triggering of undrained shear strength in the compacted clay core and underlying upper glacial till (UGT) is now assumed.
- Failure Stage 4 represents the advanced state of failure with the undrained shear strength of the UGLU reduced to its remolded value.
- Failure Stage 5 represents the failed embankment coming to rest on the weakened foundation at a FoS of 1. This final state was achieved by two factors: the reduction of driving force as the crest of the embankment dropped, and the increase in resisting force with the buckling and mounding of displaced soils at the embankment toe.

CONCEPTUAL SEQUENCE OF DAM FAILURE

Failure Stage	**Description**	**Approximate Movement in UGLU** (m)	**Shear Strength in UGLU**
1	Static conditions using peak effective angles and piezometric conditions prior to failure.	0	φp’ = 22°
2	Peak undrained shear strength mobilized at 5% strain within the UGLU as a result of local yielding. Peak drained strength in all embankment fills and other foundation soils.	0.1	Su = 50 + 0.13 σvo'
3	Post-peak undrained shear strength achieved in the UGLU at 20% strain due to continued movement. Peak undrained strength triggered in other contractive embankment fills and foundation soils.	0.4	Su = 36 +0.11 σvo'
4	Remolded undrained shear strength in the UGLU and peak undrained shear strengths in contractive fills and foundation soils.	> 1	Su = 22 +0.03 σvo'
5	Failed embankment at equilibrium in post-failure configuration with a factor of safety close to 1.0	> 3	Su = 22 +0.03 σvo'

9.2.2. BREACH PROGRESSION

Breach of the embankment followed Failure Stage 5 as the impounded water pond overtopped the down-dropped crest of the embankment.

Following the structural failure of the dam, the breach increased progressively. While it is difficult to assign specific durations to each element of this sequence, flow records from the pump at the Perimeter Sump indicate the volume of water overtopping the dam at the times noted in Figure 9.3.

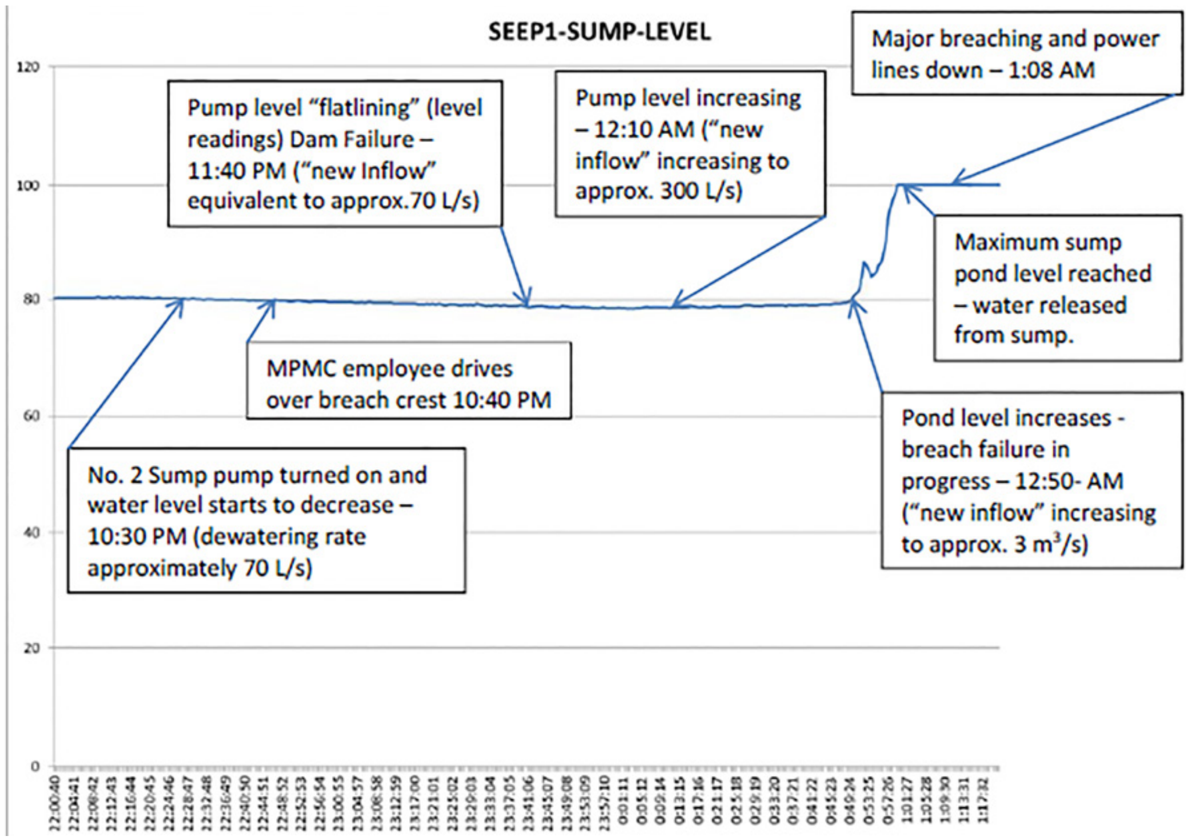


Figure 9.3 Perimeter Sump Volumes Appendix 3, Fig. 5-1

Overtopping flow rates began to increase at approximately 10:30 pm, and by 11:40 pm the rate was 70 L/s. By 12:10 am, the rate had increased to approximately 300 L/s. As the breach was in progress by 12:50 am, the flow level increased to 3 m^3/s (or 3,000 L/s). The breach increased with sufficient flows to take down the power lines below the dam by 1:08 am.

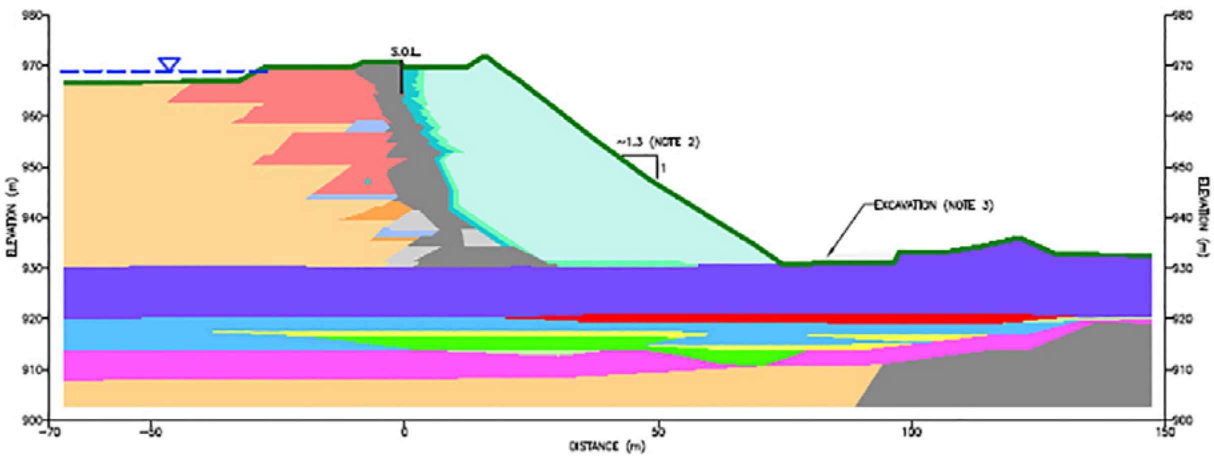
The investigation hypothesizes this progressive breach process as shown in Figure 9.4. Note that the blue triangle symbol tracks the level of water in each diagram.

LEGEND:

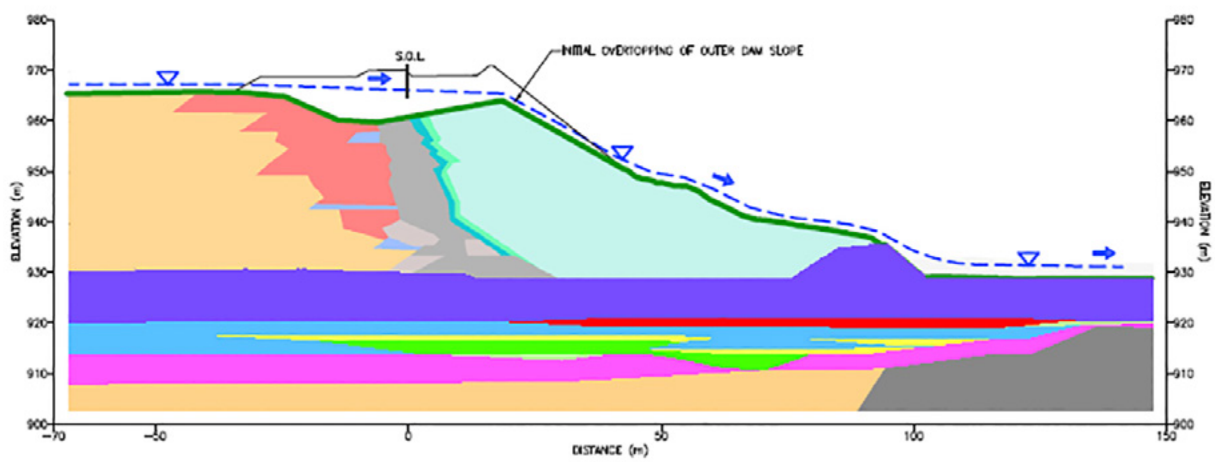
- UGT — UPPER GLACIAL TILL
- UGLU — UPPER GLACIOLACUSTRINE
- MGT — MIDDLE GLACIAL TILL
- LGLU — LOWER GLACIOLACUSTRINE
- UGF — UPPER GLACIOFLUVIAL
- LGF — LOWER GLACIOFLUVIAL
- LGT — LOWER GLACIAL TILL
- WB (Sed) — WEATHERED BEDROCK (SEDIMENTARY)
- WB (Mafic) — WEATHERED BEDROCK (MAFIC-IGNEOUS)
- WB (Vol) — WEATHERED BEDROCK (VOLCANICS)

NOTES:

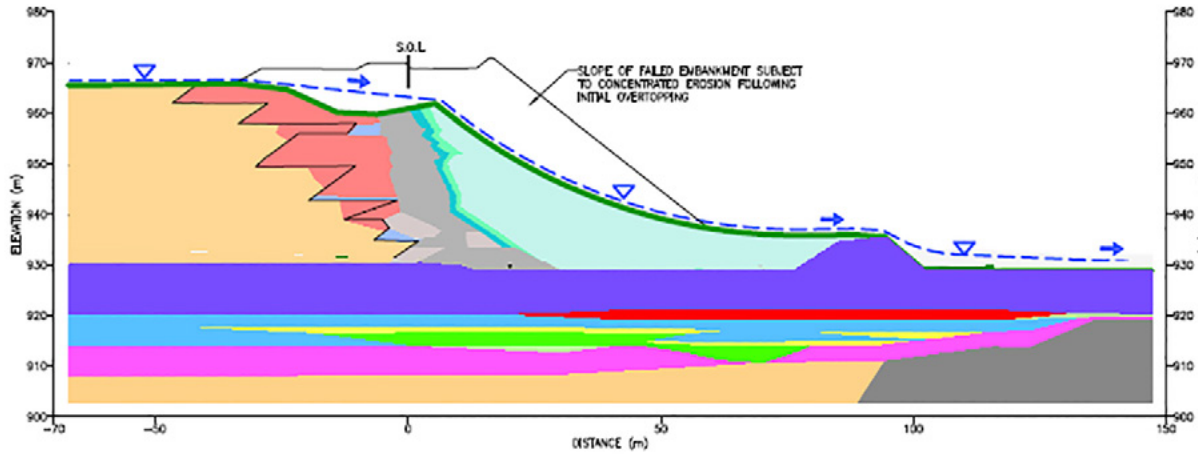
1. REFER TO APPENDIX IV FOR MATERIAL ZONATION.
2. DOWNSTREAM SLOPE FLATTENS TO 1.8H:1V BELOW EL. 946 m (REFER TO FIGURE 2.6).
3. A 2 m DEEP EXCAVATION (TO APPROXIMATELY EL. 930 m) WAS INCLUDED TO REFLECT THE SITE STRIPPING IN PREPARATION FOR CONSTRUCTION OF A FUTURE TOE BUTTRESS.



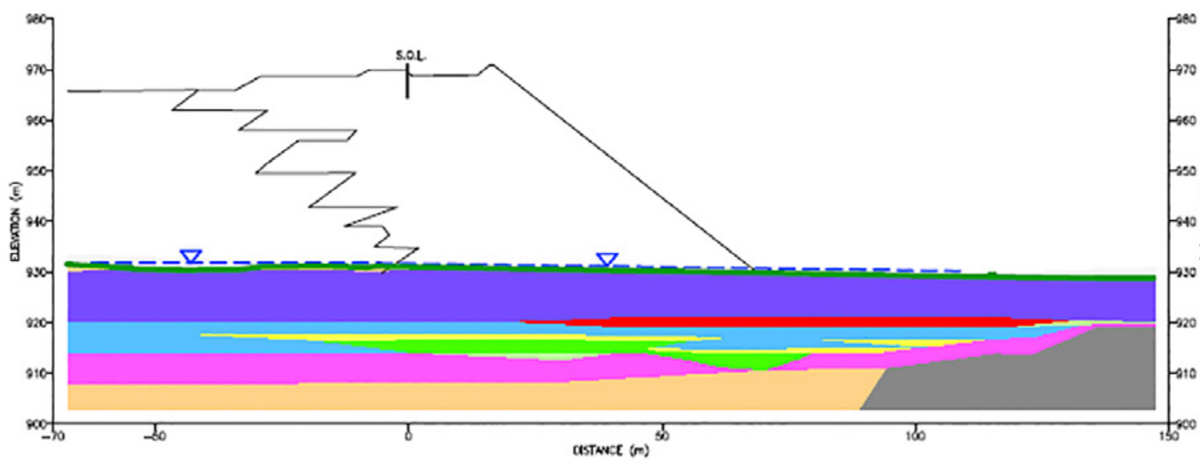
TIME INTERVAL I – PRE-FAILURE



TIME INTERVAL II – DAM FAILURE AND INITIAL OVERTOPPING



TIME INTERVALS III – DOWNCUTTING OF EMBANKMENT BY CONCENTRATED WATER FLOW



TIME INTERVAL IV – DOWNCUTTING OF EMBANKMENT IN BREACH COMPLETE

Figure 9.4 Hypothesized Embankment Breach Sequence
Appendix 2, Fig. 3-12

This chapter has explained and illustrated the events that occurred on August 3 and 4, 2014 at the Mount Polley TSF. To describe why this failure took place, the following chapter analyzes the causes of the event back to the originating, or "root," causes.

CAUSES OF THE EVENT 10

10.1. CAUSAL ANALYSIS APPROACH

Root Cause Analysis (RCA) is "a structured evaluation method that identifies the root causes of an undesired outcome and the actions adequate to prevent recurrence."[1] While many approaches and tools are available for the implementation of RCA, the Chief Inspector selected the Root Cause Analysis Tool (RCAT), a flexible and comprehensive suite of protocols and software tools developed by the National Aeronautics and Space Administration (NASA). RCAT serves as a structured, adaptable template to investigate the full spectrum of events that NASA might encounter: from industrial accidents in ground facilities to aviation accidents and close calls to loss of spacecraft. NASA licensed the RCAT software for the Mount Polley investigation.

RCA helps determine what happened, how it happened, and why it happened. It also identifies absence of, or deficiencies in, various defenses that could have prevented or mitigated the undesired outcome. "RCA is more than just a search for the obvious cause; it is a comprehensive analysis to identify root causes, both the basic and underlying organizational factors. With an in-depth look at causes and contributing factors, RCA enables the analyst to generate specific recommendations that can prevent a repeat of the undesired outcome, and prevent similar problems, close calls, and mishaps from occurring. This is conducted through the creation and implementation of recommendations that specifically target the root causes of the undesired outcome."[2]

ROOT CAUSE ANALYSIS

seeks out root causes of undesired outcomes at the organizational level

The RCAT used in the investigation uses a structured language including the following terms to describe important analytical concepts, which will be used throughout this chapter:

Undesired Outcome. Any event or result that is unwanted and different than the desired and expected outcome is an undesired outcome. This can include, for example, loss of productivity, poor quality, increased risk, increased cost, delay in schedule, damage to property, harm to the environment, or harm to personnel. "An undesired outcome may also include intangible costs such as loss of public confidence or a decline in motivation. Most of these undesired outcomes are event-based. They usually do not occur because of one single event, but rather from a series of events and actions, with specific conditions present. All events and conditions must be identified and evaluated in order to identify the cause of the undesired outcome and generate a solution to prevent its recurrence."[3]

Root Cause. A root cause is one of multiple factors (events or conditions) that are organizational in nature and contribute to or create a proximate cause and subsequently the undesired outcome. If a root cause is eliminated or modified, the undesired outcome would have been prevented or would not have occurred. Typically, multiple root causes contribute to an undesired outcome.

It is important to note that, under the discipline of RCA, a true root cause is always an *organizational* factor, usually representing some deficiency at the operational, policy, or management level. Organizational factors include any operational or management structural entity that exerts control over the system at any stage in its life cycle, including, but not limited to, the system's concept development, design, fabrication, test, maintenance, operation, and disposal. The objective of RCA is to continue the analysis until organizational factors have been identified (or, alternatively, until all available data or avenues of inquiry are exhausted). Examples used by NASA include budget, information, responsibilities, reporting, scheduling, documentation, performance, and accountability.[4]

Cause-Effect Relationship. A cause can be an *event* (a single discrete occurrence), or a *condition* (any as-found state of a system or entity). RCA defines and structures causal chains using a specific set of criteria. For an event or condition to be a cause, it must have *preceded* the effect or occurred simultaneously; have a demonstrable relationship, not simply association; be *necessary* for the effect to occur; and be *sufficient* to produce the effect.

Proximate Cause. A proximate or direct cause is one or more events that have occurred, including any condition(s) that exist immediately before the undesired outcome, that lead directly to its occurrence. The elimination or modification of a proximate cause would prevent the occurrence of the undesired outcome.

Contributing Factor. An event or condition that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence. Contributing factors change the probability of an undesired outcome.

Barrier. A passive physical device or an administrative intervention employed without human intervention to prevent or reduce the likelihood of the undesired outcome occurring. Barriers provide physical intervention (e.g., a guardrail) between hazards and the target or provide separation. Barriers are passive in that their presence does not require active surveillance or reaction, and can be engineered (like a guardrail) or administrative (like a stop sign).

Control. In contrast to the passive nature of a barrier, a control is an active mechanism used to *detect* the initiation of an event and/or hazard and enable an active device (hardware, software, or human) to *prevent* or reduce the potential that the hazard will produce an undesired outcome. Controls minimize the effects of the initiating event by detecting and correcting it before it transitions to a negative effect.

Controls can be extremely important components of any complex engineered system. They often include such active components as:

- audit, inspection or investigation
- alarm/alert
- design, peer, technical review
- independent assessment
- inundation analysis
- monitoring and surveillance
- operational check
- quality check
- redundancy
- risk analysis/assessment
- sign off, check off
- technical authority
- verification
- warning (audible, visual, tactile)

DEFENSES

barriers and controls are passive or active defenses that can keep a causal chain from occurring

Defense. Barriers and controls together comprise defenses that function to keep an event or condition from becoming a causal factor. Not all defenses work all the time. When sufficient defenses are not present or defeated, a significant event can take place, such as an aircraft crash, a building collapse, or the release of tailings and water from the Mount Polley TSF. Defenses can fail for a number of reasons:

- defenses *don't exist* (they were never placed into the system, or the mechanism by which the initiating event affects the hazard was not understood or known)
- defenses *do not control* the hazard or only control part of the hazard (they are inadequate, or the hazard was impossible to control)
- defenses *fail* prior to or during the initiating event, or the initiating event destroys the defenses
- the organization did not have the *resources* (financial, time, personnel, or technical knowledge) to develop an adequate defense, or were responding to *external pressures* (corporate, environmental, financial) that reduced the priority of establishing defenses

- defenses could have been *temporarily and deliberately* removed to save time (a short-cut), to perform some sort of maintenance or test activity, or to resolve a problem, and personnel forget to re-instate the defense

Recommendations. The ultimate objective of RCA is to support recommendations that can create or reinforce existing defenses or alter organizational behaviours so that the event is precluded in the future, or that its undesired consequences can be minimized. A recommendation, under the discipline of RCAT, must meet five criteria:

- *track* with a finding of root cause;
- *address a problem* in some manner (eliminate, reduce, or mitigate);
- *be clear* (identify who needs to act, the action recommended, and the result anticipated);
- *be verifiable* (so that implementation can be verified by inspection or audit); and
- *be achievable*

Under the RCAT, the analytical result is an Event and Causal Factor Tree (ECFT) that graphically depicts multiple chains of causality, working backward from the undesired outcome to the root causes (see Figure 10.1). It simplifies the relationships uncovered during the analytical process and links conditions and events graphically to the analysis of barriers and controls that failed or were missing. This result captures the nature of complex events with multiple, interconnected causal chains. The failure of the TSF was not a simple linear process; rather it was a complex system of factors and their relationships. These elements are captured and the outcomes are described with the ECFT.

The following section describes the Chief Inspector's Root Cause Analysis of the TSF failure and its undesired outcomes, beginning with a simplified ECFT developed in the course of the analysis.

10.2. ROOT CAUSES OF THE EVENT

This chapter presents the full analytical component of the RCA process undertaken by the investigation. The analysis is summarized in the ECFT in Figure 10.1.

The causal factor tree then explores the proximate causes and failed controls that populate each branch. Viewed in a chronological framework, the fault tree is read from the bottom up: events, conditions, and failed controls produce certain events or conditions, which themselves become proximate causes of undesired outcomes, until the ultimate release of water and tailings occurs. The diagram also serves as an outline of the structure of the chapter, which follows the thread of consequences down through proximate causes to root causes. It also illustrates how controls, had they been in place or exercised, could have broken these causal chains.

The ECFT traces the ultimate undesired outcome, the breach of the PE and subsequent release of water and tailings into the environment, through its two categories of proximate causes, both of which were necessary for the breach to occur: first, the structural failure of the embankment; and second, the twinned proximate causes of insufficient beaches and surplus supernatant water. These two together led to the embankment breach, which emerged as the undesired outcome.

Three proximate causes are associated with the structural failure of the PE: geometry of the embankment, an uncharacterized foundation glaciolacustrine unit, and an open sub-excavation at the embankment toe. The proximate causes are linked with an "and" gate, indicating that each of the three causes was necessary to produce the structural failure.

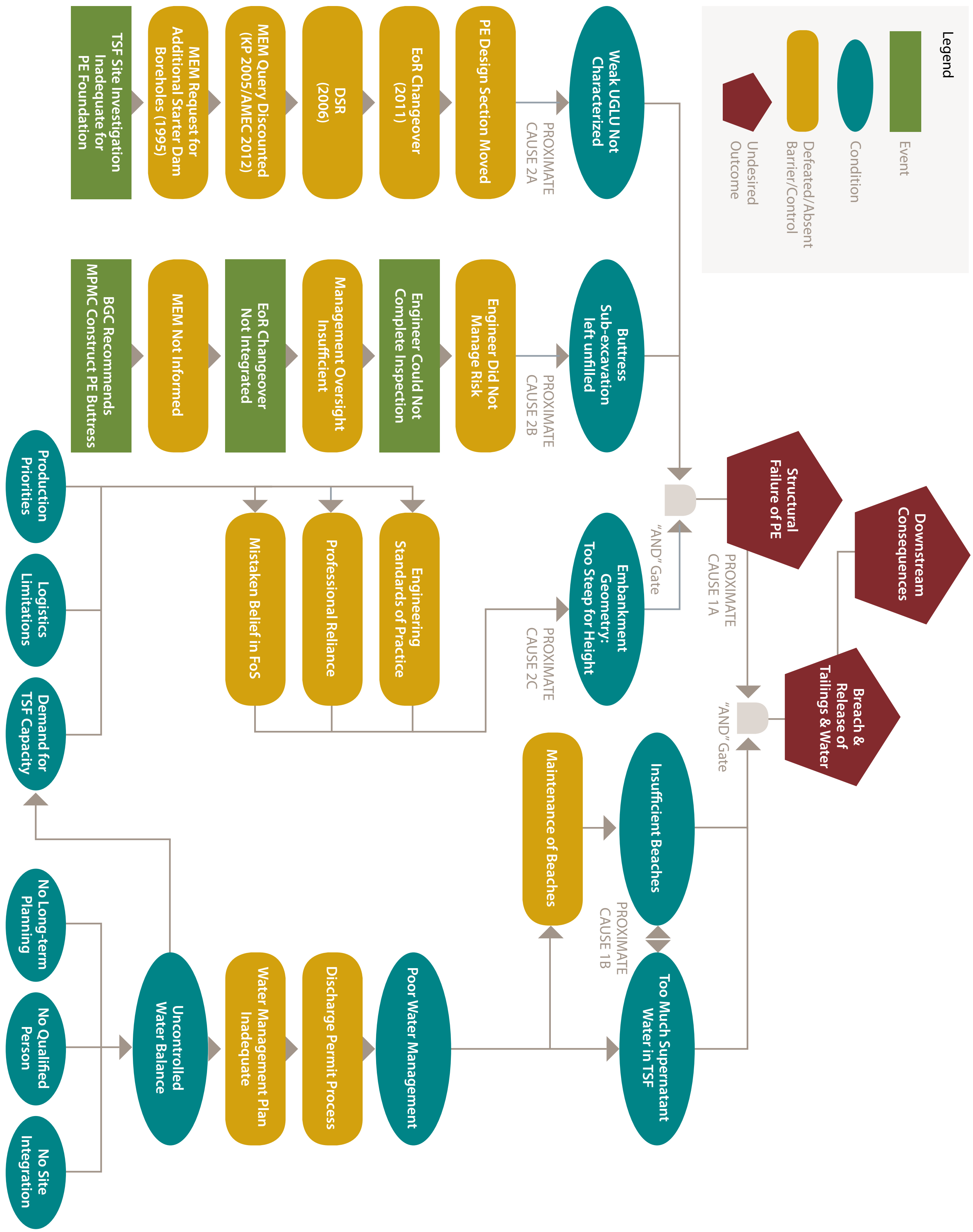


Figure 10.1 RCA Event and Causal Factor Tree - Summary Ministry of Energy and Mines (2015b)

10.3. PROXIMATE CAUSES OF BREACH OF DAM

The event at Mount Polley unfolded in a sequence of events, each of which played a causal role in the next. This section describes the logic of each step in the RCAT process, working down through the ECFT shown in Figure 10.1, and backwards through time to arrive at the root causes of each branch of the diagram. The ultimate undesired outcomes of the event are labelled Downstream Consequences in the ECFT, encompassing the effects of the dam breach on the environment downstream of the embankment and ultimately far beyond the mine's boundaries. These downstream consequences are discussed in Section 10.7.

At each step, a single element, such as "Breach and Release of Tailings and Water," can be both an undesired consequence and the cause of the next step. Following this diagram deeper into the chain of causality in the TSF event, the breach and release of tailings and water was initiated by two preceding causes, each of which was necessary for the breach to take place. These two proximate causes are the structural failure of the PE (Proximate Cause 1A) and the combination of insufficient beaches and too much supernatant water in the TSF (Proximate Cause 1B). The structural failure is discussed in Section 10.4, and the beach/water proximate cause is discussed in Section 10.5.

The structural failure was a sliding failure through the lightly overconsolidated glaciolacustrine clay unit (UGLU) located approximately 10 m into the foundation. The failure caused the embankment crest to drop approximately 5 m, and can be considered the initiating event of the breach of the tailings dam.

However, the structural failure alone was not sufficient to account for the breach and release of between 21 and 25 million m^3 of tailings and water into the environment. The RCAT revealed that it is possible for the dam to fail structurally and yet not lead to a breach and release of TSF contents. Triggering the breach required a second proximate cause: the lack of an adequate beach at the location of the failure and a surplus of supernatant water in the facility. These two conditions are tightly coupled and are considered to represent a single proximate cause of the breach. The initial release of water and tailings over the crest of the dam led to erosion of the dam crest and, over a period of at least six hours, a complete breach of the dam.

10.4. PROXIMATE CAUSES OF STRUCTURAL FAILURE OF EMBANKMENT

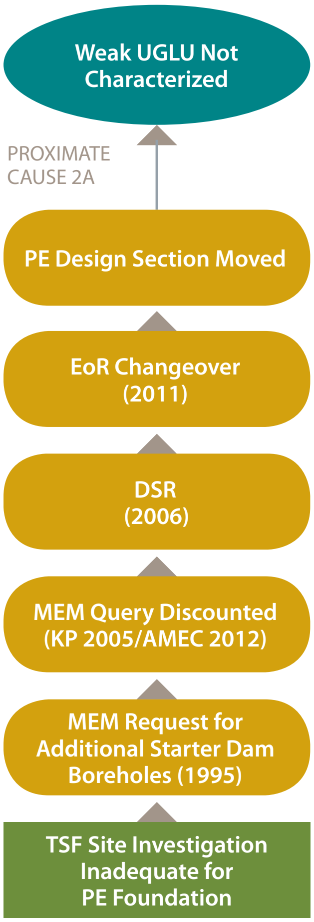
Following the causal chain back to its origins, the proximate causes of the PE structural failure must next be identified. Proximate causes are those which, had they not occurred, would have prevented the undesired event from taking place. To cause the structural failure of the PE to occur at the time it did, *each* of the following three proximate causes had to be present:

- 2A Uncharacterized upper glaciolacustrine unit (UGLU)
- 2B Open sub-excavation of buttress foundation at embankment toe
- 2C Over-steep geometry of embankment

10.4.1. PROXIMATE CAUSE 2A: UNCHARACTERIZED WEAK UGLU

It is now well understood that the basic mechanism of failure at the Mount Polley tailings dam was a sliding failure through the lightly overconsolidated glaciolacustrine clay unit (UGLU) in the foundation, which dropped the crest enough to allow the pond to overtop the slumped embankment. It is the engineering and organizational responses to this glaciolacustrine unit, not the nature of the UGLU itself, that defines this proximate cause.

Chapter 7 provides a detailed discussion of the nature of the UGLU, its characteristics, and the various site characterization activities undertaken to characterize the foundation soils of the TSF. While the location of the UGLU directly under a part of the PE was unfavourable the subsurface investigation was inadequate to the engineering requirements of the TSF — both at the site investigation stage prior to construction and for subsequent lifts. The existence of the UGLU would not have precluded the construction of a safe structure as there are engineering approaches to safely build on such soils, such as simply creating a less steep embankment slope.



Site Investigations. Initial site investigations (up to 1996) failed to identify or capture the significance of the UGLU. The UGLU was not identified in the one deep reference hole in the footprint of the dam located in the area of the breach. The hole, MP89-231, was the only deep drill hole in the approximately 2 km length of the PE foundation. MP89-231 had been drilled with a rotary diamond with sampling of drill cuttings. This drilling method is not adequate to characterize foundation soils, particularly when there is potential for interbedded glacial soils. Chapter 6 describes the drilling programs in greater detail.

The significance of the UGLU was also not recognized in the groundwater monitoring well (GW96-1A), located approximately 140 m downstream of the breach area. This groundwater well produced a drillcore profile identifying a glaciolacustrine unit of "laminated silt with variable clay layers" at approximately 919 - 923 m (see Figure 10.2).[5] Overall, the decision to discount the possibility of structurally weak glaciolacustrine layers under the PE was not supported with existing site investigation data.

In subsequent investigations (up to 2010), there were many shallow drill holes (less than 8 m depth), for the purpose of characterizing borrow areas and till blanket depth; but again, these investigations did not adequately characterize foundation soils to an appropriate depth, given the dam's height of up to 40 m.

In 2011, three deep drillholes were placed along the PE at a spacing of approximately 500 m for instrumentation placement and foundation soils investigation. In contrast, the average spacing of deep drill holes on the ME is on the order of one hole every 150 m and on the SE approximately every 330 m.

There exists no prescriptive recommended number or spacing of drill holes for site investigations of a dam foundation. The drilling and sampling plan's requirements should be considered with respect to the complexity of the geologic environment and the dam design assumptions. At a minimum, the hole commonly extends to a depth equivalent to the height of the dam; some contemporaneous reference documents suggest a spacing of 100 m to 150 m or less for dams.[6] Given the occurrence of UGLU only 140 m downstream of the dam, and the complexity of the geologic environment, the Chief Inspector determined more drilling would have been warranted and would not have been in excess of prudent industry norms.

WEAK UGLU NOT CHARACTERIZED

the root cause associated with Proximate Cause 2A is that the site investigation conducted for the Perimeter Embankment was inadequate

The inadequate site investigation influenced stability analysis of the dam structure. The mistaken belief in the strength of the foundation soils led to inaccurate parameters for dam stability analyses up to the time of the breach.

It appears upon investigation that the following can be summarized regarding foundation soils:

- The glacial history of the dam foundation was not adequately understood.
- There was a disconnect between the level of understanding and an appreciation of uncertainty with respect to that understanding. The risk associated with the potential for weak UGLU was not appreciated, and never taken into account with stability analyses. There was limited effort to either conduct more soil exploration or to anticipate potentially unknown soils with a more conservative design. Either approach would have, in all likelihood, avoided the failure.
- Site investigations appeared to be focused on the initial starter dam (which was limited to the ME) or at most, the first two stages. Subsequent construction stages seemed to operate on the assumption that all necessary foundation studies had been completed during the initial design phase, and that test holes were mainly for installation of monitoring instrumentation.

Failed or Defeated Controls. The Chief Inspector's investigation identified a number of failed or defeated controls that, had they been in place, could have blocked or mitigated the effect of the inadequate site investigation from triggering Proximate Cause 2A (Weak UGLU Not Characterized).

MEM Geotechnical Review (1995). Following an inspection of the TSF development site in 1995 by George HEADLEY, C.O. BRAWNER raised a concern with respect to foundation preparation: "only one hole appears to have been drilled in the main embankment area. In B.C. valleys there is always the possibility of buried high permeability zones. It is recommended that 2 more boreholes to expand the geotechnical information be drilled and tested."[7] Although the request was narrowly focused on the starter dam (the ME), it accurately identified a general concern with sufficient geotechnical information to adequately characterize the foundation.

THE UGLU

The glacial history of the dam foundation was not adequately understood

MEM Query Discounted (KP 2005, AMEC 2012). As part of the Stage 4 *Mines Act* permit amendment application, MPMC submitted the 2005 KP report *Design of the TSF to Ultimate Elevation*. In his review of the document, Senior Geotechnical Engineer Chris CARR raised a concern with borehole GW96-1A, located downstream of the breach location. He referred the following question through MPMC to KP: "Glaciolacustrine deposit is noted in GW96-1A on cross-sections 9 and 10 [*in Dwg. 1627.011*; see Figure 10.2]. The material is described as firm. What are the characteristics and extent of this deposit and could it have an influence on dam stability locally?"[8]

The concern was discounted first by KP and later by AMEC, as not being applicable to the foundation within the dam footprint.

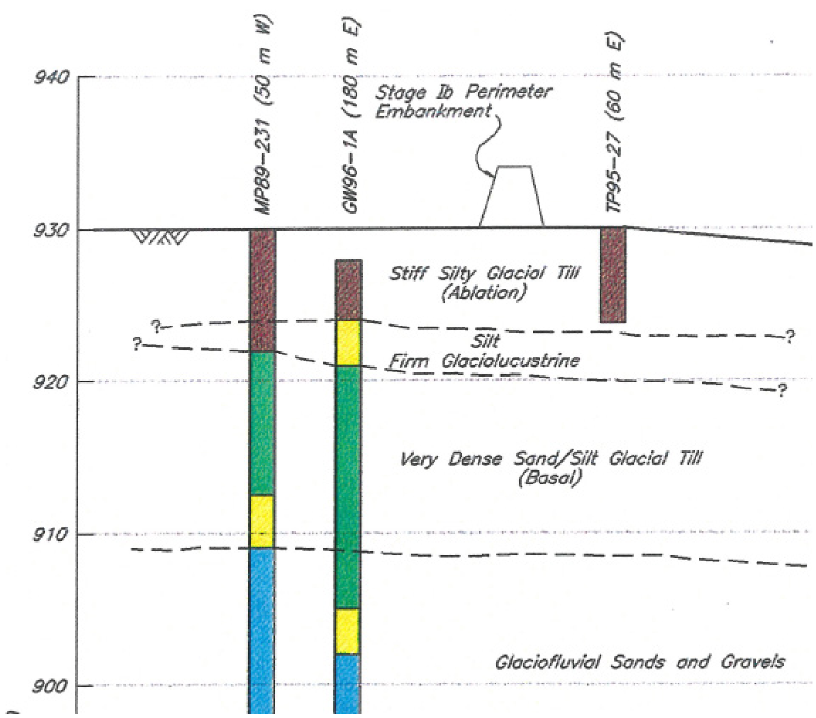


Figure 10.2 Detail of UGLU
Knight Piésold (1997c) Dwg 1627.011

A response from Les GALBRAITH, P.Eng., and Ken BROUWER, P.Eng., of KP, stated, "the glaciolacustrine deposit encountered in GW96-1A and shown on cross-sections 9 and 10 consists of glaciolacustrine layers (silt, some clay) with lesser fine-grained glaciofluvial layers (sand). The material was described as firm based on an SPT N value of 6. The glaciolacustrine unit encountered within the TSF basin is a continuous unit near the Main Embankment, *but is only present as thin, discontinuous layers within the glacial till unit to the northeast near the Perimeter Embankment*. This was investigated during development of the original borrow area during the initial Stage 1 construction program which involved excavating approximately 50 testpits and drilling approximately 22 hollow and solid stem auger holes on a 50m grid pattern. The location of the original borrow area is illustrated on Drawing 1627.001. The borrow area was also inspected during Stage 2 construction. These investigations *confirm that the glaciolacustrine deposit encountered in GW96-1A is a discontinuous unit and will not adversely affect the dam stability* (italics added)."[9]

AMEC made a similar conclusion in 2012. "The upper GLU in GW96-1 is described as firm, but it is not of significant concern in this instance as the drill hole location is approximately 140 m further downstream from the current toe of the dam… In general clay layers within the GLU appear to be discontinuous and less than 5 mm in thickness which suggest a distinct facies change relative to the GLU along the ME alignment… Based on available information, foundation concerns along the PE appear more favourable than those along the ME, in terms of the presence and extent of clay-rich zones."[10]

The cited test pits and auger holes were not only in areas completely separate from the PE foundation, they were of insufficient depth to reach the UGLU. The EoR discounted a query that could have exposed the weak UGLU, and may have sparked additional test bores that could have identified the extent of the weak layer. These events represent failed controls, in which MEM engineers raised a concern about foundation properties and the concern was discounted by the EoR.

Dam Safety Review (2006). The Dam Safety Review (DSR) conducted in December 2006 by AMEC (then a third-party reviewer) suggested, "the minimal increase in computed factor of safety for a 2H:1V geometry over a 1.4H:1V embankment for all cases analyzed is consistent *with no plane of weakness in the foundation soils being assumed. Though not implying a plane of weakness*, evaluating the potential ramifications for a subhorizontal presheared plane in the glaciolacustrine (or similar) soil *would be prudent dam safety engineering"* (italics added).[11] This concern was limited to preshearing, which was determined *not* to have been a factor in the failure. However, it represents a failed control: had this concern been interpreted carefully, it may have triggered additional investigation of the subsurface structural conditions.

Engineering Changeover from KP to AMEC (2011). Change of EoR engineering firm represents an opportunity for a fresh, objective assessment of design assumptions to date. The transfer from KP to AMEC presented an opportunity to ensure that the transfer was seamless and that key information, data, and learnings maintained continuity over the life of the TSF. KP transferred some materials and engaged in knowledge transfer, but lab test data were not transferred. It was also an opportunity for a fresh set of eyes and minds to review the design of the dam. This event is a defeated control.

PE Design Section Moved (2011). In 2011 three deep holes were drilled within the dam footprint along the toe of the PE between Station 2+200 to 4+850 to install instrumentation and examine foundation soils. Two of the holes were drilled between Station 3+700 and Station 4+850, with a spacing on the order of 500 m. The drillholes missed the upper clay layer (UGLU).

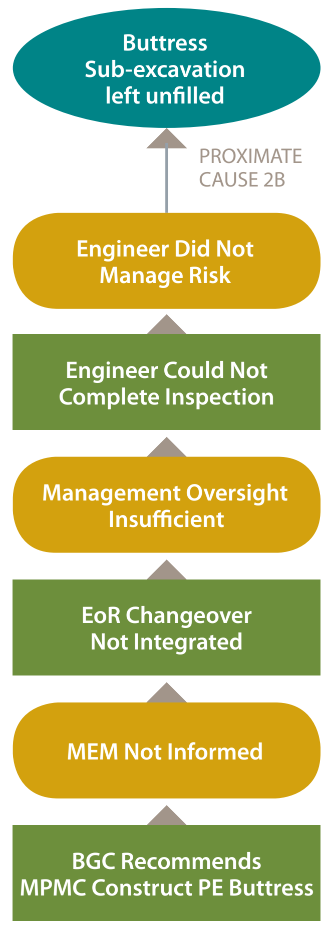
The site investigation program proposed by AMEC in 2011 included drilling in the area of the breach (Section G). However, MPMC was using this area for an access ramp onto the dam crest and consequently, access for the drill rig and security for the installed instrumentation could not be provided. As a result, Section G was relocated approximately 200 m west of the original section. Had drilling been carried out on the original Section G (renamed G' by AMEC), it is likely that AMEC could have encountered the UGLU and revised the design accordingly. The failure of the embankment at the location of the original Section G demonstrates that the KP engineers accurately identified a design section of the PE. Moving the section for the purpose of expediency on the ground represents a defeated control.

Summary of Failed or Absent Controls. KP and AMEC assessments of the significance of the UGLU encountered in GW96-1A did not address the depth of drilling, quality of soil sampling, and spatial distribution of the site investigations in the PE foundation. MPMC's acceptance of the relocation of Section G by AMEC did not recognize the significance of moving the instrumentation section from the low point in the PE foundation in what was previously a design section.

MEM relied on the EoRs' (both KP's and AMEC's) professional assessment of the significance of the UGLU encountered in GW96-1A. Responses to concerns raised by MEM reviewers were answered by professional engineers. Based on this reassurance, MEM did not further question or comprehensively review all site characterization data (see also Professional Reliance discussion in Section 10.6.1).

There are no formalized guidelines or regulatory requirement for site investigations. Standards of professional practice regarding the adequacy of foundation soils investigation may have provided an adequate characterization of the UGLU. This condition represents an absent control.

10.4.2. PROXIMATE CAUSE 2B: BUTTRESS SUBEXCAVATION



The second proximate cause structural failure of the embankment was the existence of an unfilled foundation excavation, approximately 2 m or more in depth, extending from the toe of the embankment outward by up to approximately 20 m, along a length of the PE from approximately Station 4+100 to 4+300. This section of embankment corresponds to the location of the structural failure.

Background. *Design Basis*. Approval of the Stage 9 raise was granted in a *Mines Act* permit amendment on August 9, 2013. There was no reference to buttress foundation excavation or buttress stripping on the PE in the *Mines Act* permit amendment application.

That construction season, MPMC contracted with BGC Engineering Ltd to conduct stability modeling of the TSF to address concerns around surplus water storage. On October 3, 2013, BGC provided a draft *Interim Stability Analysis Project Memorandum* to MPMC and MOGER. The memorandum included modelling for dam elevations of 970, 975, 980, and 985 m. At each elevation, a calculation of area for foundation sub-excavation was computed, and design drawings for the extent of such foundations were supplied.

Even at the design height of 970 m, stability analysis indicated that an area of 60,300m^2 would need to be prepared for buttress construction. The memorandum also indicated an awareness of the practical utility of putting the Peterson contractor to work during the fall of 2013 to prepare for buttress expansion.[12] It is unclear whether MPMC or BGC communicated these findings to AMEC, the EoR at the time.

The issues raised in the BGC memorandum were reflected by BGC in its Stage 10 *Mines Act* permit amendment application, which proposed a buttress on the PE. The Stage 10 design was the first attempt to restore a less steep downstream slope, which had been constructed to 1.3H:1V in Stages 7 through 9. BGC designed Stage 10 to incorporate a buttress along the entire PE, as well as extending the existing buttress on the ME. The buttress was to have been constructed following the raise to 972.5 m beginning late in 2014 and continuing into 2015.[13]

The design for the PE buttress, including detailed construction drawings, was submitted to MEM as part of the Stage 10 *Mines Act* permit amendment application prepared by BGC Engineering, and received by MEM on July 25, 2014 — 10 days before the breach event.

Design Approval. Since it was not provided to MEM, it is assumed that the BGC *Interim Stability Analysis Project Memorandum*

BUTTRESS SUB EXCAVATION LEFT UNFILLED

The root cause associated with Proximate Cause 2B is that an unapproved buttress subexcavation reduced the PE Factor of Safety was solely intended as an internal document to support the planning of Stage 10, which was being undertaken by BGC as early as mid-2013. It is the opinion of the Chief Inspector that MPMC acted on the recommendations in the project memorandum; these plans were not conveyed to MEM, although it appears that AMEC concurred with the work undertaken, since in most areas AMEC engineers approved the foundation preparation.

Construction. The excavation was made as a part of an extension of the buttress foundation along nearly the entire length of the PE in late fall of 2013 (during Stage 9).[14] It is not possible to discern the exact date of the excavation from the daily construction reports. *[Mine Personnel]*, TSF Supervisor, recalled the subexcavation to have taken place in December,[15] but most reports, including numerous statements and the as-built report, suggest that the subexcavation at the breach location was excavated in November 2013.

AT THE LOCATION OF THE BREACH

a 200 metre-long excavation at the toe of the dam was left unfilled for eight months

There were no construction procedures supplied in the construction manual for the buttress excavation. The actual construction did not include provisions for inspection and backfilling, which would normally be included in construction procedures. The excavation from Station 4+100 to 4+300 was left unfilled from the date of its construction to the failure of the dam, approximately eight months.

According to *[Mine Personnel]*, "there was an agreement with MPMC that if Peterson had any slowdowns due to the mine area [such as delays in obtaining rock], they would be diverted to hourly work and continue on other projects MPMC had on the go," such as the buttress foundation preparation.[16] It was reported that Luke MOGER was directing the buttress foundation sub-excavation.[17] While the practice of providing for work to fill available time and avoid construction downtime may be appropriate for certain construction tasks, including those that are not mission-critical, it is never appropriate for such actions to be taken on unapproved structures that affect the FoS of the embankment.

The as-built report further documents this foundation subexcavation in the following photograph (Fig. 10.3). The location or station number along the PE was not supplied; however, the photo represents the general layout and scale of the foundation disturbance. (Note also the visible steepness of the downstream slope on the PE.)

Figure 10.3 Typical Buttress Subexcavation
AMEC Environment and Infrastructure (2014a) Appendix A)

The as-built report for the 2013 portion of Stage 9, issued in March of 2014, reported that over 1,700 m of buttress foundation preparation had been completed for the PE. "Foundation preparation was also conducted downstream of the Perimeter Embankment within the final dam footprint. The area was stripped of all organics and soft and over wet soils to expose dense inorganic native soils. The area was then approved by the AMEC Support Engineer and waste material hauled outside the proposed dam's footprint. The area was approximately 1,700 m in length, extending from Station 2+700 to 4+400,"[18] which included the area of the breach.

The as-built report also noted, as an outstanding task whose completion is "important to the proper completion of the development of the tailings embankment," that a section of the foundation had not been filled: "inspection of the prepared foundation between Station 4+100 and 4+300 was attempted late in the season but was covered with snow. It should be noted that this section will require approval prior to any backfilling activities."[19] This section of open excavation corresponds to the location of the embankment failure.

Impacts on Factor of Safety. Post-failure geotechnical analysis conducted by KCB included modeling of the impact of the buttress excavation on the embankment's FoS. Stability analysis indicated that "without the 2 m deep excavation at the embankment toe, the FoS increased from 1.27 to 1.34 for static conditions using peak effective strengths and from 1.02 to 1.10 for a condition where local yielding occurred in the UGLU mobilizing peak undrained strengths. The FoS fell below unity [FoS = 1] for a condition with remolded undrained strength in the UGLU. The increases in FoS, especially for peak undrained strength conditions, which indicate that the embankment failure may not have occurred on August 4, but could be expected to occur as the dam was being raised higher, although further analysis would be required to define the elevation."[20] The addition of the excavation to the existing foundation and embankment profile thus reduced the static FoS by approximately 5%.

Failed or Defeated Controls. The Chief Inspector's investigation identified a number of failed or defeated controls that, had they been in place, could have prevented or mitigated the effect of the buttress preparation from initiating the event, Proximate Cause 2B (Buttress Subexcavation Left Unfilled).

MEM Not Informed. MPMC did not provide MEM with notification of the buttress subexcavation or an application for a *Mines Act* permit amendment to accommodate the departure from the approved work. The Chief Inspector did not find any reference to a buttress on the PE in TSF design stages before Stage 10. Most significantly, the Stage 9 *Mines Act* permit amendment approved work that incorporated *only* an extension of the buttress on the ME, and in that location *only* atop the existing buttress. In other words, there was no approval of any expansion of the dam's foundations to accommodate future buttress construction.

Design drawings submitted as part of the *Mines Act* permit amendment application for Stage 9 reflected the following condition: on the ME, the existing buttress would be raised. On the PE, the only construction was to extend the height of the dam atop the embankment and extend the abutment at the extreme western end of the PE, at station 4+980. This extension, following the same foundation preparation specifications used throughout the construction of the TSF, would accommodate any lengthening of the PE as it approached the hillside that formed the western side of the TSF, and then only to accommodate the anticipated raise to 970 m authorized for Stage 9.

Excavation construction records lacked sufficient detail to reconstruct an accurate timeline of this work in the breach area. The lack of accurate construction documentation represents a failed control in the administrative function of both AMEC and MPMC: no one was sufficiently informed of the open excavation to recognize its risk; and MEM was unable to carry out its regulatory oversight role it would have played had this information been documented and reviewed.

Insufficient Management Oversight. The timeline of events surrounding the buttress subexcavation indicate that the construction took place during the early stages of the handover of EoR responsibilities from AMEC to BGC. The work each firm was undertaking was occurring at the same time, but there is no indication that the work was integrated or coordinated by MPMC. As such, MPMC did not provide the appropriate level of management oversight on the construction activity around the PE buttress subexcavation. Had the mine exercised such oversight, the subexcavation would not have been left open for eight months.

Numerous employees on site expressed concern with the unfilled status of the excavation. Despite this concern, the open excavation was treated as a low-priority issue. *[Mine Personnel]* reported: "across the site there were multiple conversations related to how the excavation needed to be completed, but nothing was ever done about it."[21]

The lack of an appropriate system through which employees of either of the construction contractor or of MPMC could escalate their concerns from witnessing the unfilled excavation at the toe of the dam represents an absent administrative control. Effective communication of valid concerns of ground-level employees regarding the potential impact on the embankment's structural integrity could have raised a red flag to management, and additional measures could have been taken to adequately inspect the excavation and allow for its refilling. This lack of oversight by MPMC represents a failed control.

MPMC managers did not recognize or address the risk of the open excavation. MOGER reported that "nobody raised the question to [him] that the toe excavation should be filled, and [he] did not see any concern with the toe excavation remaining unfilled," although he acknowledged that "an open excavation at the bottom of the slope would decrease the FoS."[22]

Although occurring in different circumstances, further indication of this lack of awareness of the risk associated with the practice of removing material from the toe of an embankment took place post-failure on September 7, 2014, when two MEM inspectors witnessed a worker digging into the toe of the PE with an excavator. The inspectors issued an immediate verbal "Stop Work" order to the pit shifter and followed up with a written order to the mine manager on September 7, 2014.[23]

Engineer Did Not Manage Risk. Throughout the unfolding of the buttress subexcavation, there was a failure of the engineering oversight control. The design was not submitted for approval to MEM, and did not appear in any design documents prior to construction. No specific construction procedure was developed, which could have focused attention on the open excavation.

It is the opinion of the Chief Inspector that AMEC accepted the construction of the buttress subexcavation. AMEC reported on the progress of the subexcavation in its 2013 as-built report, and Luke MARQUIS, AMEC support engineer, was onsite filling the duties of the TSF field inspector from the end of August to mid-December, during which time the foundation preparation took place. Although MARQUIS attended the subexcavation to inspect it prior to backfilling, he could not complete the inspection due to snowfall. The excavation remained open for eight months without additional action or risk mitigation.[24]

The transfer of EoR responsibilities from AMEC to BGC was planned to take place at the conclusion of Stage 9 construction. The transition, however, was already under way as early as mid-2013: BGC performed stability analysis and consulted with MPMC on steps to take. However, AMEC was not involved in these activities, although they certified the 2013 construction work. Additionally, there were four EoR designates within AMEC between 2011 and the breach, and AMEC's original EoR had since transferred to BGC.

Although the work was not incorporated into the Stage 9 design and construction documents, AMEC certified that "in general, the 2013 Stage 9 raise of the embankment is judged to have been carried out in conformance with design intent. This conclusion is based on AMEC's periodic observations of the construction, review of reports prepared by MPMC when AMEC was not on site, and the review of QA/QC records."[25]

[Mine Personnel] reported that the water needed to be drained from the subexcavation before approval for refilling could begin. AMEC was to approve the excavation and MPMC was awaiting that approval to complete filling.[26] The AMEC support engineer's repeated on-site inspections did not

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identify the risk inherent in the open excavation.

The failure of the EoR to adequately manage risk posed by the subexcavation during the Stage 9 construction season represents a failed administrative control to effectively manage risk on the TSF.

Summary of Failed or Absent Controls. While post-event stability analysis suggests that the open buttress subexcavation contributed only a small reduction in the embankment's FoS, this reduction was a proximate cause of the structural failure. Had the subexcavation been filled, the failure would not have occurred when it did. Stability modeling demonstrates that the failure would only have been delayed, not avoided. However, it is possible that the delay may have allowed for other interventions to be implemented.

The casual approach to the design and construction of the subexcavation, without MEM approval or management oversight, allowed the subexcavation to occur and remain open for eight months — nearly a whole construction season — without comment or concern from either MPMC or the EoR. The lack of integration of the anticipated changeover of the responsible engineering firm led to inconsistent oversight of the construction process, including inspections by the EoR.

10.4.3. PROXIMATE CAUSE 2C: EMBANKMENT GEOMETRY

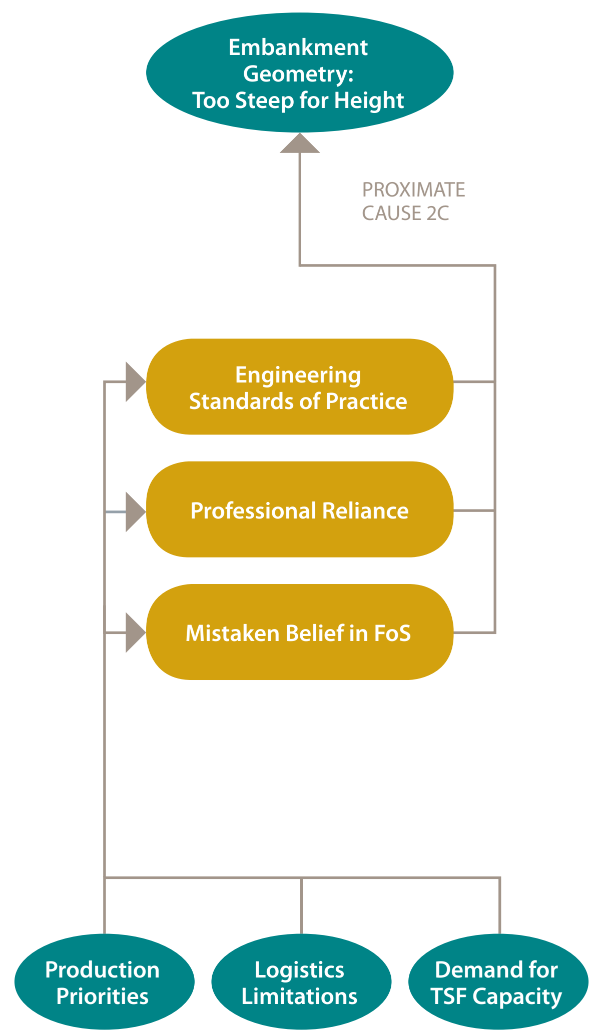
The final proximate cause of the structural failure of the PE is embankment geometry: both steepness of the downstream slope and the height of the embankment (see Figure 10.4). A downstream rockfill shell with adequate slope represents a conventional engineered barrier: it is a completely passive, effective defense against failure of an embankment.

At the time of failure, the downstream slope angle of the PE was 1.3H:1V, which is the steepest slope that dumped rockfill can typically maintain (the "angle of repose"). Coupled with the rising height of the dam (nearly 40m at the site of the failure), this geometry comprised a proximate cause of the embankment failure.

AMEC's daily construction reports indicate that by August 1, 2014, Zone C placement had reached its target elevation and was being graded to 969 m. The till core was completed to 968.8 m on July 31 (but surveyed elevations from either side of the breach indicate the till core was closer to 970 m).[27] On July 28 and 29, Zone C rockfill was placed at the breach site to an elevation of 969.0 m.[28]

Chronology of Downstream Slope Geometry. Design parameters for the slope of the downstream Zone C shell of the TSF embankments had been specified at 2H:1V from the initial design in 1995.[29] At the time, a slope of 2H:1V met stability requirements as indicated in a number of stability analyses, and also met the reclamation specifications for tailings facilities under the Code. As-built drawings show that 2H:1V downstream slopes were achieved in all construction stages up to and including Stage 4.

In Stage 5, the design was modified during the 2007 construction season as recorded in KP's design documents, including a steepening of the slope to 1.4H:1V "to allow the embankments to be raised using the modified centerline method in the timeline required to maintain the storage and freeboard requirements of the TSF." It appears that prioritization of rockfill material or logistics led to this design change.



The steepened slope was intended to be an interim slope, to be expanded to 2H:1V once the Stage 5 elevation was reached.[30] MEM approved the design including the interim slope as submitted. As-built drawings issued after the Stage 5 construction program confirm that the downstream slope of the PE changed from 2H:1V to 1.4H:1V at approximately 944.0 m.[31]

INTERIM SLOPES

KP asserted the steeper "interim" slope was driven by balancing construction material requirements with the waste production schedule

The *Construction Manual* used for the *Mines Act* permit amendment application for Stage 6, prepared in June 2009, again indicated a designed downstream slope of 2H:1V for the perimeter Embankment. However, the Stage 6a as-built report issued in July 0f 2009 noted "the slope of Zone C at the end of Stage 6a varied for each embankment, but on average was 1.4H:1V." In addition, the PE drawing noted an "interim slope for Zone C rockfill approx. 1.4H:1V."[32]

In the 2009 *Annual Inspection Report*, KP states "the tailings embankments currently have a downstream slope of approximately 1.4H:1V. This was previously constructed as an interim slope to balance the construction material requirements with the waste production schedule for that particular year. This short-term slope configuration still exists. It is recommended that the downstream slope of the ME be evaluated during the Stage 7 design phase to assess whether it requires flattening at this time."[33]

ANGLE OF REPOSE

the downstream slope angle was 1.3H:1V, the steepest slope that dumped rockfill can typically be placed

In the Stage 6b as-built report issued in January 2011, the final report under KP's direction, the PE drawing again noted an "interim slope for Zone C rockfill approx. 1.4H:1V."[34] The report concluded, once again, that "the outer slope of Zone C at the end of Stage 6b varied for each embankment; the average Zone C downstream slope is 1.4H:1V."[35] The use of an interim slope continued due to demands for increased TSF storage capacity, lack of rock placement in Zone C, and balancing construction material requirements with waste rock production.

As-built construction record drawings for Stages 6a and 6 show the interim steeper slope continued after Stage 6. Additionally, there appear to be inconsistencies in the reported as-built downstream slopes between years, with both AMEC and KP. For example, a change in steepness of the downstream slope (the break point between the 2H:1V slope and the 1.4H:1V slope) occurs at a lower elevation on the Stage 6 record drawings, at approximately 938 m.[36] KP recommended the stability of the as-built embankment with 1.4H:1V be analyzed in Stage 7, to determine whether flattening was required.[37] KCB noted the stability of the PE for the Stage 6 design report was analyzed assuming a downstream slope of 2H:1V.[38]

In January of 2011, AMEC took over as EoR for Stage 7. The AMEC record drawings that show Stage 6 indicate an average slope of 1.4H:1V.[39] The as-built drawing for Stage 6 includes a discrepancy: the slope of the line measured on the drawing is 1.8H:1V.[40] Without a ground survey, the Chief Inspector can only speculate which value reflected reality. As in all prior stages, the Stage 7 design specified a 2H:1V slope for the downstream shell.[41] The as-built report, however, noted a 1.3V:1H slope in the PE[42], despite the statement that "based on AMEC's observations of the construction, review of reports prepared by MPMC when AMEC was not on site, and the QA/QC records, the 2011 Stage 7 raise of the dams was carried out in conformance with design intent."[43]

Mirroring the Stage 7 as-built report, the *Stage 8 (2012) Construction Manual* acknowledged an as-built slope of 1.3H:1V, with the drawing (see Figure 10.4) noting a 2H:1V slope as the "ultimate design slope,"[44] the slope that would remain after closure. Language referring to an "interim slope" no longer appeared in design documentation. The *Stage 8 As-Built and Annual Review Report* documented a 1.3H:1V slope as of October 2013 without comment on the as-built drawings.[45] The slope became accepted in Stage 9: the *Stage 9 Construction Manual* specified a 1.3H:1V downstream slope without comment.[46]

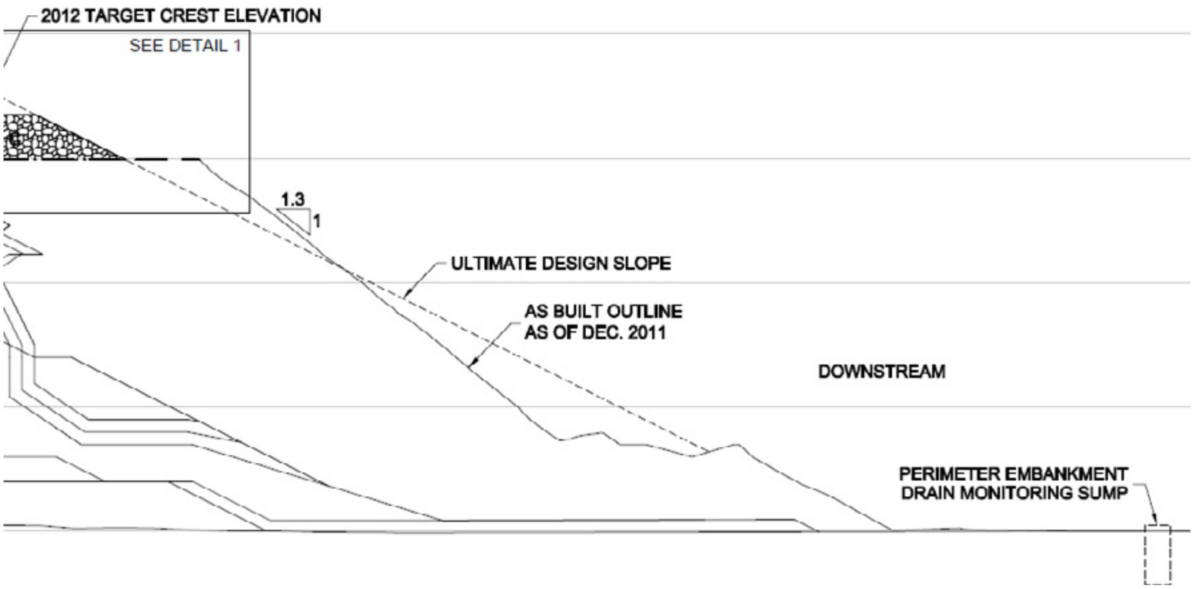


Figure 10.4 PE Downstream Slopes. AMEC Environment and Infrastructure (2012c) Dwg 2012.05

The steepness of the downstream slope contributed to the initiation of the failure of the PE on August 4, 2014. The over-steepened slope and increased height of the dam led to stress concentration below the downstream slope of the dam within the UGLU, which ultimately induced undrained strength behavior, leading to progressive failure of the dam.

Root causes. The root causes of the geometry of the PE are organizational in nature. The onset of an oversteep downstream toe occurred in conjunction with the greatly increased Zone C rockfill requirements of Stage 5. It is clear from the record that this oversteep condition was initially accepted only as an interim solution to be addressed once construction pressures eased. This interim condition gradually drifted to acceptance, despite generally accepted engineering practices allowing for angle-of-repose dam steepness only when the foundation was well-understood to be very competent, a condition that was not present at the PE.

In determining why the embankment was oversteepened, the Chief Inspector identified three conditions that comprise the root causes:

Production Priorities. Although production priorities are inherent in any enterprise, the Chief Inspector observed an overarching focus on production to the detriment of other issues at the mine, such as TSF operations limitations. Likewise, even the prioritization of health and safety issues at the mine was subordinate (see Appendix 1). These choices influenced other activities and planning at the mine, including the following two points.

AS THE PE BECAME STEEPER AND HIGHER

the forces exerted by the embankment penetrated deeper into the foundation soils, eventually finding the weaker clays of the UGLU

Logistics Limitations. There was ongoing difficulty in MPMC's ability to obtain sufficient Zone C rockfill due to availability of trucks, lack of an adequate haul road to the TSF, and prioritization of hauling ore over TSF construction materials. These challenges were compounded by production priorities: a manager may be inclined to devote scarce resources such as mine trucks in the ore supply logistical chain, rather than in the TSF construction tasks that could be delayed.

Demand for TSF Capacity. Increasing production at the mine coupled with increasing water surplus conditions required dam raises that outstripped MPMC's ability to maintain the original 2H:1V slope. Production demand coupled with a surplus water balance condition compelled MPMC to pursue adequate freeboard with continuing lifts.

Failed or Defeated Controls. The following controls either failed, defeated, or absent in the causal chain that led to the Embankment Geometry: Too Steep for Height (Proximate Cause 2C)."

EMBANKMENT GEOMETRY: TOO STEEP FOR HEIGHT

the root causes associated with Proximate Cause 2C are production priorities, logistics, and demand for TSF capacity driving the PE higher and steeper

Mistaken Belief in FoS. Oversteepening was tested by successive EoRs using standard engineering numerical modeling of stability analysis. Test sections were created and defined using data gained from drillcore assessment. The calculated FoS was, in all cases, greater than 1.5 on the PE. However, the parameters of the stability analysis were flawed because the strength of the UGLU was not characterized accurately. If it had been, the risks associated with the embankment geometry as built would have been exposed clearly and adjustments to the design geometry could have been be made.

In its post-breach investigation, KCB conducted further stability analysis of the PE taking into consideration various embankment elevations and additional factors specific to calculating the PE factor of safety (FoS). Had the PE's downstream slope been at the less steep 2H:1V (versus the 1.3H:1V slope at the time of failure), the dam's FoS would have increased from 1.27 to 1.59 and the stress concentrations would also have been diminished, preventing a failure.[47]

Professional Reliance. Professional reliance places a substantial burden on the EoR, both in design and in ongoing oversight of the TSF. The approach is based on a reliance on the technical skills, knowledge, and experience of the engineer, who in turn assumes responsibility for the adequacy of the work with his or her professional seal.

Both MPMC and MEM rely on the EoR's recommendations for such design elements as downstream slope. Steeper slopes than the design specified were built in Stage 6 through 8 (Stage 9 was designed for a slope of 1.3H:1V.) Despite this inconsistency, all as-built reports indicated that the construction was in "general conformance" with the design plans.

Steeper slopes reported in these documents from Stage 6 through 9 all indicated an FoS greater than 1.5.

In the permitting process, MEM approves work to be carried out in accordance with an engineered design, and in these cases it is not MEM's mandate to endorse or refute the judgement of the EoR at mines across the Province.

A recognition of the increased risk of maintaining the steep "interim" slope of the PE, and thorough review of as-built reports from as early as Stage 5 could have exposed the risk of the steep slope's significance on the FoS.

Prudent Engineering Standards. A steepened slope coupled with a confirmed lack of certainty regarding subsurface conditions would typically result in a more cautious approach to embankment design. Empirically, steep slopes on variable soil foundations should be flatter than 1.3H:1V despite the calculated factor of safety. A prudent standard of practice would imply flatter design slopes. The control exists in the system but was not implemented as intended.

Summary of Failed or Absent Controls. The intrinsic geometry of the PE contributed to the failure. And, while a number of controls exist in the current system to counter such erroneous design decisions, the authority and competence of the EoR at each stage of the TSF's construction was not questioned, because there is a general expectation of professional competence and responsibility. Engineering firms contracted to design mining dams in BC are often highly respected authorities, and it is beyond the level of experience — and resourcing — of either the client mine or MEM geotechnical engineers to challenge their recommendations. In the numerous cases where MEM asked a question regarding the design, the question was answered by the EoR.

Misplaced confidence in the knowledge of foundation characteristics contributed to an ongoing faith in the original design parameters of the TSF, including subsequent stability analyses that produced the erroneous FoS for the embankment.

10.5. PROXIMATE CAUSE 1B: BEACHES AND SUPERNATANT WATER

Returning to the breach and release of tailings and water, the root cause analysis exposed two proximate causes: Proximate Cause 1A, the structural failure of the PE (discussed above), and Proximate Cause 1B, insufficient beaches and too much supernatant water in the TSF. These two conditions are sufficiently interrelated to warrant presentation as a single proximate cause.

Proximate Cause: Insufficient Beaches. Beaches in a tailings impoundment are formed by spigotting tailings from the dam crest. They may be an intrinsic design requirement, particularly for centerline and upstream constructed tailings dams, and may perform multiple roles, including structural support of the embankment's critical components, especially the core zone; reducing hydraulic gradients in the dam; reducing the likelihood of piping; and providing a buffer against release of supernatant water should the embankment slump (fail).

Regardless of the facility, a smaller water pond — and larger beaches — serve as viable barriers to a potential dam breach. Beaches can mitigate the impacts of a failure of the embankment. As such, beaches can be viewed as an element of risk management in the operation of a TSF.

BEACHES AS BARRIERS

a beach can mitigate the consequences of a structural failure

Throughout the lifetime of the Mount Polley TSF, design documents called for the establishment and maintenance of beaches along all embankments. There was no consistent indication of target beach width but some design drawings indicated beaches extending over 200 m. For example, an above-water beach averaging over 250 m on the PE was shown in the Stage 8 *Construction Manual* submitted in 2012.[48]

In the opinion of the Chief Inspector, both MPMC and its engineering consultants had difficulty reconciling the conflicting objectives of beach maintenance and surplus water volume. For example, the OMS prepared in 2013 stated, "the fundamental requirement of the tailings deposition plan is to ensure that a blanket of tailings solids is present immediately upstream of all embankments and along the abutments. There is a fundamental objective to establish beaches adjacent to the embankments, but it is not necessary to continuously maintain a minimum width of exposed beach adjacent to the embankment, and periodic, temporary (less than two month duration), shallow flooding (less than 0.5 m depth) of the beaches is anticipated."[49]

The requirement for a beach was defined by the consultant engineers as necessary to provide adequate support for the core of the dam. The beach width was not necessarily predicated on the requirement to continuously maintain the free water pond away from the dam crest, but the engineers all agree that this outcome is desirable. The lack of adequate tailings beach for construction of Zone U was recognized as early as 1997 and borrow material was used to construct this zone for the ME. As the impoundment grew over time, MPMC's ability to deliver tailings to adequately develop beaches was limited by two constraints:

- as the dam elevation became higher, MPMC did not have adequate pumping capacity to deliver tailings to the ME, and
- MPMC did not have a tailings deposition plan integrated with the water balance, which would likely have demonstrated that construction of a beach was not possible as the increasing water inflow volumes would "over-ride" the beach.
- MPMC initiated studies to assess how a beach could be established and/or how material could be used to construct Zone U.
- The use of cyclone sand was assessed in 2007, demonstrating that cyclone sand could be produced for Zone U and possibly for the downstream shell zone of the dam. This option was probably not pursued due to the limitation of the pumping capacity to provide adequate hydraulic head to produce cyclone sand, or variability, and cost.
- Construction of sand cells was trialled in 2009 and implemented in 2011. However, the construction of sand cells was constrained by variability in the ore being milled, which resulted in "system

upsets" due to high fines (silts and clays) in the tailings, reducing productivity; delivery of tailings to the ME was still not conducted because of inadequate pumping capacity; and the increasing pond water level, due to an increasing water surplus, resulted in intermittent flooding of the sand cells and increased the requirements on materials for the sand cell.

Up to the time of failure, rockfill and sand cell construction continued to be used to augment Zone U material requirements.

Although the role of beaches was not fully appreciated as a potential barrier against the risk of a failure leading to a massive breach, efforts were taken to manage tailings deposition and dam raises to allow for beach generation. However, tailings management was not effectively meshed with water balance, leading to inadequacies in both systems. Above all, risk recognition and management were not incorporated into operations or expansion plans.

The Dam Safety Inspection (DSI) in 2010 stipulated that beaches of at least 10 m must be present, and where missing must be reestablished within two weeks. The requirement to adhere to MEM conditions establishing beaches along all embankments was reiterated by KP engineers.[50]

The Chief Inspector believes the mine found it difficult to maintain beaches, especially at points far from the tailings slurry line such as the ME. The 2012 DSI noted, "in 2012, given the orientation of the gravity-fed tailings line, insufficient tailings line pressure prevented cell construction along the central portion of the Main Embankment … The tailings delivery line is currently being redesigned with the expectation that the new alignment will allow for upstream tailings cell construction to take place along the Main Embankment in 2013."[51]

In their assessment of the TSF in 2014, BGC noted a number of concerns about the lack of adequate beach establishment, registering concern that the lack of beaches essentially converts the TSF into a water-retaining structure, with characteristics quite different from the initial design.[52]

Despite these efforts, as Figure 10.5 shows, very limited beaches were established at the site of the embankment failure only days prior to the event (July 29, 2014).

Figure 10.5 NASA High Altitude imagery, July 29, 2014

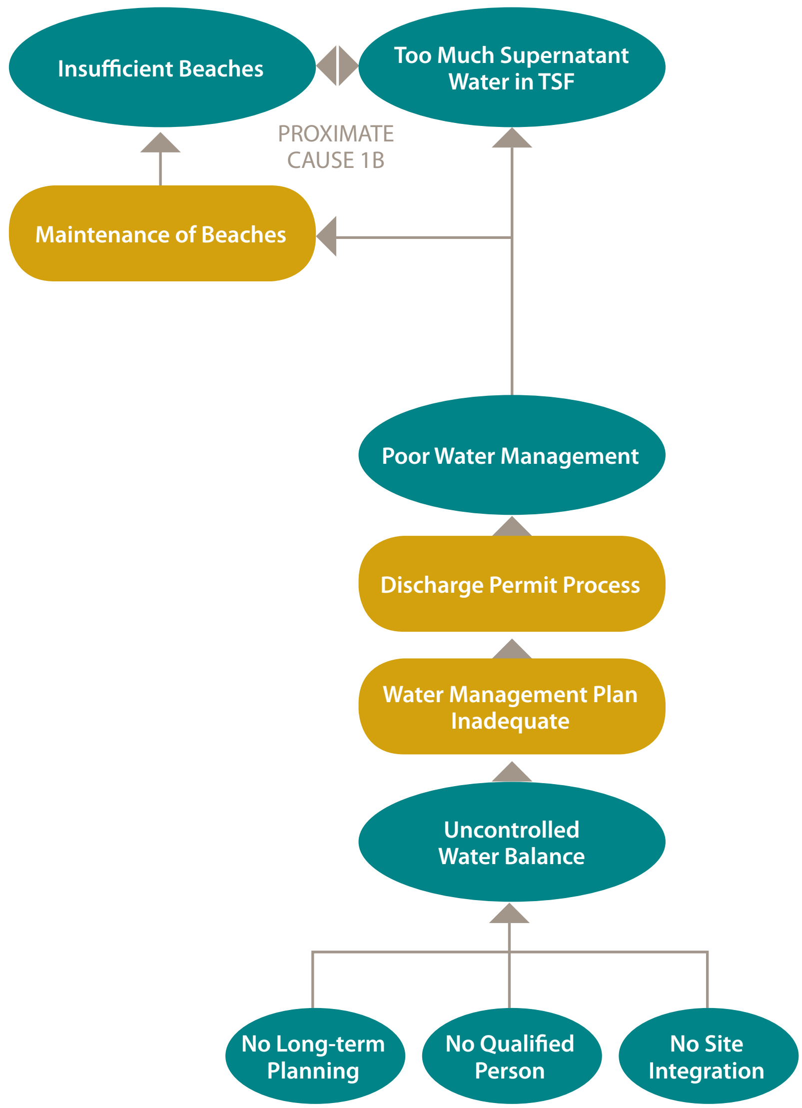
Defeated Control: Maintenance of Beaches. Although it is impossible to accurately predict what the impact of sufficient beaches would have been at the time of the embankment failure, the lack of beaches represents a barrier that, had it been present, would have mitigated or prevented the structural failure of the PE from becoming a breach.

Proximate Cause: Too Much Supernatant Water. The lack of beaches can be attributed directly to the chronic growth of surplus supernatant water as well as shortcomings in tailings deposition. Surplus water submerges beaches, reducing their role in buffering the embankment from the pond. The amount of supernatant water in the TSF pond at the time of the breach was at least 10.6 million m^3, the amount calculated by Imperial Metals Ltd. released in the breach event.[53]

Water Levels. Both a tailings deposition model and an effective water balance are needed to assess if the tailings beach can be maintained throughout the operation of the TSF. Historical pond elevation and tailings beach levels are shown in Figure 10.6 below. The pond elevation immediately prior to failure was 966.8 m (freeboard was reported to be between 2.7 and 3.0 m) as reported in AMEC's daily report dated August 3, 2014. The beach elevation in the area of the breach at that time was estimated to be 966.3 m as inferred from the post-failure tailings contours outside the breach area, the observed submergence of the tailings beach and photographic records from August 2014.[54]

No procedure for measuring pond level is included in the OMS; in addition, MPMC's tailings check procedure refers only to checking the pond level on the computer before field-checking the TSF.[55]

There is likewise no reference to measuring or evaluating freeboard, a term referring to the difference between pond level and the lowest point in the Zone S till core. However, daily construction reports include pond elevation and the location and elevation of the lowest point in the till core (Zone S)[56]. Interview statements suggested that monitoring of freeboard and measuring of pond water levels were inconsistent and conducted with varying frequency, leading to questionable reliability of results.



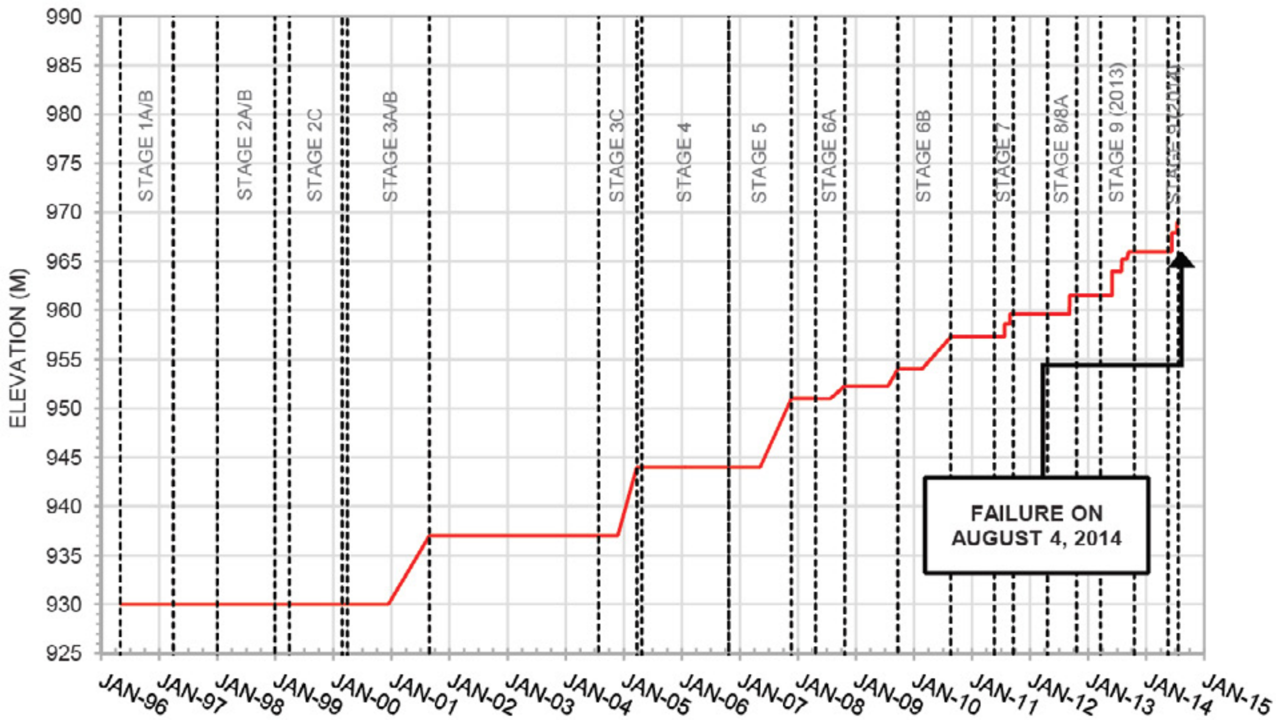


Figure 10.6 Embankment Zone C Elevation Over Time
Independent Expert Engineering Investigation and Review Panel (2015), p. 5-5

WATER SURPLUS

expansion of disturbed area for mine operations contributed to a surplus of 2 million m^3 annually

The embankment crest was raised to meet freeboard requirements and to allow development of the beach upstream of the embankment. Starting in June 2011 (Stage 7), rises in the pond level hampered the ability to maintain tailings beaches. Subsequently, the tailings beach along the PE in the breach area was partially submerged during Stage 8 and completely submerged during the final Stage 9 construction.

Given the pace of dam raises on a continual basis, and the requirements for sufficient freeboard to contain Predicted Maximum Precipitation (PMP) events and wave run-up, MPMC struggled to generate sufficient storage volume in the TSF to accommodate all water entering the system. The mine operated the tailings impoundment with an observed triple-use function, where the TSF was the storage basin for tailings from milling operations; for process water storage and recycling; and for storage of runoff water from disturbed areas of the mine's footprint.

Water Balance Planning. Initial engineering estimates of water balance for the mine conducted in 1995 indicated a deficit state would exist, and the mine would need to withdraw water from Polley Lake at intervals during dry months[57]. However, as early as 1997, MPMC received notification the mine would experience a hydrologic surplus state. The original MOE effluent permit, issued in May of 1997, stated: "it was noted in the *Ministry's Technical Assessment* that a review of climate data using the records for the Likely weather station indicated that the area has about 150 mm/year more precipitation than the estimated evaporation for Mt. Polley suggesting that enhanced evaporation or enlarging the depth of the tailings impoundment will have to be implemented before the end of mine life to maintain a negative tailing impoundment water balance and avoid discharge."[58] Water balance was also influenced by the storage of water in the voids of the tailings, and consequently, even with higher precipitation it could be anticipated that a deficit water balance could occur in initial mine operations. However, the effect of higher precipitation would become exacerbated over time, especially given the increase of the mine's disturbed area.

Water management, especially the maintenance of sufficient freeboard in the TSF, continued to be a challenge for MPMC, as demonstrated by the overtopping event in May 2014 (see section 6.13.4).

Responsibility for Water Management. Following the re-start of operations in 2005, the mine's disturbed area footprint continued to expand with the opening of the high-grade ore Wight Pit, commencement of underground operations, and expansion of waste rock storage areas. This expansion increased the water surplus onsite to well beyond initial predictions, with increased volumes of mine contact water yielding an annual surplus of up to approximately 2 Mm^3 in 2014.[59] At the same time, responsibility for water balance was removed from the engineering consultants and assumed by MPMC personnel.

For the period of 2006 to January 2012, the TSF was managed by Mr. Ron MARTEL, environmental technician. MARTEL was actively involved in all aspects of the TSF, including construction, consultant overview, water balance, environmental reporting and regulatory reporting. Prior to this period, water balance had been developed and reviewed by KP in its role as EoR. In January 2012 TSF responsibilities devolved to Tailings Project Manager Luke MOGER and various others in the group responsible for water management. The level of knowledge transfer with respect to TSF and associated water management is unknown.

According to the OMS, the tailings project manager is responsible for all aspects of construction of the dam. The Water Management Leadership Group[60] is responsible for site-wide water management and integration with TSF management. However, the definition of responsibilities was not clearly documented in the OMS, which resulted in no one individual responsible for the TSF who also had the training and expertise to fulfill the requirement of that position. Indicators of this condition include:

- While the MPMC environment department was responsible for water balance, this role was not adequately integrated into TSF planning. Consequently, the MPMC Water Management Leadership Group did not fulfill its mandate of management of water, as demonstrated by the dam overtopping in May 2014 and the delays in planning the necessary discharge treatment.
- The mine manager was not fully aware of all of the activities of the TSF or its management.
- The tailings project manager's responsibilities were defined as only being for the construction of the dams.

In its 2012 annual review of the TSF, submitted in April 2013, BGC noted, "MPMC maintains the water/mass balance model which is updated monthly with actual tonnages (milled/mined), precipitation data and surveyed pond water elevations to maintain the accuracy of the model and pond level projections. The MPMC balance has not been reviewed by BGC."[61]

It is the opinion of the Chief Inspector that the organizational structure of the MPMC Water Management Leadership Group itself resulted in a diffusion of responsibility for integrated water management and its direct impacts on the capacity of the TSF.

MPMC appeared to focus on meeting freeboard requirements for the coming year only. MPMC did not carry out adequate long-term planning of the water balance to predict annual volumes of surplus water. MPMC was focused on meeting the minimum annual requirement, although even this was exceeded with the dam overtopping in May 2014. The methodology that MPMC adopted for determining annual water storage requirements assumed the ability to predict water inflows in freshet (based on snowpack) and timely dam construction/raises, neither of which turned out to be reliable parameters.[62]

Discharge Permit Process. In 1989, during the exploration phase, Imperial Metals initiated an initial environmental assessment. MOE reported on the company's commitment at that time. "Although it was considered unlikely that tailings pond water would need to be discharged Imperial Metals Corporation made a commitment to design and install whatever treatment system would be necessary to ensure that any discharge of tailings supernatant or open pit water, if required, would meet appropriate discharge requirements."[63]

An effluent discharge permit was issued on May 30, 1997 for discharge of tailings slurry into the TSF. The permit was routinely amended over the years but did not allow discharge of water into the environment, with the following exceptions: prior to the first operational stage and during the care and maintenance stage, MPMC was permitted to discharge seepage water from the ME seepage pond to a tributary of Hazeltine Creek under Permit #PE-11678.[64]

Additional accommodation was made for the care and maintenance period. On February 7, 2002 MPMC received a *Mines Act* permit amendment for entering into care and maintenance, for transfer of supernatant water from the TSF to the Cariboo Pit, and release of effluent from the PE and ME seepage ponds to nearby surface water courses. These accommodations were requested because dam raises would not be feasible during shut down conditions. Upon re-starting the mine and milling operations, an additional amendment was issued. It included pumping of pit water to the tailings impoundment and termination of the PE settling pond discharge, which was now being pumped back to the tailings impoundment. The mine had also requested discharge from the tailings impoundment to Polley Lake but this discharge was not granted in the permit amendment.[65]

"In early 2005, Mount Polley forwarded a proposed approach to developing site-specific water quality objectives (SSWQO) to the MOE and embarked on an exercise of identifying priority parameters upon which to focus their efforts and, for those priorities, of evaluating options for developing SSWQO. The former represented an effort by the mine to identify any parameters, in addition to copper, that could be considered priorities or 'contaminants of concern' as defined by risk of their causing an adverse effect on the future aquatic receiving environment. In April 2005, Mount Polley met with MOE and presented the overall approach as well as preliminary findings. At that time, there was a general agreement on approach and discussion around the need for an additional Water Effect Ratio (WER) toxicity test. Mount Polley proceeded with the additional toxicity test and the identification of priority parameters."[66]

The amendment application to allow for discharge of surplus water proceeded through the MOE evaluation process on the following timeline:

October 2006	Amendment Application Commenced	**July 2009**	Revised Application
April 2007	Initial Draft Application	**October 2009**	Revised Application
July 2007	Modified Draft Application	**September 2010**	Revised Application (Final)
December 2008	Complete Application Package	**November 2012**	Decision Record/ Permit Issuance

INSUFFICIENT BEACHES AND TOO MUCH SUPERNATANT WATER

the root causes associated with Proximate Cause 1B include lack of long-term planning, no single qualified individual with overall responsibility, and no site integration

The discharge permit was ultimately issued in November of 2012, with the opinion that "although Mount Polley has maximized water recycling the water balance is such that they now have an annual surplus of approximately 1.4 Mm^3 and a discharge is required."[67] Although the permit sought was for site-specific water quality objectives, allowing discharge directly into Polley Lake, MOE denied the site-specific objectives permit. Instead, a discharge permit for up to 1.4 Mm^3 annually was issued, with discharges dependent on water quality, flow rates of Hazeltine Creek, and seasonality (for fisheries protection).

Since only dam-filtered seepage water met water quality objectives, only approximately 100,000 m^3 of water was actually discharged annually. In addition, undisturbed runoff "must be diverted so that it does not flow into the tailings impoundment, or to the mine or mill areas."[68]

The Chief Inspector did not determine the root causes of the duration of this permit process. However, regardless of the cause(s), the time delay in completing the permitting process was identified as a contributing factor in the proximate cause of surplus supernatant water.

Interim measures to reduce surplus water conditions were initiated with the installation of evaporators around the ME seepage ponds and elsewhere on the mine site. MPMC conducted some experimental processing of tailings pond water using a pilot-scale aerobic biological reactor (ABR), to process water for future discharge, under MARTEL's direction. The trial was ongoing but reportedly had limited success.

Ultimately, MPMC recognized that some form of water treatment was essential to achieve a realistic water balance on site. MPMC indicated that they had ordered a reverse osmosis water treatment system with a treatment capacity of 3 million m^3/year that was scheduled to be implemented in late 2014 or early 2015.[69]

Root Causes. There were three root causes identified with the proximate cause of Insufficient Beaches/Too Much Supernatant Water in the TSF (Proximate Cause 1B): a lack of long-term planning for water management; no qualified, individual role to take on responsibility for water balance; and no integration of water planning across the entire mine site. These conditions led to poor water management, which in turn led to Increased Demand for TSF Capacity (in Proximate Cause 2C) and resulted in the uncontrolled water balance that continued to challenge the mine.

No Long-Term Planning. Managing surplus water balances on a mine that is expanding operations and its disturbed area requires long-term planning with targets set on more than an annual basis. In many ways, MPMC's planning was guided solely by the predicted water balance and production targets for the coming year. These annual goals were the driver in determining TSF embankment raises, the only water management tool MPMC used with effect. Planning for water treatment and discharge should have been a high priority throughout the life of the mine.

No Qualified Responsible Person. Responsibility for water management underwent a number of transitions during the mine's operational history. MPMC shifted responsibility for water balance from KP to MPMC upon reopening in 2005; under MPMC's management, the complexities and risks associated with water balance and management were not fully understood by the company. Water balance, especially under surplus conditions, is not only intricate and challenging; it increases risk significantly.

No Site Integration. Finally, effective water management requires not only a long-term perspective, but a synoptic view that takes into account the entire mine site, not just the TSF. Although the OMS identified the elements of the water management system across the site (from ditches to process water reclaim to the TSF), the Chief Inspector's investigation found there was no integration of these components across the site. For example, expansion of the mine and its disturbed area footprint in 2005 did not increase urgency in managing the growing surplus.

Failed or Defeated Controls. Two failed controls contributed to the condition of uncontrolled water balance at Mount Polley Mine. The first was the inadequacy of the water management plan, and the second was handling water discharge: both treatment of water to reach discharge standards, and obtaining of discharge permits from MOE. Effective water management planning and discharge capability would have reduced excess supernatant water and increased the likelihood of maintaining effective beaches — which in turn could have kept the structural failure from becoming a large-scale breach.

Inadequate Water Management Plan. An effective water management plan that accounts for the mine as an integrated site; is developed and managed by an appropriately qualified individual; and is responsive to water balance over the long term represents a powerful control that can meet water balance objectives, manage appropriate water levels in the TSF, and support the maintenance of adequate beaches. Instead, MPMC maintained an inadequate water management plan that ultimately was reduced to proposing embankment lifts that could only marginally contain annual water and tailings influx with adequate freeboard. Indicators, such as the overtopping of the PE in May 2014, did little to place more focus on this process.

Discharge Permit Process. The failed control, an ineffective discharge permit process, was identified as a contributor to the condition of uncontrolled water balance. Discharge was the only measure available to deal with surplus water balances year after year; TSF surplus water would require treatment to MOE standards prior to discharge; and the process of obtaining discharge permits continued for seven years.

The mine had ample warning. Indicators as early as February 2004 and again the following year (see Section 6.7.4) indicated a growing awareness of the urgency of water discharge planning.

MEM Query Discounted (2006). MEM raised concerns regarding beach establishment on a number of occasions. In 2006, MEM requested MPMC provide specification of the minimum design beach width required for construction and operation of the TSF (see Section 6.8.4). The response, prepared by KP for MPMC, claimed that there was no requirement for maintenance of continuous beaches.

10.6. SUMMARY: FAILED CONTROLS

The discipline of Root Cause Analysis (RCA) provides the opportunity to build a systematic roadmap of the causes of an event and identify defenses whose absence or failure allowed the causal chain to continue.

CONTROLS

controls require both detection and preventive action to keep a hazard from its target

Defenses can take the form of barriers and controls. In contrast to the passive nature of a barrier, a control is an active mechanism that is used to detect the initiating event and/or the hazard and enable an active intervention to prevent or reduce the potential that the hazard will produce an undesired outcome. However, in order to function, controls require two active events to occur: *detection and prevention* of the hazard from reaching a target (that is, becoming an undesired consequence). Several general themes emerge in the assessment of the failed or absent controls exposed by the RCA.

10.6.1. PROFESSIONAL RELIANCE AND ENGINEERING STANDARDS OF PRACTICE

Professional reliance is employed in many applications every day, in all industries. However, it is not well understood or well defined; and when there are failures in the control, the impacts can be substantial. The mine manager must apply professional reliance; complex engineering tasks such as design of a large TSF must be carried out by engineers with specialized knowledge and experience. Such knowledge and experience should not need to be tested by either the mine manager or the Regulator.

However, professional reliance can lead to mistaken belief, such as faith in the adequacy of site investigation, leading to misplaced faith in design parameters and stability modeling. Professional reliance can also be blinded by the confidence of an authority, or by the assumed accuracy of prior testing. In the case of the TSF, it appears that engineers guiding initial site investigations focused on the study of the ME foundations since the ME was the highest — and first — embankment to be constructed. They may have expected similar foundation studies to be undertaken prior to starting the PE and SE, but left no documentation of this intent. It is more likely that focus on the importance of the ME kept the PE foundation from receiving the attention it needed. Likewise, the professional authority of the designers kept the oversteep downstream slope from emerging as an item of concern, and the subexcavation of the buttress stayed open and exposed for nearly a year without raising concern by the engineer.

The Regulator must have the capacity to assess the adequacy of the designer's work product, and when questions arise, must have an appropriate vehicle to receive substantive answers.

Professional reliance can be diluted when it conflicts with client expectations. While clients must rely on the judgement of the EoR, they should not create conditions that exert undue influence on the professional with respect to minimum standards.

In addition, any task that requires specialized knowledge must be assumed by an individual with the appropriate knowledge. There was, for example, no requirement for a qualified professional to design and manage water balance, and no guidelines to require water management of an adequate scope to address these complex issues at Mount Polley Mine.

At the time of the construction of the TSF, no formal standard of practice guidelines for site investigation in British Columbia were in existence, and the professional opinions exercised were not sufficient. Likewise, there are no standards guiding the definition and practice standards of an EoR, although the concept is commonly applied.

Finally, professional standards of practice or practice guidelines around the change of an EoR (especially the transition from one firm to another) are not defined. The potential loss of corporate knowledge can be significant, and the transitions require a well-defined handoff of responsibilities.

10.6.2. RISK MANAGEMENT

The issue of risk identification and management is woven through these failed controls. In general, risk management as a professional practice was absent on the TSF. Despite assertions to the contrary regarding the Mining Association of Canada's Toward Sustainable Mining (TSM) program, MPMC had not conducted a comprehensive risk assessment on the mine, nor had an inundation study been conducted for the TSF. Also, no formal risk assessment was carried out by the EoR at any time in the life of the TSF.

Risks as significant as the inadequate foundation studies, variance and absence of beaches, rapidly growing surplus water, reactive TSF raise planning, an overtopping of the TSF and the toe excavation were all discounted, dismissed, or not identified at all. Concerns raised by workers regarding slope, material availability, buttress excavation, and supervision did not appear to be elevated or reviewed by management. Concerns raised by MEM around foundation soils, beaches, and surplus water were also discounted.

This condition is a reflection of the broader theme of flawed risk perception and risk management that was evident at Mount Polley Mine. This theme also encompasses the lack of effective management by MPMC in issues as broad as water management, materials supply, definition of accountable roles and responsibilities, life-of-mine planning, and overall responsibility under the *Mines Act*.

10.6.3. REGULATORY REVIEW

Regulatory oversight can also influence the defeated controls, and in many cases cited the Regulator's role did not support effective controls. The regulatory regime does not place any requirement on suitably-qualified persons to manage water balance. Nor does it place requirements on minimizing information loss upon the transfer from one EoR to another.

The Regulator has full authority to question, and request clarification of engineering specifications and design elements; however, it does not have the capacity to make full use of this authority in many cases. Many of the defeated or absent controls identified in the RCA relate to the limitations of

MEM with respect to professional reliance on which the Regulator relies. A formalized mechanism of requests for additional information, coupled with additional technical resources to evaluate responses, would support the implementation of these controls.

10.7. UNDESIRED OUTCOME: DOWNSTREAM CONSEQUENCES

The undesired outcomes (failure of the impoundment structure and subsequent release of tailings and water from the TSF) led directly to a number of consequences that extended far beyond the confines of the Mount Polley Mine.

The downstream consequences of the release represent threats to the key strategies of British Columbia's mining industry. These strategies, presented in the provincial *Government's Mineral Exploration and Mining Strategy*, include:

- Enhance our competitive edge
- Streamline regulatory processes
- Ensure the health and safety of our workers
- Protect the environment
- Build partnerships with First Nations
- Develop a skilled workforce[70]

The specific consequences of the breach event presented below affect the ability of MEM, as well as the industry as a whole, to achieve these key strategies.

The undesired outcome of a breach to the PE was proximate to the ultimate undesired outcome: the release of approximately 21-25 million m^3 of tailings, interstitial water, supernatant process water, and construction debris into the environment, affecting the watercourses from Polley Lake, Hazeltine Creek and Quesnel Lake.

This outcome represented a large-scale failure to meet corporate, government, and industry objectives. The impacts of this undesired outcome include at least the following:

- **Environmental**. A major purpose of the Code is environmental protection. Long-term environmental impact is not known at present, but the release affected both the Polley Lake and Quesnel Lake ecosystems, and devastated the full length of Hazeltine Creek. Turbidity and chemical changes to lake water have been recorded throughout Quesnel Lake, although the relatively low toxicity of the tailings water and the dilution throughout the lake could mitigate the effects. Remediation efforts to restore anadromous and freshwater fish habitats and terrestrial terrain are under way, but the results in these fisheries have not yet been quantified.
- **Public Safety**. Injury or loss of life was avoided in part due to the timing of the breach (there were no workers on the PE at the time of the failure) and in part due to fortuitous circumstances (there were no recreational users on Polley Lake or the Hazeltine Creek floodplain). Health and safety of the public is a key priority of the Code.
- **Social Contract.** All citizens of BC have a reasonable expectation that their interests are considered in the development and regulation of the mining industry. These expectations include safety, public health, environmental protection, interests of First Nations, and economic well-being. All these expectations have been threatened with the TSF breach.
- **Economic**. Economic impacts of the event have been felt throughout the mining industry in Canada, from Imperial Metals and their investor relations to the broader perception of risks of investing in mining in BC and across the country, potentially reducing both industry revenues and job creation. Larger spinoff effects in the regional economy, including tourism as well as other sectors, are also at risk. The event, cessation of production at the mine, and potential complications of the incident on other mining activities in BC and elsewhere in Canada could pose threats to secure, well-paid jobs in mining communities — not only direct jobs in the industry, but larger spinoff impacts throughout the local and regional economies.

- **International Relations**. The event has shaken the reputation of the Canadian mining industry, both within Canada and internationally. In particular, the relationship with Alaska cultivated by the mining industry, especially due to the mine development in northwest BC, where drainage passes through fish-bearing streams of the Alaska coastline. Cross-border relationships and treaties are under stress or being revisited. Potential consequences may be felt in terms of future water, fisheries, and other treaties with US interests both in Alaska and across the 49th Parallel.

FOOTNOTES

1 *NASA (2009) p. 1*

2 *NASA (2009) p. 1*

3 *NASA (2009) p. 2*

4 *NASA (2009) p. 26*

5 *Knight Piésold (1995d) Drg. No. 1627.009*

6 *US Bureau of Reclamation (1987)*

7 *Brawner (1995a) p. 2*

8 *Carr (2005b)*

9 *Galbraith and Brouwer (2005) p. 1*

10 *AMEC Environment & Infrastructure (2012a)*

11 *AMEC Earth & Environmental (2006a) p. 12*

12 *BGC Engineering Ltd. (2013) p. 23*

13 *BGC Engineering Ltd. (2014)*

14 *AMEC Environment & Infrastructure (2014a)*

15 *[Mine Personnel] (2014)*

16 *[Mine Personnel] (2014)*

17 *[Mine Personnel] (2014)*

18 *AMEC Environment & Infrastructure (2014a) p. 18*

19 *AMEC Environment & Infrastructure (2014a) pp. 18-19*

20 *Klohn Crippen Berger (2014a) p. 41*

21 *[Mine Personnel] (2014)*

22 *Moger (2014c)*

23 *See Appendix 1 Section 1.5*

24 *Marquis (2014)*

25 *AMEC Environment & Infrastructure (2014a) p. 24*

26 *[Mine Personnel] (2014)*

27 *Klohn Crippen Berger (2015a) p. 14*

28 *Mount Polley Mining Corporation (2014c)*

29 *Knight Piésold (1995a) Fig. 6.6*

30 *Knight Piésold (2006) p. 9*

31 *Knight Piésold (2008) Dwg. 225*

32 *Knight Piésold (2009b) p. 6; Dwg. 225*

33 *Knight Piésold (2011b) p. 6*

34 *Knight Piésold (2011a) Dwg. 225*

35 *Knight Piésold (2011a) p. 6*

36 *Knight Piésold (2009b); Knight Piésold (2011a)*

37 *Knight Piésold (2011b) p. 6*

38 *Klohn Crippen Berger (2015b) p. 133*

39 *AMEC Environment & Infrastructure (2012b)*

40 *Knight Piésold (2011a) Dwg. 225*

41 *AMEC Earth & Environmental (2011a) Dwg. 560.2011.05*

42 *AMEC Environment & Infrastructure (2012b) Fig. No. 2011AB.05*

43 *AMEC Environment & Infrastructure (2012b) p. 17*

44 *AMEC Environment & Infrastructure (2012c) Fig. No. 2012.05*

45 *AMEC Environment & Infrastructure (2014b) Dwg. 2013AB.04*

46 *AMEC Environment & Infrastructure (2014b) Dwg. 2013.05.01*

47 *Klohn Crippen Berger (2015a) p. 14*

48 *AMEC Environment & Infrastructure (2012c) Dwg. 2012.02*

49 *Mount Polley Mining Corporation (2013) p. 63*

50 *Knight Piésold (2011b)*

51 *BGC Engineering Inc (2013a) p. 5*

52 *BGC Engineering Inc. (2013)*

53 *Imperial Metals Corp. (2014)*

54 *Klohn Crippen Berger (2015b) p. 13*

55 *Mount Polley Mining Corporation (2007)*

56 *Mount Polley Mining Corporation (2014a)*

57 *Knight Piésold (1995a) p. 57*

58 *Ministry of Environment (2012a) p. 2*

59 *Klohn Crippen Berger (2015b) p. 133*

60 *Mount Polley Mining Corporation (2013) p. 4*

61 *BGC Engineering Inc (2013a) p. 17*

62 *Klohn Crippen Berger (2015b) p. 129*

63 *Ministry of Environment (2012a)*

64 *Mount Polley Mining Corporation (2006c)*

65 *Ministry of Environment (2012a) p. 3*

66 *Mount Polley Mining Corporation (2006c)*

67 *Ministry of Environment (2012a) p. 3*

68 *Ministry of Environment (2012c) p. 4*

69 *Frye (2015)*

70 *Ministry of Energy and Mines (2012)*

FINDINGS OF THE CHIEF INSPECTOR

11

11.1. RESPONSIBILITIES

MPMC has an obligation as the Permittee to perform in accordance with the *Mines Act*, the Code, and the *Mines Act* permit.

A responsibility is imposed on the mine manager for all matters occurring on the mine site, and in particular — but not exclusively — maintaining a safe working environment, maintaining the integrity of mine structures, and preventing uncontrolled discharge of mine waste or contaminants to the environment, all of which could cause harm in some form to employees, the general public or the environment.

In the British Columbia mining industry, the services of a qualified professional geotechnical engineer — including the EoR for such large structures as the TSF — are commonly met by a specialized engineering firm contracted by the mine manager.

RESPONSIBILITY

is imposed on the mine manager for all matters occurring on the mine site

The mine manager engages the EoR with an expectation of professional reliance. It is generally the responsibility of the client to ensure that the contractor is performing in a professional and capable manner. Likewise, the Regulator has an expectation of professional reliance on the advice, certification, and judgment of the EoR. It is the purview of the Association of Professional Engineers and Geoscientists of BC (APEGBC) to regulate the performance of its Professional Engineer (P.Eng.) members.

Similar to the engineering contractor, the construction contractor works on behalf of the Mine, and the mine manager retains the responsibility for adhering to the *Mines Act*.

The Regulator (the Chief Inspector of Mines) maintains a specific role with regard to the TSF, performing *Mines Act* permitting and inspections of the mine, and ensures that it is performing work in accordance with the *Mines Act, Regulation*, Code, and *Mines Act* permit. It does so by periodic on-site inspections and review of documents (in the case of the Mount Polley TSF, such records as as-built reports and Dam Safety Inspection reports). The Regulator seeks to ensure that such documents are approved and sealed by a P.Eng. In addition the Regulator relies on the professional engineer to indicate that construction has been carried out in general conformance with the approved plan. The Regulator does not serve as an additional professional resource for the mine, and does not provide professional advice or engineering design contributions.

11.1.1. FINDINGS

It is the responsibility of the Chief Inspector to make formal determinations regarding any event investigated pursuant to the *Mines Act*. A finding is a considered, objective conclusion issued by the Chief Inspector based on his assessment and consideration of the facts and analyses conducted as part of the investigation. This assessment was accomplished through the RCA as described in Chapter 10: conditions; events; and absent, defeated or failed controls identified through this objective analysis support the findings as summarized below.

FINDINGS

a finding is a formal determination of fact often informed by analytical opinion as determined by the Chief Inspector

Following the findings, Chapter 12 presents a series of lessons which emerged from the event and its investigation. Chapter 13 outlines the Chief Inspector's final recommendations from the investigation.

The Chief Inspector makes the following findings with respect to the breach of the tailings storage facility (TSF) at Mount Polley Mine on August 4, 2014.

IT IS THE FINDING OF THE CHIEF INSPECTOR THAT:

1 a structural failure of the Mount Polley Mine tailings storage facility Perimeter Embankment occurred at approximately 11:40 pm on August 3, 2014; that the failure led to a major and ongoing erosion breach at approximately 1:08 am on August 4, 2014; and further that the breach resulted in uncontrolled release of tailings and process water into the environment.

2 undesired consequences beyond the mine site resulted directly from the breach, affecting the environment, the mining industry, First Nations, and the citizens of British Columbia.

3 the structural failure of the embankment occurred because of three proximate causes: an uncharacterized glaciolacustrine unit in the native soil foundation of the dam structure; an over-steepening of the downstream slope of the dam, coupled with the constructed height; and an unfilled excavation at the toe of the embankment at the site of the failure.

4 the mechanism of the structural failure was a sliding failure through the lightly overconsolidated glaciolacustrine clay unit (UGLU) located approximately ten metres into the foundation. The failure caused the embankment crest to drop approximately 5 metres, and can be considered the initiating event of the breach of the tailings dam.

5 MPMC and its engineering consultants did not fully recognize and manage geotechnical and water management risks associated with the design, construction, factor of safety, and operation of the tailings storage facility.

Findings Relevant to Foundation Soils

6 adequate studies of the embankment foundation were not conducted on the Perimeter Embankment, and site investigations for the Perimeter Embankment did not meet generally accepted standards of practice for embankment structures. There was an assumed degree of certainty that the foundation soils were dense and strong, which was not supported by a robust understanding of the foundation characteristics.

7 initial site investigations at the Perimeter Embankment foundation did not include adequate geotechnical characterization of soils at depth. Further, no subsequent site investigations were conducted on the Perimeter Embankment until 2011; drillholes were widely spaced and were principally for the placement of instrumentation and the assessment of lower glaciolacustrine soils.

8 although the upper glaciolacustrine unit (UGLU) was detected during site investigations, its significance remained unrecognized, and the risk associated with the extent and characterization of strength of this layer was a proximate cause of the embankment failure. Multiple opportunities to review and characterize the foundation soils arose, either in response to queries by Government inspectors, or available in extant drillcore records; but these opportunities were unnoticed, ignored, and/or discounted.

Findings Related to Supernatant Water and Beach Adequacy

9 the structural failure of the embankment alone did not cause the breach, but coupled with the condition of the tailings pond — with insufficient beaches and too much supernatant water — a progressive erosional failure of the embankment rapidly widened into a complete breach.

10 adequate beaches could not be continuously maintained primarily as a result of surplus supernatant water.

11 an adequate water management plan did not exist. Mount Polley Mining Corporation failed in its management of the water balance with respect to long term planning, including site integration, effective treatment, discharge plans and permits. There was no qualified individual responsible for the water balance, and MPMC did not adequately characterize the risk of surplus supernatant water, which had been compounding since the mine reopened in 2005.

Findings Relevant to MPMC Management

12 it was the responsibility of Mount Polley Mining Corporation to maintain a safe structure, irrespective of the Mine's reliance on external geotechnical engineering expertise. Mount Polley Mining Corporation did not meet this responsibility.

13 delegation of engineering tasks to a contractor with the skills, knowledge, and abilities to perform a required task — even when the contractor is licensed and regulated as a professional engineer by APEGBC — does not release the Permittee from this responsibility. The responsibility resides with the mine; it cannot be delegated.

14 Mount Polley Mining Corporation did not recognize the risk of the excavation for the buttress foundation, resulting in a small reduction in the FoS. This work was not recognized as a substantial departure from the approved work plan by MPMC, and the Chief Inspector was not notified.

15 Mount Polley Mining Corporation did not identify or manage risks associated with changing Engineers of Record at the tailings storage facility.

16 concerns regarding steep slope, dam construction material availability, buttress subexcavation, and supervision were identified by employees but not elevated for action by MPMC management.

17 the mine failed to conduct a risk assessment, in accordance with Towards Sustainable Mining (TSM) guidelines developed by the Mining Association of Canada (MAC), which may have been sufficient to identify concerns about the steep geometry, the toe sub-excavation left open and unfilled, and the absence of sufficient site investigations.

Finding Relevant to MEM

18 the Regulator works within the bounds of professional reliance; but the implementation of professional reliance is not adequately structured or formalized in policy.

In addition to these findings of the Chief Inspector, additional conclusions and recommendations supporting the investigation and can be found in Appendix 3, Chapter 10: *Summary of Opinions in Support of the CIM Investigation*, by KCB.

11 FINDINGS OF THE CHIEF INSPECTOR

LESSONS LEARNED 12

The history of engineering is replete with examples of hard-earned lessons, often as an outcome of an industrial accident or disaster. Every bridge collapse or aircraft crash offers the opportunity to make improvements in operating practices, standards, and design that not only reduce the likelihood of similar events occurring in the future, but also advance the understanding of engineering across the sector. It would be irresponsible for any individual or organization involved — including Mount Polley Mining Corporation, the Regulator, the industry, the Mining Association of Canada, and professional organizations such as the Canadian Dam Association (CDA) and the Association of Professional Engineers and Geoscientists of BC (APEGBC) — to fail to learn, benefit and evolve from the equally hard-earned lessons of the Mount Polley TSF failure of August 4, 2014.

These lessons learned relate to:

- oversight, policy, practice, and organization broadly across the Mount Polley mine site (relating to management, communication, accountability, definition of roles and responsibilities, etc.);
- issues that could not be proven to have played a direct role in the event, but are suspected to be contributory;
- issues that have the potential to degrade safety at other tailings impoundments in the Province or beyond; and
- issues that stem from adherence to or interpretation of global, national, or industry standard practices demonstrated to be lacking in the mining industry.

12.1. LESSONS FOR THE MINE OPERATOR

While this section incorporates lessons learned specific to MPMC, the lessons are equally applicable to all mines in the sector.

- **Mine Development Planning**. The mine did not make use of best available practices (BAP) or life-of-mine planning in managing its site water balance and material for TSF dam construction. Water management appeared to be focused on short-term requirements: the TSF raises eventually became a recurring annual attempt to maintain adequate freeboard. Materials for dam construction were sometimes starved based on logistical difficulties and production planning that were not aligned with freeboard requirements and slope recommendations.
- **Water Management**. A substantial expansion of the mine's disturbed area footprint did not lead to effective management of increased site water volumes. Despite a chronic water surplus recognized by senior management, limited means to safely discharge water were developed. The pace and urgency of water treatment — critical to water discharge — did move forward, but were never sufficient. It took seven years to obtain a water discharge permit, but the Chief Inspector found no information suggesting there was action to simultaneously obtain water treatment infrastructure to address the chronic water surplus in a timely manner.
- **Mine Dam Safety Manager**. While there was a defined role for construction oversight of the TSF, there was no dam safety manager with the knowledge, skills, and abilities to be accountable for management of the TSF. This same role should also address accountability and authority for a synoptic, long-term, integrated perspective in water balance management.

- **Role of the Engineer of Record.** The role of the EoR was not well articulated or integrated with the responsibilities of the mine manager. Frequent changes of the EoR (the individual as well as the contract engineering firm) led to a loss of site-specific knowledge, and there was little effective continuity over the change of tenure from KP to AMEC. Broader lessons include communication, continuity of knowledge, and clear definition of the responsibilities of the EoR.
- **TSM Guidelines**. While MPMC asserted its compliance with the Mining Association of Canada's Towards Sustainable Mining (TSM) framework, a number of elements were missing in the MPMC submission. The value of a management system that supports the TSM framework cannot be underestimated; the structure, accountability, and perspective offered by TSM can minimize communication, coordination, and continuity issues in any operation.
- **Construction Reports.** The mine did not ensure that accurate, detailed TSF construction reports were maintained. Detailed construction reports in relation to the work on the PE buttress foundation would have supplied critical information either to the EoR (to perceive a risk of the open sub-excavation) or to MEM (to assist in the analysis of the nature of the organizational control failure).
- **Employee Contributions to Risk Recognition**. Risk education coupled with a process that encourages reporting and follow-up of concerns may increase the potential of effective risk management. Adequate recognition and characterization of risk should be an essential daily component for every worker on the mine. A fundamental understanding of situations that may influence health and safety needs to be an ongoing component of worker education. Such education starts at the crew tailgate safety meeting, continues through the effective work of the Occupational Health and Safety Committee (OHSC), and should be implemented as part of an educational curriculum for mine workers. This process needs to include the escalation of concerns or alerts from workers to management, and effective response of management to these concerns.
- **Mine Emergency Response Plan**. An effective Mine Emergency Response Plan (MERP) requires site integration and designated persons. The breach took place at a time with the least site supervision: in the early morning hours in the middle of a long weekend, when most of the management staff, and many employees, were not only off duty but unreachable. Conversely, it may have happened at the most fortunate time: when no one was at work at or below the breach or engaged in recreational activities on Polley Lake or Hazeltine Creek, particularly since no accurate tally of personnel on site was available, and there was no expedient means of communication with underground personnel.

  Employees who were onsite as the event was detected reacted to the best of their ability given their understanding and the availability of a mine emergency response plan. This improvised emergency response was required because the MERP was inadequate and out of date, and designates had not been named or trained on how to use the MERP. It was also evident that the MERP did not include a usable reference guide for action as the emergency developed. The MERP did not include any reference to emergencies involving the TSF; instead, it only contained a cross-reference to the OMS. The OMS was equally opaque as an emergency reference. There was no mention of downstream warnings. No practice exercise of the plan was required by MPMC. On the mine, at least five individual MERPs were maintained separately.

  This situation points to a broader need for more effective emergency planning, including inundation studies and disaster table-top exercises, at mines across the Province; training, including practice drills; and for MERPs that are actually effective in guiding response to events.

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12.2. LESSONS FOR THE MINING INDUSTRY

A disaster of the magnitude of the Mount Polley TSF breach has generated repercussions throughout the mining industry. It announces, in no uncertain terms, that the status quo is no longer acceptable. It offers a glimpse of the consequences of short-term planning, and the importance of oversight to integrate systems across the mining operation. These are hard-earned lessons that suggest a way forward.

- **Life-of-Mine Planning**. Life-of-mine planning, especially when applied to tailings storage and water management, is more effective than an ongoing series of annual design plans. While it may not be possible to design production and water management with certainty over the life of the mine, a life-of-mine planning frame of reference allows for early initiation of water management and discharge planning. Early development of discharge capacity is essential to water balance on mines facing water surplus conditions. A long-term, integrated, synoptic view of site water, tailings storage, material supply and delivery (such as rockfill) is essential to the successful operation and closure of tailings facilities.
- **Full Implementation of TSM**. In general, mining operations place significant reliance on external professional expertise, from geotechnical engineers and designers as well as through practice standards and guidelines from independent organizations. Professional reliance depends on working in partnership with external professional, rather than seeking means to avoid or delay implementation of their recommendations. Guidelines such as those developed in the Towards Sustainable Mining (TSM) program of the Mining Association of Canada (MAC) provide a framework of standards and protocols for responsible mine operation. Instituting these guidelines can build credibility for the mining operation, promote self-regulation, and achieve the expectations of the Regulator.
- **Effective Emergency Response Tools**. Developing tools that can serve as an immediate reference and roadmap to implement emergency response plans should be a priority at every mine. Placing these tools within reach of personnel, and providing sufficient training in their use, should also be incorporated into ongoing employee training. In addition, the practical applicability of emergency response should be evaluated, trained, and tested on an annual basis.
- **Risk Identification and Management**. Comprehensive risk assessment, management, and mitigation must be an ongoing component of all mine site activities. MAC should extend the OMS standard to include an update of risk assessment and risk management plans on an annual basis (or during any substantial change to design).
- **Role of Mine Dam Safety Manager**. Organizational structure played a role in the Mount Polley event. There was no single authority on site to manage and be accountable for the TSF; and since the TSF was inseparably bound to site water management, this single authority should have been accountable for water balance, management, and discharge planning. A person responsible for tailings dam safety, including a long-term, synoptic perspective on water and tailings management, should be the standard of practice for all facilities.
- **Independent Review**. The nature of the breach event speaks to the merits of independent review at multiple points in the life of the facility. Dam Safety Reviews were conducted too infrequently despite reminders from MEM. Independent review provides an additional set of expert eyes, and an opportunity to recognize design, construction, and other issues that might otherwise go unnoticed. Independent review should be sought out at design, site investigation, construction phase completion, and closure checkpoints. Review of as-built reports, annual safety inspection reports, and OMS updates presents another opportunity for independent review. In addition, an independent assessment of deviations from approved work plans or from standard practice could potentially catch operational errors before they affect mine safety.

- **OMS Guidelines**. Guidelines should be enhanced to require designation of a Mine Dam Safety Manager for each TSF; define roles and responsibilities of the manager as well as the EoR; develop TSF documentation systems that can be audited externally; develop means of implementing appropriate corporate management systems to integrate TSF safety into the existing health, safety and environment systems guidelines; and integrate risk assessment and risk management plans into annual OMS updates.

12.3. LESSONS FOR PROFESSIONAL ORGANIZATIONS

Professional organizations such as the Canadian Dam Association (CDA) provide guidelines for tailings dam safety; the Association of Professional Engineers and Geoscientists of BC (APEGBC) certifies professional designations of engineers and oversees their actions. Guidelines produced by professional organizations have in some cases been incorporated into regulatory requirements by specific reference. While the Mount Polley TSF breach caused some inevitable damage to the public's confidence in the engineering community, it also presents an opportunity to improve design and professional practice guidelines to reduce the likelihood of similar occurrences in the future.

- **Moving Practice Guidelines Nationwide**. The Professional Practice Guidelines prepared by APEGBC should be considered by all provinces. The most current relevant guideline is the Dam Safety Review Guideline (2014). APEGBC is currently preparing a guideline for site characterization of dams, as recommended by the Independent Expert Panel.
- **Engineering Integrity**. APEGBC and its counterparts in other jurisdictions should review professional practice guidelines around the potential conflicts between mining companies and the consultants who advise them. Maintaining professional engineering integrity that may run contrary to client expectations represents an ongoing challenge that APEGBC could potentially address.
- **Factor of Safety in Tailings Dams**. The Canadian Dam Association (CDA) provided technical specifications for FoS for embankment stability, which were incorporated into the Code. However, some ambiguity permitted misapplication of the FoS standards to the dam structure. Although the TSF had been in full use since its opening in 1998, a series of EoRs applied the construction FoS for dams during operation. Rewriting these specifications to exclude any ambiguity and to provide specific standards for tailings embankments would benefit the industry.
- **Post-Closure Guidelines**. CDA guidelines should also emphasize risk reduction at all stages of the TSF life cycle, with emphasis on landform design and reducing the risk of long term environmental legacy risk.
- **Consequence Classification**. The CDA also develops guidelines for consequence classification for dams. The Mount Polley TSF breach provides strong empirical evidence to assist in the refinement of the definition of the actual consequences of a failure in a dam with a specific set of characteristics. The consequences of the failure (see Section 10.7) were far-reaching, and posed more impact than the current guidelines suggest. The adequacy of the current consequence classifications should be reviewed to tailor the standards of practice attached to each consequence to these realities.
- **External Practice Guidelines**. CDA, MAC and APEGBC should evaluate and consider incorporating into their guidelines certain standards, whose absence may have contributed to the Mount Polley event. These include developing procedures for any actions that affect FoS: clear operating procedures, restriction on any deviations from plan, and requiring professional engineering presence on site during any construction that impacts FoS; guidelines or minimum standards for adequate site investigation; standards of practice for transfer of EoR, especially when the transfer involves changing engineering companies. Transfer of EoR may dilute the knowledge base, and such losses must be minimized.

12.4. LESSONS FOR THE REGULATOR

This investigation examined the role of the Chief Inspector as Regulator. While the Regulator is not the designer of the impoundment, it plays a role in ensuring safe design and operation.

MEM geotechnical inspectorate evaluates and issues *Mines Act* permits, conducts periodic geotechnical inspections, and reviews as-built reports and Dam Safety Inspection reports. The Regulator plays an important role but cannot assume responsibility for neither design of engineered structures such as tailings facilities nor construction oversight by approving or improving upon the work of the design engineers. By necessity, the Regulator must defer to the technical expertise and experience of the designer, who is, in turn, regulated and overseen by their professional association, in this case APBGBC.

Likewise, it is not realistic to expect that geotechnical inspections, no matter how frequent or thorough, will expose the risk of such events as those that occurred at Mount Polley. The purpose of these periodic inspections is to ensure compliance with the Act, Code, and permit conditions; identify hazards to health and safety; and review permit changes in mining structures as the mine develops.

There are a number of areas MEM can address to improve the safety of tailings facilities across the Province. These include the following:

- **Application of Elements of BAP and BAT**. The Regulator should use its best efforts to encourage the application of best available practices (BAP) and best available technologies (BAT) in mining operations. BAT for tailings storage should be applied to reduce risk as far as practicable. Although filtered tailings storage (or "dry stacking") is appropriate in some applications, the Chief Inspector recognizes that it may not be an appropriate technology, at its current state of refinement, for most low-grade, high-tonnage operations in BC or other areas challenged by climate and topography. Through the guidance of regulatory instruments, BAP and BAT in areas of site assessment and foundation characterization, water and water management, tailings management and storage, and closure landforms must be assessed for incorporation into the mining operations plan.
- **Workplan Deviations**. The Regulator should review and consider strengthening the Code section addressing substantial deviation from approved workplans (Section 10.1.11).
- **Incorporating Standards into Legislated Requirements**. Updates to standards and guidelines from professional organizations are not yet reflected in the Code. This evaluation should include the TSM protocols as well as other updates discussed in Section 12.3 above.
- **Risk Education**. There is an ongoing need for defined education of industry personnel in safe practices and identification of hazards as possible at the TSF. This need may be met by requiring training programs similar to those in place in the health and safety area. Training allows the front-line worker to escalate recognized concerns, and encourages management to be more responsive to risk identification, enhancing capacity in risk management.
- **Reconciling Competing Roles in MEM**. The Regulator faces multiple challenges in achieving its objectives, and the Mount Polley event is a microcosm of these often competing challenges. Many agencies have faced the same dilemma the inspectorate does: promoting and fostering the success of an industry while at the same time regulating it. The role of the inspectorate as well as its perception and understanding by industry must be refined and reinforced.
- **Resourcing the Inspectorate**. Support developing the internal capacities and skills to provide the geotechnical and health and safety inspectorate to adequately enforce the *Mines Act* and Code.
- **Investigative and Enforcement Tools**. The inspectorate does not have an ongoing capacity to investigate multiple significant events concurrently. There is a need to develop operational policies, develop a robust and effective enforcement structure, and build effective tools for the

inspectorate. There is also a need to address the current gap in the existing penalty structure in the statute, which limits the Regulator's compliance and enforcement tools.

- **Improved Integrated Investigative Capacity**. The inspectorate would benefit from expertise in investigation, and should reach out to other agencies across government (including such related organizations as the RCMP, WorkSafeBC, the Justice Institute of BC, and the Conservation Officer Service, MOE) to gain this expertise. The Mount Polley investigation provides a number of lessons that can be applied to future events: it initiated development of a scalable investigation approach (including independence of the Chief Inspector from external influences, isolation of regulatory versus prosecutorial investigation considerations, and the requirement for transparency —including FOIPPA — versus investigative integrity).
- **Records and Information Management**. The investigation of the breach informed MEM about the need for a comprehensive records management system. The Regulator's records and information management pertaining to mines does not adequately support operational, emergency response, investigative, or FOIPPA disclosure requirements. Such a system would assist MEM in regulatory oversight capabilities, investigations, project tasking, and providing formal documentation and recording of all decisions, inspections, communications with permittees, and responses. It would also enhance the ability of MEM to meet the expectations of the citizens of British Columbia for transparency and disclosure of all appropriate information pertaining to mine permits within the limitations of privacy considerations. Such a system could also support long-term, integrated decision making by the permittee and consulting professionals with responsibilities on mines.
- **Regulatory Trigger Events**. The TSF overtopping in May 2014 was a strong indication of the fragility of the water management situation at Mount Polley, and — in hindsight — may have been a missed opportunity for identification by the Regulator. This event could have triggered additional review and orders addressing water balance concerns and/or other actions; the unfortunate lesson from this particular event is that no regulatory measures in place at the time would have prevented the eventual failure of the embankment.
- **MAC Guidelines**. The Mining Association of Canada (MAC) has developed a comprehensive mine management program, Towards Sustainable Mining (TSM), that provides a framework of protocols and standards of practice for responsible, credible mining operations. The program invites voluntary participation from mine operators. Consideration should be given to requiring mine operators to implement the MAC TSM guidelines relating to tailings dam safety, and to submit to periodic audit by a third party.
- **Alignment of Regulatory Objectives**. While many objectives are congruent, there exists a fundamental dilemma between the regulatory priorities of the Ministry of Environment and the Ministry of Energy and Mines. MEM focuses on mine safety and the protection of land and watercourses; MOE focuses on environmental protection for the receiving environment and the regulation of mine discharges. In some circumstances, such treatment may not be practical or realistic given current technology and risk to the environment. Instead, risk of accidental discharge was governed in part by accumulation of surplus water in the TSF, which could be addressed only through discharge. The breach led to a failure in both ministries' key objectives: safety, productivity, and water quality. Collaboration between the Regulators, involving the industry and encouraging innovation at large, is essential to address the urgency of improving the technology of water treatment and the process of permitting.

RECOMMENDATIONS OF THE CHIEF INSPECTOR 13

This chapter lists the Chief Inspector's recommendations emerging from the investigation of the TSF failure at Mount Polley Mine on August 4, 2014. Recommendations comprise the ultimate outcome of the Root Cause Analysis (RCA) described in the findings of the Chief Inspector in Chapter 11, and in lessons learned, set out Chapter 12.

An effective recommendation will, once implemented, reduce the likelihood of a similar event by:

- eliminating a hazard;
- creating an engineering barrier to minimize risk through design;
- producing an administrative barrier to minimize risk through procedure;
- introducing or strengthening controls to minimize risk by inserting hazard identification and correction; or
- developing administrative procedures including standards and guidelines, regulations, and related training requirements to minimize risk.

The Chief Inspector has identified a series of seven recommendations, directed to the mining operator (MPMC), the mining industry, professional organizations and the Regulator.

13.1. RECOMMENDATIONS FOR THE MINING OPERATOR

13.1.1. RECOMMENDATION 1: PROPONENT GOVERNANCE

RECOMMENDATION 1-1: MINE DAM SAFETY MANAGER

Any mine with tailings storage facilities (TSFs) should have a qualified individual designated as a mine dam safety manager responsible for oversight of planning, design, operation, construction and maintenance, and surveillance of the TSF, and associated site-wide water management. The individual must possess the requisite knowledge, skills, and abilities to perform these responsibilities. Functions of this role may include coordinating relevant parties involved with the TSF (*e.g.,* consultants, contractors); ensuring appropriate approval of all activities has been obtained; maintaining compliance with applicable permit conditions, *Mines Act*, and Code; life-of-mine planning for water, waste and tailings management; site integration; integration of the OMS and MERP; and consideration of potential factors that may influence tailings dam safety.

A qualified individual in this this role may prevent a TSF failure or breach by anticipating, recognizing and preventing conditions from developing that could impact the safety of the tailings dam.

RECOMMENDATION 1-2: WATER BALANCE MANAGEMENT

Water management and water balance issues for mining projects must be designed by a qualified professional. These issues require the integration of relevant mine departments. Mine operators should designate a responsible qualified individual to oversee site-wide water management and water balance.

A qualified professional design and a qualified individual to oversee the water balance and water management plan will be able to anticipate site conditions and long-term considerations towards water management. Effective water management may prevent a structural failure from developing into a breach.

RECOMMENDATION 1-3: TSF OPERATIONS, MAINTENANCE AND SURVEILLANCE MANUAL

The mine manager should ensure the Operation, Maintenance and Surveillance manual (OMS) required by the Code for all impoundments adheres to applicable CDA and MAC guidelines. Additional guidance for the OMS should include incorporation of an annual risk assessment/risk management plan and relevant findings of an independent technical review board. The OMS emergency response section should be written so that it can be effectively utilized during an emergency, and should be integrated into the Mine Emergency Response Plan (MERP).

An effective and well-implemented OMS will make all related personnel more attuned to hazard identification and mitigation, knowledgeable in potential downstream consequences, and capable in emergency response.

RECOMMENDATION 1-4: MINE EMERGENCY RESPONSE PLAN

The mine manager must ensure that the Mine Emergency Response Plan (MERP) adheres to applicable regulations, is maintained on a regular basis for currency, incorporates appropriate response measures to emergencies including those involving the TSF, and is written and distributed in such format as to serve as a procedural guide during an emergency or other event. Site emergency response plans should be practiced and integrated across possible eventualities on the mine site allowing for coordination of resources. Training should also be provided to improve effective emergency response.

An effective MERP gives responding site personnel an actionable plan to implement during an emergency, which can be instrumental in protecting lives and the environment.

RECOMMENDATION 1-5: RISK RECOGNITION AND COMMUNICATION

All mine personnel have a role to play in recognizing and reporting risk conditions, especially those that could affect health, safety and environmental protection; and should be educated in the recognition of conditions and events that could impact TSF safety or contravene applicable permit conditions and regulations.

An effective reporting mechanism for employees' safety or environmental concerns on the mine site (whether directly or anonymously) should be established, implemented and monitored.

Personnel educated in risks associated with TSF-related activities can offer ongoing insight into conditions that may compromise the safety of the structure.

13.2. RECOMMENDATIONS FOR THE MINING INDUSTRY

13.2.1. RECOMMENDATION 2: TSF DESIGN

RECOMMENDATION 2-1: DESIGN OBJECTIVES

Tailings storage and water management systems and structures should be designed for worker and public safety and the protection of the environment. TSF design should incorporate a comprehensive feasibility assessment that considers technical, environmental, social, and economic aspects of the mining project in sufficient detail to support the submitted design. An assessment of the applicable best available technologies and best available practices for the project should be incorporated into the design considerations to reduce the risks associated with the TSF for life-of-mine from construction to post-closure.

Design based on a comprehensive feasibility assessment will reduce the likelihood of unexpected conditions developing that could negatively impact the safety of the structure.

RECOMMENDATION 2-2: INDEPENDENT TECHNICAL REVIEW BOARD

Mines with impoundments should each develop independent technical review boards (ITRB) to provide additional perspectives on site investigation, site selection, design, construction, maintenance, operations, surveillance, water management and closure. The ITRB's review should provide additional oversight to include BAP/BAT for tailings storage and water management. The ITRB would include one or more individuals with appropriate engineering expertise with similar structures; and its opinions should be integrated into the mine's TSF management system. The requirement for an ITRB should be determined and incorporated into the Code.

ITRBs will strengthen oversight and risk management by providing review, professional opinion, and feedback to the EoR and the mine regarding the TSF.

13.3. RECOMMENDATIONS FOR PROFESSIONAL ORGANIZATIONS

13.3.1. RECOMMENDATION 3: PROFESSIONAL AND ASSOCIATION STANDARDS

RECOMMENDATION 3-1: PROFESSIONAL RELIANCE STANDARDS

The Chief Inspector recognizes the necessity of reliance on professional practice for the design, construction, operation and closure of mines and mine facilities. The Regulator does not design the mine or associated structures, and thus is reliant on the professional practice of the designer.

Reliance on professional practice requires that the organizations overseeing the professionals or developing guidelines and standards for the professional community incorporate best available practices into their oversight. Organizations supporting such standards include:

- Association of Professional Engineers and Geoscientists of BC (APEGBC). Responsibilities include professional practice guidelines. APEGBC should develop specific practice guidelines for site investigation, roles and responsibilities of the Engineer of Record (EoR), standards of practice for transfer of EoR, especially when the transfer involves changing engineering companies, and standards for engineering presence on site during construction.

- Mining Association of Canada (MAC). Responsibilities include participatory guidelines applicable to tailings and water management, including applicable safety, operations, design, construction, surveillance, and planning; and corporate governance standards of practice. MAC should review existing guidelines to define the roles and responsibilities of the mine dam safety manager, and should develop guidance on what is required to document the tailings management system such that it can be audited by a qualified third party such as the International Standards Organization (ISO).
- Canadian Dam Association (CDA). Responsibilities include the ongoing development of design guidelines for water and mining dams. CDA should update safety guidelines to reduce ambiguity, and develop specific guidelines for mining embankments which recognize the continued changes and raises during the life of the TSF and the consequence classification associated with a tailings dam failure.

Strengthening standards of practice will enable better design, construction, and operation of impoundments, improve governance, and establish benchmarks to evaluate these practices.

RECOMMENDATION 3-2: INTEGRATION OF STANDARDS

The Regulator should consider and incorporate as appropriate guidelines from these external associations as applicable and consistent with MEM objectives.

The Regulator will be able to incorporate improved standards and guidelines to better align with appropriate professional and industry practices.

13.4. RECOMMENDATIONS FOR THE REGULATOR

13.4.1. RECOMMENDATION 4: REGULATOR FUNCTIONS

RECOMMENDATION 4-1: REVIEW OF THE CODE

MEM should undertake a comprehensive review of the Code to ensure that the lessons learned and recommendations from this report are fully considered and appropriately incorporated; and that all relevant standards and guidelines from external bodies (such as MAC, CDA, and APEGBC) are fully considered in the review as appropriate.

Enhancements to the Code will assist the inspectorate in the enforcement of necessary management and engineering standards and guidelines.

RECOMMENDATION 4-2: LIFE-OF-MINE PLANNING FOR PERMITTING

Short-term, incremental *Mines Act* permit amendment applications can obscure life-of-mine conditions and long-term risks. The Regulator should ensure a perspective that spans the life of the mine be considered for *Mines Act* permit applications, while acknowledging that the nature of mining frequently requires changes to the life-of-mine plan.

Requiring life-of-mine planning in TSF design and the permitting process will enhance the robustness of the overall design of proposed structures.

RECOMMENDATION 4-3: INVESTIGATION, COMPLIANCE AND ENFORCEMENT REVIEW

The Regulator must enhance its investigative capacity, as well as its ability to exercise its existing compliance and enforcement authority under the *Mines Act* and Code. A supported director-equivalent position specific to investigation, compliance and enforcement should be established to evaluate and oversee these roles. This oversight should extend to applying recommended standards to the Regulator's compliance and enforcement function. A full range of regulatory tools, such as incentives, administrative penalties, outside agency collaboration and other best practices should be considered.

Improved investigative and enforcement capacity will enhance the ability of the Chief Inspector to increase compliance and achieve greater safety at mines, improve industry practices, and lead investigations in the future.

RECOMMENDATION 4-4: GEOTECHNICAL OVERSIGHT

The Regulator has a responsibility to oversee the decisions of the EoR. The Regulator must maintain sufficient technical capacity to conduct appropriate oversight of the professional opinions on which it relies. A Regulatory Dam Safety Manager dedicated to the coordinated regulatory oversight of tailings dams in the Province could be responsible for ongoing policy development, technical review, and inspection capacity as it relates to tailings impoundments.

Effective oversight of professional reliance in the design, maintenance, and operation of tailings impoundments will increase compliance with engineering and operational standards, reducing risk in tailings storage facilities across mines in the Province.

RECOMMENDATION 4-5: ORGANIZATIONAL REVIEW OF INSPECTORATE

There exists an ongoing need to adequately support the increased tempo of review, monitoring and inspection that would be placed on MEM's inspectorate. It is recommended that a comprehensive internal review of operational and business practices be conducted.

An organizational review of the Inspectorate is warranted by the scope and urgency of the recommendations of this report, and will strengthen MEM's ability to fulfill the Chief Inspector's obligations to the citizens of BC.

13.4.2. RECOMMENDATION 5: STRENGTHENING RECORDS MANAGEMENT

RECOMMENDATION 5-1: INTERNAL RECORDS MANAGEMENT

A formal MEM management system of documentation for all mines from development to post-closure should be established. The system will assist the Chief Inspector in integrating regulatory oversight capabilities; assist with investigation, project tasking, formal documentation and indexing; and enhance the ability of MEM to meet the expectations for transparency and appropriate disclosure within the limits of privacy considerations.

An effective records management system will support long-term, integrated decision making by the Regulator, the permittee and consulting professionals.

13.4.3. RECOMMENDATION 6: REGULATORY INTEGRATION

RECOMMENDATION 6-1: ALIGNMENT OF REGULATORY OBJECTIVES

Agency objectives (environmental protection, worker health and safety, facilities integrity) overlap but are not always integrated. MOE and MEM interests, disciplines and standards should be reviewed for alignment opportunities to support timely and effective program outcomes while optimally fulfilling the mandates of both agencies.

RECOMMENDATION 6-2: PERMITTING PROCESS ALIGNMENT

Separate permitting processes for MEM and MOE should be reviewed for opportunities to integrate and align these processes as appropriate to avoid duplication and increase efficiencies. There should be a mechanism to flag each agency's participation in the process to ensure that risks, such as those related to the discharge permitting process, are adequately characterized and prioritized.

13.4.4. RECOMMENDATION 7: FOSTERING INNOVATION

RECOMMENDATION 7-1: COLLABORATIVE EDUCATION

MEM, the industry, professional organizations, and educational institutions should continue to seek new collaborative opportunities to foster education (including formal academic, onsite or online employee-focused, public-facing, and professional continuing education). This initiative could include the availability of standards for education to better define the knowledge, skills, and abilities for various accountabilities within mining; and to increase the knowledge base, information sharing, and innovation. MEM could ensure that resources are allocated to enable the implementation of this objective.

RECOMMENDATION 7-2: RESEARCH AND DEVELOPMENT

Current technologies in tailings processing, dewatering, and discharge water treatment have not achieved a sufficient level of technical and economic feasibility in many projects. Both government and industry should support research and development efforts to improve these technologies for practical application.

Alignment of these recommendations with the findings and lessons learned in this report were developed by the Chief Inspector.[1]

13.5. INDEPENDENT EXPERT PANEL RECOMMENDATIONS

While the Chief Inspector's investigation was conducted in isolation from that of the Independent Expert Panel, the recommendations from both investigations overlap. Some of the recommendations from this investigation reflect the Chief Inspector's mandate to investigate the root causes — in terms of organizational processes, policies, and behaviours, of the major parties in the TSF failure event — which extend beyond the Panel's terms of reference. The following table summarizes the alignment of the two authorities' recommendations.

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13.6. NEXT STEPS: TOWARD A SAFER MINING INDUSTRY IN BRITISH COLUMBIA

As government, industry and others prepare to respond to the Chief Inspector's recommendations, action in response to the Mount Polley dam breach is already under way. For example, the Province has accepted all the recommendations of the Independent Expert Engineering Panel and has begun working with the mining industry, unions and First Nations to conduct a major review of the Code. The review is focused on a number of areas, including:

- Application of best available technologies (BAT) and best available practices (BAP) in mining
- Enhancing validation of safety and regulation of all phases of a TSF
- Improving dam safety and TSF management requirements

The BC Environmental Assessment Office has established additional requirements for evaluating tailings management options for proposed major mines in BC. It has also taken steps to ensure that best available technologies will be part of the environmental assessment process.

Across BC, all mines in the Province were ordered to conduct accelerated Dam Safety Inspections and assess the safety of their impoundments. APEGBC, which represents professional engineers and geoscientists, is developing professional practice guidelines for dam site characterization assessments, to help ensure that future dams are built to consistent safety standards. CDA and MAC are likewise moving forward with revisions to their guidelines.

These steps suggest that all affected parties are willing and able to work together to act on the lessons learned from the Mount Polley dam breach, helping to improve the safety of workers, communities, First Nations, and the environment.

The recommendations of the Chief Inspector will continue to focus the attention and commitment of government and the mining community to build a safer, more sustainable industry in BC.

FOOTNOTES

1 *Ministry of Energy and Mines (2015c)*

BACK MATTER

REFERENCES

APPENDIX 1: ACTIONS OF THE CHIEF INSPECTOR

APPENDIX 2: ASSESSMENT OF FAILURE MECHANISM

Prepared by Kohn Crippen Berger and incorporated by reference. The full document is available online at the following web address: *www.gov.bc.ca/mountpolleyinvestigation*

Printed copies of the *Assessment of Failure Mechanism* report include the report's text and initial appendices. All appendices (the Reference Documents and Drawings) are available online at the address above.

The *Assessment of Failure Mechanism* report also relies on field investigations and supporting laboratory testing published in *Progress Reports* 2 and 4 (the final versions of draft *Progress Reports* 1 and 3), which are incorporated by reference into this Appendix. The *Progress Reports* are also available online at the address above.

APPENDIX 3 SUMMARY OF OPINIONS IN SUPPORT OF CIM INVESTIGATION

Prepared by Kohn Crippen Berger and incorporated by reference. The document is available online at the following web address: *www.gov.bc.ca/mountpolleyinvestigation*

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Cited references that are part of the Chief Inspector's investigation database are identified by their 4-digit document identifier, DOC*nnnn*. References in this database are available for review via Internet-based links. On the softcopy version of this report, the links are embedded into DOC number. Readers of the hardcopy version of this report may refer to *www.gov.bc.ca/mountpolleyinvestigation* for links to individual documents. Interview statements and other documents withheld subject to FOIPPA cannot be referenced from this report and are marked "*withheld*."

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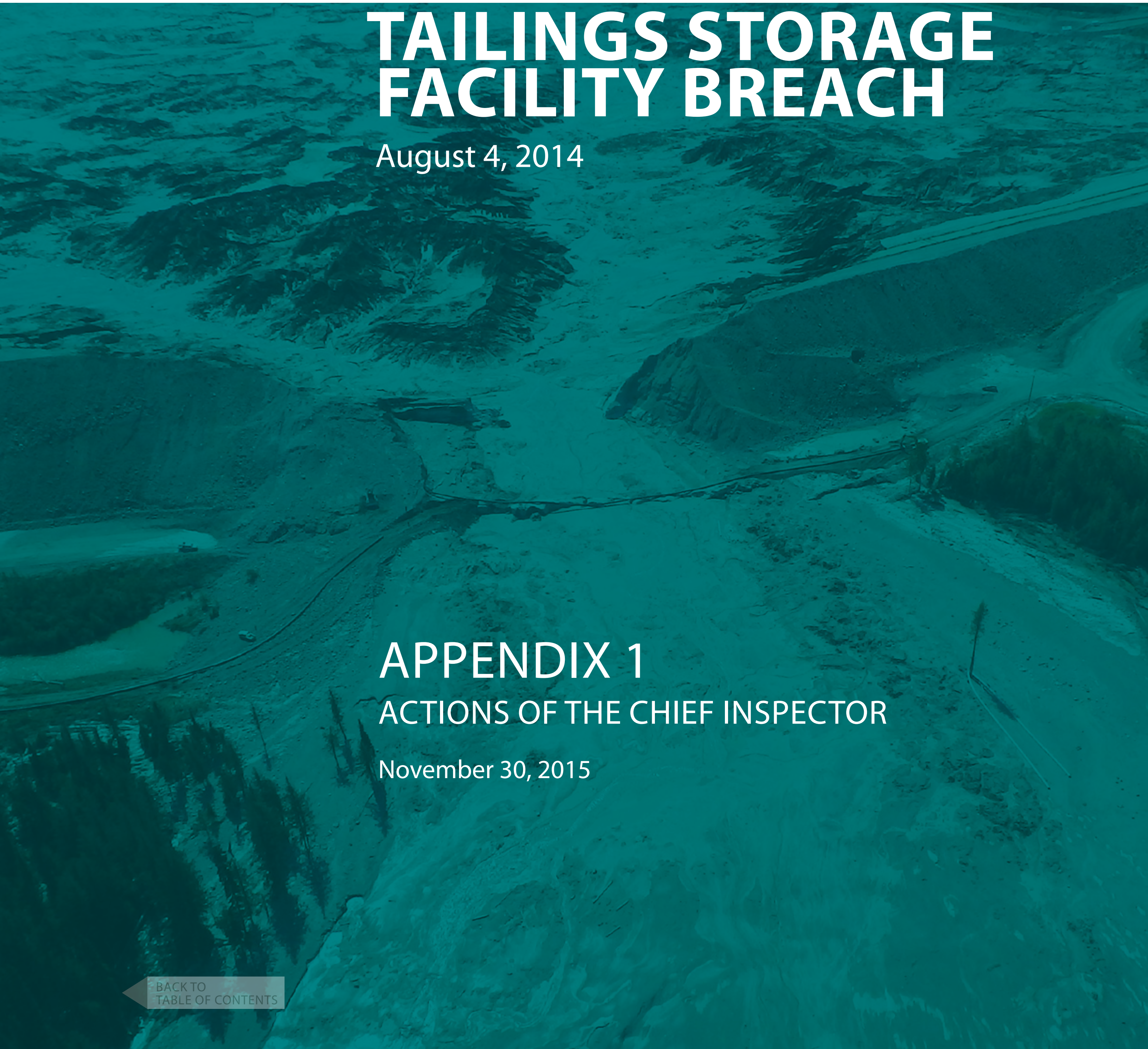
Mining and Mineral Resources Division
Ministry of Energy and Mines

MOUNT POLLEY MINE
TAILINGS STORAGE FACILITY BREACH

August 4, 2014



APPENDIX 1
ACTIONS OF THE CHIEF INSPECTOR

November 30, 2015

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APPENDIX 1 ACTIONS OF THE CHIEF INSPECTOR

This attachment documents the actions of the Chief Inspector of Mines (Chief Inspector) subsequent to the breach of the Mount Polley TSF on August 4, 2014. It describes the orders to all tailings dam operators in the Province, actions carried out in response to the recommendations of the Independent Expert Panel, the launch of a comprehensive review of the *Health, Safety and Reclamation Code* ("the Code"), and health and safety inspection actions. The chapter concludes with documentation of all orders issued to Mount Polley Mine following the breach on August 4, 2014. These actions supported the mandate of the Chief Inspector to reduce the risk of a similar event occurring in BC.

1. DAM SAFETY INSPECTION ORDER

The Chief Inspector issued orders on August 18, 2014, to all mining companies in the Province with permitted tailings dams in response to the Mount Polley event. The Chief Inspector ordered:

- The deadline for 2014 Dam Safety Inspections (DSIs) be accelerated from March 31, 2015 to December 1, 2014;
- Those inspections be reviewed by an independent, qualified, third-party professional engineer from a firm not associated with the tailings storage facility;
- The dam's consequence classification be reviewed by a third party; and,
- For dams with a consequence classification of high, very high or extreme: the Emergency Preparedness and Response Plans (EPRP) be reviewed, tested and updated as required.

CHIEF INSPECTOR ACTIONS

to enhance TSF embankment safety across BC -- and at Mount Polley

The third-party reviews (TPR) were to include the reviewer's comments on the overall condition and consequence classification of the dams as well as the reviewer's recommendations to improve the overall safety of the tailings storage facility.

All mines with High to Extreme consequence classifications conducted a Dam Break Inundation Study, and updated and tested their Emergency Preparedness and Response Plans as required by the Chief Inspector's orders. Through these exercises, the mine managers and responding agencies have a better understanding of their emergency management procedures and requirements.

The Chief Inspector also ordered that companies submit letters:

- outlining commitments for completing the recommended work proposed in the DSI and TPR reports, along with a schedule for implementing that work.
- summarizing their Emergency Preparedness and Response Plan test and any identified gaps and lessons learned from that test. "The orders expedited the normal annual Dam Safety Inspection (DSI) reporting schedule from March 31, 2015 to December 1, 2014.

According to the contractor's report, "the intent of the orders was to provide an overall picture of dam safety in the Province of BC, recognizing that the orders, and associated document submissions, provide information on a component of a much larger dam safety framework.

"The general findings of the review are as follows:

- Good response from mines to fulfill the Chief Inspector's orders by the specified time
- The majority of reports were deemed to satisfy the orders, some with additional information required;
- The dam safety inspections and third party reviews did not identify immediate safety concerns at any of the tailings storage facilities in the province;
- mine managers have provided commitments to complete any necessary maintenance or repairs;

- Mines with a High to Extreme consequence classification were required to conduct a Dam Break Inundation Study, and to update and test their EPRP. Through these exercises, the mine managers and responding agencies have a better understanding of their emergency management procedures and requirements, and mining companies are able to identify gaps and incorporate lessons learned into the EPRPs; and,
- All outstanding requirements have been documented in the Chief Inspector's response letters to the mine managers and will be followed-up for compliance."

The completed review and inspections have been posted online.

The Chief Inspector engaged First Nations, sharing the information obtained through the Dam Safety Inspections between February and April, 2015. There were 15 meetings involving 19 First Nations held throughout the Province.

2. ACTIONS PURSUANT TO EXPERT PANEL RECOMMENDATIONS

An Independent Expert Panel, established by the Government of BC through the Ministry of Energy and Mines together with the Williams Lake Indian Band and the Soda Creek Indian Band, investigated and reported on the Mount Polley Tailings Storage Facility breach. The Panel concluded its investigation and issued a final report on January 30, 2015, setting out a series of seven recommendations, which Government has accepted.

In response to the Panel recommendations, the Chief Inspector ordered all operating mines with tailings dams, and all closed mines with tailings dams classified as significant or higher consequence classification, to provide a letter of assurance by June 30, 2015 to confirm whether materials such as glaciolacustrine clays similar to those at Mount Polley exist in the foundation of any of their dams. If those materials are present, the letters must also confirm whether sufficient investigations and testing were completed to properly understand the strength and location of those materials, and whether the dams were designed to account for those conditions.

In addition, the Chief Inspector order included a requirement for an assessment of water balance adequacy and filter adequacy. If any gaps were identified, a plan and schedule for addressing these issues was required to be submitted.

Proponents for new mines are being asked to evaluate the conclusions and recommendations of the Panel and to indicate how these were considered for the proposed project. Finally, the Chief Inspector has initiated a comprehensive review of the Panel's recommendations in terms of its relation to the existing Code, and potential means of reconciling the Panel recommendations with Code updates.

3. MINES ACT PERMITTING

In December 2014, following emergency work by MPMC to mitigate further release of tailings subsequent to the breach, the Deputy Chief Inspector approved an amendment to the MPMC *Mines Act* permit to allow the company to begin repairing the breach in the TSF. The *Mines Act* permit amendment process involved a detailed technical review of the permit application by the Mine Development Review Committee (MDRC) including consultation with First Nations, the surrounding community, and other ministries.

On July 9, 2015, the Deputy Chief Inspector approved an amendment to the MPMC *Mines Act* permit to allow the company to conduct a restricted restart of mining operations at Mount Polley, subject to water and tailings management capacity. The restricted restart under the *Mines Act* (and a parallel *Environmental Management Act* permit) specifically prohibits use of the TSF; requires long-term mining and reclamation plans, including TSF reclamation plans, by September 30, 2015; and requires an updated water management plan by December 31, 2015.

4. HEALTH, SAFETY AND RECLAMATION CODE REVIEW

A comprehensive review of the *Health, Safety and Reclamation Code* for Mines in British Columbia (the Code) will be undertaken. A review committee will be chaired by the Chief Inspector and will include an equal number of nominees from mine labour unions, First Nations and mine operation management. The committee will recommend how best to fully implement the Panel's recommendations and the recommendations from the Chief Inspector's investigation that relate to the Code.

The TSF portion of the Code review is expected to be completed in early 2016 and revisions could be legally in force by mid-2016. The health and safety technical review is expected to continue through 2016 with all revisions complete and in force by spring 2017.

5. ORDERS ISSUED TO MOUNT POLLEY MINE

The Chief Inspector and his designees issued a number of orders to MPMC following the breach. These orders were issued under the authority of the *Mines Act*, and were issued subsequent to onsite inspections of Mount Polley Mine.

The Chief Inspector maintained a continuous presence of inspectors at Mount Polley following the breach to ensure work was carried out in accordance with the Code. The on-site inspectors' role focused on risk prevention through increased oversight and communication with MPMC during remediation and stabilization activities.

While a number of orders relate directly to the breach event, others address broader health and safety issues on the mine site. These orders are relevant to the investigation in that they develop a narrative of ongoing challenges in operating performance with respect to worker health and safety. This ongoing challenge across multiple mine operation areas informed the Chief Inspector's investigation. At the time of publication of this report, MPMC is working with MEM to address these deficiencies to ensure a safe and healthy work environment for future operations.

INTERNAL INVESTIGATION ORDER

On August 11, 2014, the Chief Inspector issued a letter to Mr. Dale REIMER, Mine Manager of MPMC, summarizing the directions transmitted verbally and via email in the week following the dam breach. The Chief Inspector indicated that the mine manager had "a responsibility to conduct a comprehensive investigation of the root cause(s) of the event." The terms of reference of the required investigation included the following:

"(a) Pursuant to Part 1.7.1(4) of the Health, Safety and Reclamation Code for Mines in British Columbia (Code), the Mine Manager shall ensure that the investigation is carried out by persons knowledgeable in the type of work involved as well as the co-chairpersons of the OHSC or their designates.

(b) Pursuant to Part 1.7.2 of the Code, on completion of the investigation the Mine Manager shall prepare, for the [Chief Inspector], a report that:

a. to the extent practicable identifies the causes of the accident,

b. identifies any unsafe conditions, acts, or procedures which contributed in any manner to the accident,

c. makes recommendations which may prevent similar accidents, and

d. is forwarded to the OHSC.

(c) It is requested that the investigation report be submitted to the Chief Inspector no later than January 15, 2015."

INVESTIGATION COMPLIANCE ORDER

The August 11 letter also reminded MPMC that the Chief Inspector "will be conducting a separate investigation of this incident. Pursuant to Section 15(7) of the *Mines Act*, and the Mine Regulation, you will be required to provide full access to all areas of the mine site and all relevant information."

REMEDIATION ORDER

On August 11, 2014, the Chief Inspector issued the following order in writing to Mr. Dale REIMER, mine manager of MPMC:

"Pursuant to Section 15(4)(d) of the *Mines Act* the Mine Manager shall undertake to remediate the dam failure in a manner that ensures the future stability of the tailings storage facility and prevents further release of tailings."

PERMIT AMENDMENT ORDER

On August 11, 2014, the Chief Inspector issued the following order in writing to Mr. Dale REIMER, Mine Manager of MPMC:

"The current condition of the tailings impoundment since the dam breach of August 4, 2014, represents a significant departure from the approved work system and reclamation plans for the Mount Polley Mine. Thus, pursuant to Section 10.1.11 of the Health, Safety and Reclamation Code, the Mine Manager shall submit a *Mines Act* Permit Amendment Application for the remediation of the dam failure. The application, including detailed designs, must be submitted by May 31, 2015 to the Chief Inspector for review and approval."

In addition to the order, the Chief Inspector "requested that a status update on the remedial plan and a schedule for implementation of the remedial works be provided to the Chief Inspector by January 15, 2015."

SCENE PROTECTION ORDER

On August 21, 2014, Senior Inspector of Mines Stephen ROTHMAN issued the following order in writing to Dale REIMER, Mine Manager of MPMC:

"It has been discussed and observed that the current engineered design of the coffer dam is within close proximity of the upstream toe of the remaining tailings pond dike; in particular, the breeched *[sic]* areas of the dam which need to be isolated throughout the investigative process. As per our discussion today, the area both upstream and downstream on both sides of the breech at the Mount Polley Mines TSF shall not be disturbed during the investigative process. The mine manager shall ensure the scene is protected by including in the design, a set-back distance that shall be maintained throughout construction to preserve the original dike in its found condition. The mine manager is asked to extend the flagging to expand the protected area as soon as the Polley Lake - discharge line is removed."

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STOP WORK ORDER

On September 7, 2014, Senior Inspector of Mines Greg McLEAN issued the following written order to Dale REIMER, Mine Manager of MPMC, to document the verbal order issued on the same day:

"At 8:54am on Sept.7/14, a Caterpillar Excavator was observed, by myself and Inspector Cheryl POCKLINGTON, removing a loaded bucket from the toe of the tailings dam at N 52.51992 W 121.59454 *[these coordinates are within 50m of the dam breach]*. Pit Shifter, *[mine personnel]*, was immediately requested to attend the site and was informed by myself this activity of removing any materials from the dam will cease and desist immediately and no further excavation of the tailing dam toe shall take place without the expressed approval of a geotechnical engineer. Excavation was ceased at the time of the verbal order. As per HSR Code 10.1.15, 10.1.8, 1`0.5.1, 10.5.2, 10.6.7, all tailings storage facilities shall meet the requirements of the Canadian Dam Association, Dam Safety Guidelines. The manager shall ensure that no excavation on the toe of a tailings dam occurs without the approval of an appropriate professional engineer."

EMERGENCY RESPONSE PLAN ORDER

On September 11, 2014, Senior Inspector of Mines Cheryl POCKLINGTON issued the following written order to Dale REIMER, Mine Manager of MPMC, on the basis of a review of the Mount Polley Mines Mine Emergency Response Plan, 2014:

"As per HSR Code 3.7.1, the mine shall develop and file with the chief inspector, a Mine Emergency Response Plan which shall be kept up-to-date and followed in the event of an emergency. The Mine Emergency Response Plan shall contain all of the elements required in the *Mine Emergency Response Plan Guidelines for the Mining Industry*. The MERP was found to contain commitments to some of the elements as outlined in the Guidelines, but did not lay out specific content to speak to the elements as they pertain to Mount Polley operations. This includes but is not limited to; the roles and responsibilities for nightshift/weekend/holiday coverage, roles and responsibilities outside of those defined within the "emergency control group" and emergency planning for possible impoundment failures such as a tailings dam. Essential maps, mine plans, escape routes and phone call-down lists were also not available. Although the title page indicated 2014, SOPs within the document were dated February 2005. An actual revision date on the plan was not indicated. Conversations with workers revealed poor knowledge about emergency responsibilities and of the content of the plan. This plan is out of date and not consistent with the elements contained within the Guidelines. The manager shall ensure a revision is completed without delay. It is recommended the OHSC be involved in this process. Once complete, training for all identified key personnel shall take place and shall be documented. The updated plan and training of all key personnel shall be completed by October 2, 2014. All persons who may be required to access the plan shall be able to state verbally their role and responsibilities and will know where to find and activate it. All response plans shall be organized in a central document or location with any older copies removed from circulation. In the interim, key personnel and their after-hours designates shall be identified immediately and apprised of their roles and responsibilities in the event of an emergency. The existing MERP should be used for this and a record shall be kept of this interim training."

HEALTH AND SAFETY INSPECTION ORDERS

On December 5, 2014, Chief Inspector Al HOFFMAN issued a series of written orders to Dale REIMER, Mine Manager of MPMC, on the basis of an inspection of the mine site conducted on November 24. The inspection was conducted by Rolly THORPE, Carina DOYLE, Caroline NAKATSUKA, Greg MCLEAN, Emmanuel PADLEY, and Rory CUMMING. Although none of the orders were directly related to the TSF, each addressed a deficiency in worker health or safe operations on the mine site. The orders are summarized in the following table.

Section of HSR Code Contravened	Order
1.9.1	Remediate and repair mill toilet facilities, using services of licensed professional, to eliminate overflow of sewage into mill.
1.9.1, 2.3.3	Assess and correct sitewide storage of chemicals; properly dispose of outdated chemicals; store acids and temperature-sensitive chemicals safely.
1.9.1, 2.1.1	Submit written safe work procedure for working with corrosive reagents and repairing reagent lines/tanks.
1.9.1, 2.3.6, 2.1.1	Ensure lead fumes and dust are disposed of to avoid worker exposure; conduct risk assessment and management plan for hazardous materials collected in scrubber systems; ensure flammable vapours collected in ventilation system do not pose risk of fire or explosion.
1.9.1	[Remedy] inadequate ventilation in weld barn (deficiency since April 22, 2013) to avoid worker exposure; immediately supply workers with interim PPE; establish monitoring program with certified professional; develop thermal stress program for make-up air.
1.9.1, 2.1.1	Prepare, within 60 days under direction of a qualified individual, a plan to rectify deficiencies in metallurgy sample prep room ventilation system.
1.9.1, 2.1.1	Within 30 days, ensure local exhaust ventilation captures contaminants from hydraulic hose cutting.
4.2.1.1	Within 14 days, update power distribution drawings to accurately show current configuration.
5.3.3.3, M421-11, 4.5.6, 5.7.1, 5.7.2	Electrical station-grounding system shall be installed to provide adequate ground fault protection (M421-11). Testing will be conducted annually, and records shall be available for examination (within 14 days).
4.5.5, M421-11	High-voltage relays were out of compliance and/or not tested. Within 14 days, confirm safe performance on all devices of 750V or greater. Testing must be documented and repeated every three years. Complete a site-wide audit of all high voltage relays.
4.4.1 (4), 4.4.9 (4), 4.21.4	Warrant safe condition of fall arresting anchor points, assessed by a licensed engineer. Conduct testing of all lifting devices by a qualified person, remove noncompliant devices from service. Remove rough terrain forklift number 60-054 from service until devices are repaired or replaced. Ensure all rigging, webbing slings, and other lifting equipment is suitable to the task and maintained in serviceable condition. To be remedied immediately.
6.3.2, 6.37.1	Update underground plans for ventilation and firefighting, immediately and every three months. Post updated plans.
3.7.1, 6.3.1	Update and review out-of-date Underground Mine Emergency Response Plan, within two weeks.
4.1.4, 6.12.4, 4.13.11, 6.12.4, 3.13.1	Deficiencies in compressed air supply, communications, ice buildup, and training for personnel were noted for the Alimak raise climber (secondary emergency egress from underground works). All deficiencies to be corrected.

UNDERGROUND WORKS INSPECTION ORDERS

On December 4, 2014, John COX, Inspector of Mines, issued a series of written orders to Dale REIMER, Mine Manager of MPMC, on the basis of his inspection of the underground works on the mine site conducted on December 4, accompanied by Geotechnical Inspector Michael CULLEN P.Eng. Although none of the orders was directly relevant to the TSF, each addressed a deficiency in worker health or safe operations on the mine site. The orders are summarized in the following table.

Section of HSR Code Contravened	Order
6.25.2	Travelway obstructed by loose bagged in screen must be remedied immediately.
3.3.3	Lower sumps are not equipped with life buoys and heaving lines, leading to increased risk of drowning. To be remedied immediately.
1.9.1	Heading with bad ground is not signed or roped off. All headings to be supplied with rope and signage to deny access when required. To be remedied within 30 days.
1.9.1	Ventilation system in welding barn (noted on April 24, 2014 for remedy by September 15, 2014) has not been remedied. Appropriate PPE will be issued immediately. An appropriate outdoor welding workplan must be implemented immediately. Requirement for ventilation system is not precluded.

GEOTECHNICAL INSPECTION ORDERS

On December 5, 2014, Geotechnical Inspector Michael CULLEN P.Eng. issued a series of written orders to Dale REIMER, Mine Manager of MPMC, on the basis of his geotechnical inspection of the mine site on December 4. Although none of the orders was directly relevant to the TSF, all orders addressed geotechnical deficiencies in worker health or safe operations on the mine site. The orders are summarized in the following table.

Section of HSR Code Contravened	Order
n/a	Prior to restart, Mine Plans must be up to date and consistent with the requirement of Permit M-200 Section C.1(c) Amendment March 25, 2013. Prior to restart, the Mine shall inspect work places and travelways to repair any damaged screen or excessively bagged screen. Within 3 months of restart, the Mine will be inspected by a qualified geotechnical engineer as required by the Permit.
6.23.2 (3)	Prior to restart, develop and submit to MEM for approval a safe working procedure for locations where loose rock accumulates, cannot be readily accessed, and creates a danger for persons working below.
6.23.3, 6.23.4, 6.23.5	Excavated faces must not exceed 60 degrees or overhang, and must be restored to a stable angle once reclaim work is completed.

DUST EXPOSURE ORDERS

On December 5, 2014, the Chief Inspector issued a series of written orders to Dale REIMER, Mine Manager of MPMC, on the basis of an inspection of the mine site conducted on December 10. The inspection was conducted by MEM inspectors Rolly THORPE, Carina DOYLE, Caroline NAKATSUKA, Greg MCLEAN, Emmanuel PADLEY, and Rory CUMMING. Although none of the orders were directly related to the TSF, the orders addressed a substantial deficiency in worker health or safe operations on the mine site. The orders are summarized in the following table.

Section of HSR Code Contravened	Order
2.1.1, 2.1.3, 1.9.1	A "notable accumulation" of dust in the crusher was observed, caused by "a general state of disrepair" in the dust collection system. Effective immediately, ensure employees are protected from exposure to dust; provide properly fit PPE to all employees entering the crusher building; implement an interim dust exposure mitigation plan, provided to MEM within 7 days; have a certified professional determine dust levels in the crusher, within 45 days.
2.1.1, 2.1.3, 1.9.1	Within 60 days, submit to MEM a crusher ventilation system plan including professionally-certified ventilation plan, schedule for upgrades or implementation, maintenance plan, and monitoring and occupational hygiene plan.

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