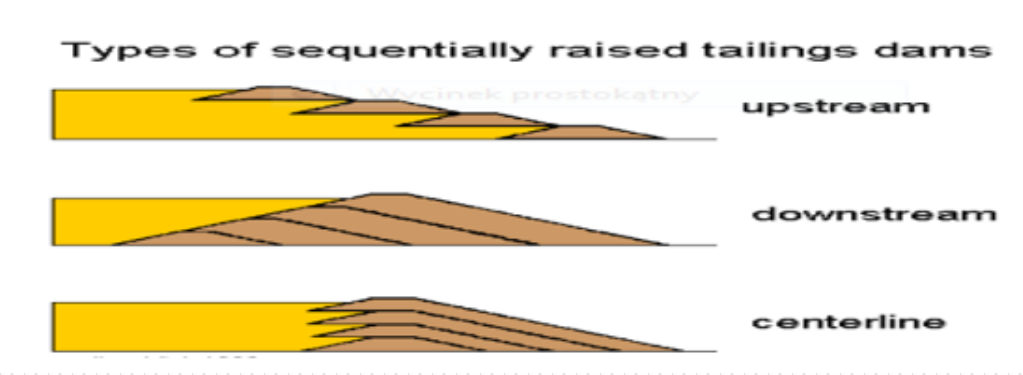
TAILINGS FAILURES AND HOW TO AVOID THEM



Jack A Caldwell, Robertson Geoconsultants

Contents

- Samarco, Fundao, Brazil: *why it failed*
- Regulatory Responses: *to make things better*
- Fundamental Principles: *to avoid failure*

Samarco, Fundao, Brazil

November 2015

Samarco, Fundao as Designed

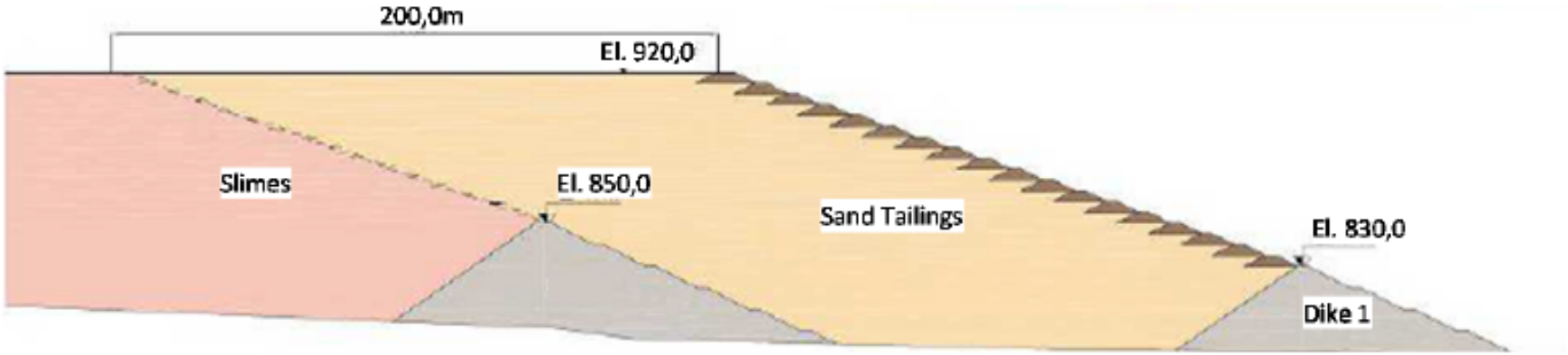
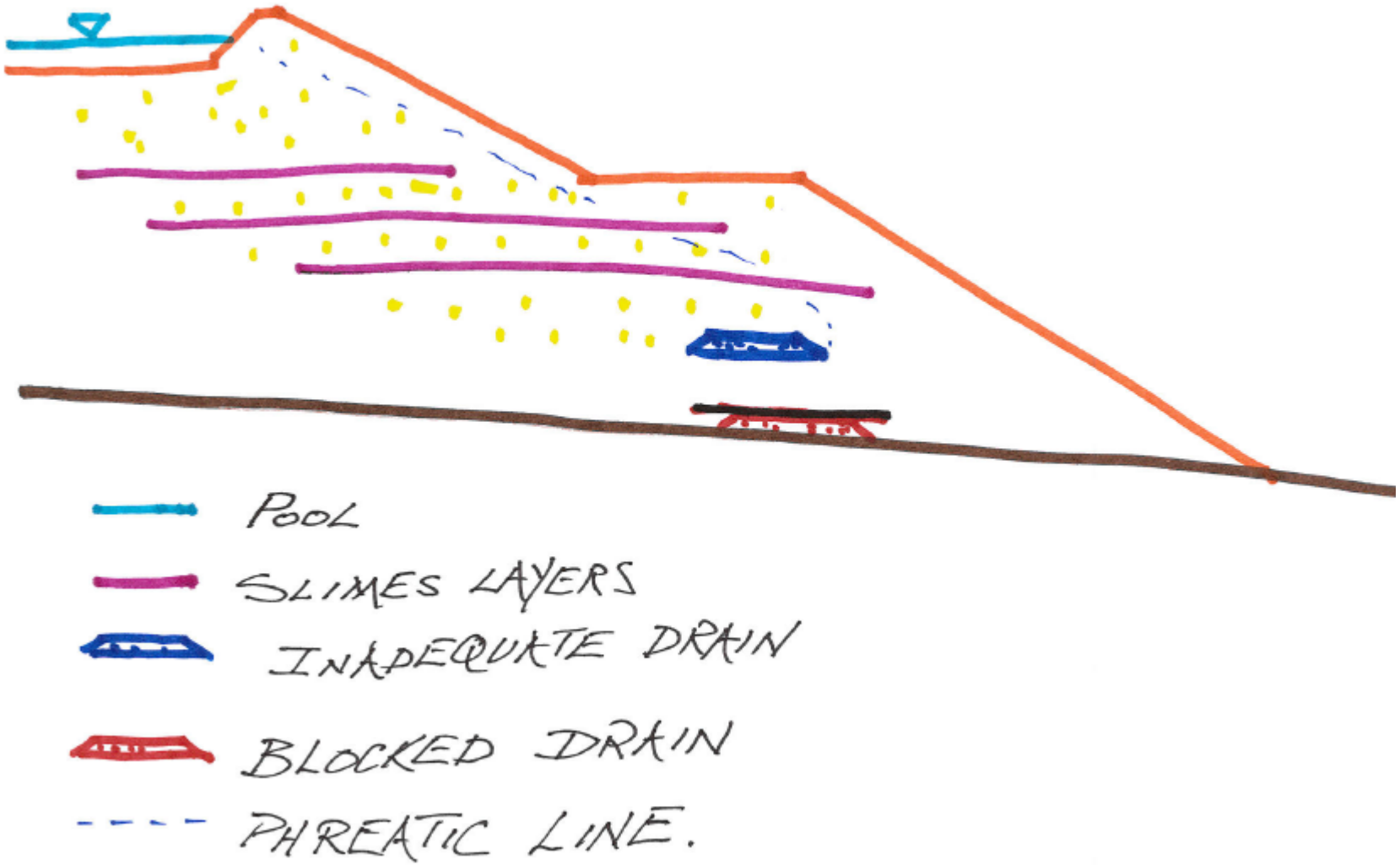


Figure 2-4 Upstream raising of Dike 1 by the "drained stack" concept

Samarco, Fundao at Failure



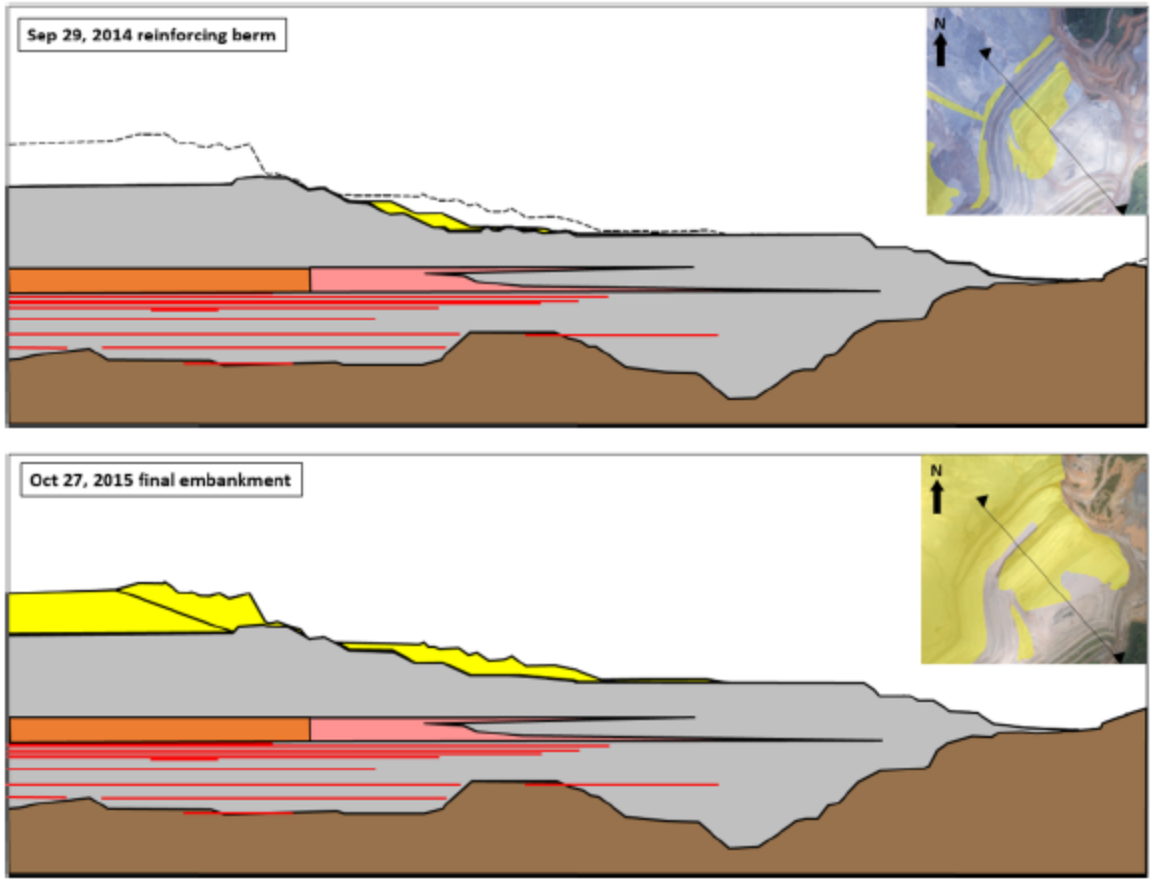


Figure 5-10 Sequential raising of setback embankment over slimes

Figure 2-18 Failure initiation sequence

Technical Causes of Failure

- Blinded drains
- Inadequate replacement drains
- Slimes beneath the slope
- Saturated sands in slope as a result of inadequate drainage
- Sand made even looser as a result of creep-type sliding along slimes
- A tiny earthquake gives the final kick

Who is to Blame?
Institutional Causes of Failure

- ***Corporate***
  - Five Class Action Law Suites
- ***People***
  - Brazil Police charge seven employees of Samarco and VOGBR
- ***Regulators***
  - In denial?

Figure 2-6 Internal erosion effects on downstream slope of Dike 1

BHPs Cost Estimate (09-29-16)

- $2.3 billion civil public actions - state prosecutors in Minas Gerais
- $3.1 billion damages - public defenders in Minas Gerais
- $620 million damages - state prosecutors in Espirito Santo
- $6.2 billion public civil claim
- $43 billion for reparations, compensation, and "moral damages“ – Brazil Federal Prosecutors

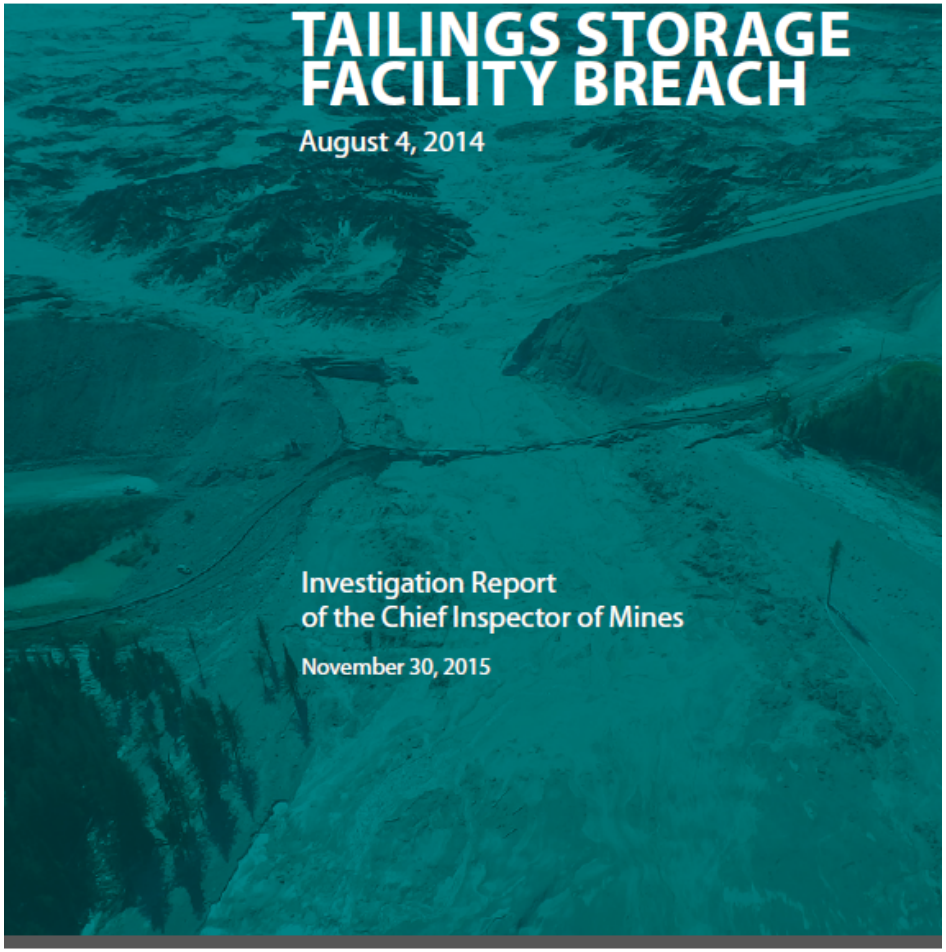
“Our potential costs and liabilities in relation to the Samarco dam failure are subject to a high degree of uncertainty and cannot be reliably estimated at this time."

BRITISH COLUMBIA

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

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

From the BC MEM Mt Polley Report

- The mine manager is responsible for the safety of the TSF
- The mine manager gets input from
  - mine engineers
  - technical folk
  - consulting engineers.
- But professional folk make mistakes
- MAC guidelines say the mine manager must use risk management to overcome professional shortcomings
- Hence in future the mine manager must include risk management as an integral part of tailings facility management.

BRITISH COLUMBIA

Guidance Document

Health, Safety and Reclamation Code for Mines in British Columbia

Version 1.0

Updated July 2016

Mine Manager

- Accountable for the Tailings Facility
- Report Tailings Facility Incidents to Regulators

TSF Responsible Person

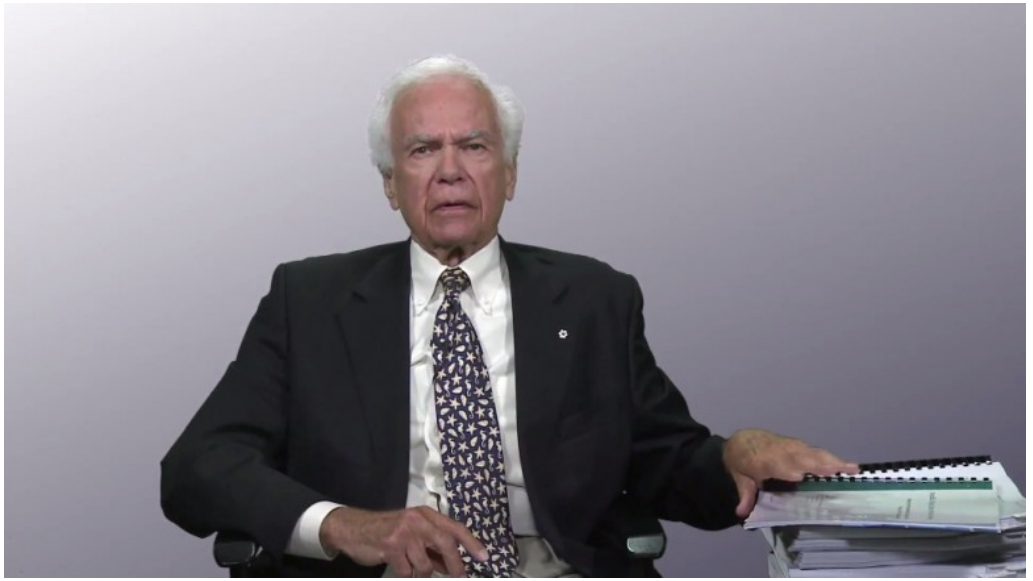
- Report to Mine Manager
- Implement TSF Management Plans
- Coordinate Design & Construction & TFS Management

Engineer of Record

- An Individual, not a Firm
- May work for Mine
- Qualified & Competent
- Professionally Responsible
- Participate in Risk Assessments

Independent Technical Review Board

- Independent Technical Experts
- Provide Independent Assessment to Senior Mine Management and the Regulators
- Not Responsible for Design etc.
- Provide Guidance, Perspective, and Experience re Best Practices



Montana

64th Legislature SB0409

AN ACT REVISING METAL MINE RECLAMATION LAWS; ESTABLISHING STANDARDS FOR TAILINGS STORAGE FACILITIES; ESTABLISHING A FEE; DEFINING TERMS; CREATING INDEPENDENT REVIEW PANELS; PROVIDING FOR REVIEWS AND INSPECTIONS; PROVIDING ENFORCEMENT; AMENDING SECTIONS 82-4-301, 82-4-303, 82-4-305, 82-4-335, 82-4-336, 82-4-337, AND 82-4-342, MCA; AND PROVIDING AN APPLICABILITY DATE.

Engineer of Record

- Not a Mine Employee
- Certify & Sign Designs
- Notify Regulators re Credible Threats to TSF

Independent Technical Review Board

- Three Independent Experts approved by the Regulators
- Not Employees of Mine or TSF Consultants
- Regulators May Participate on Board (*but not members*)

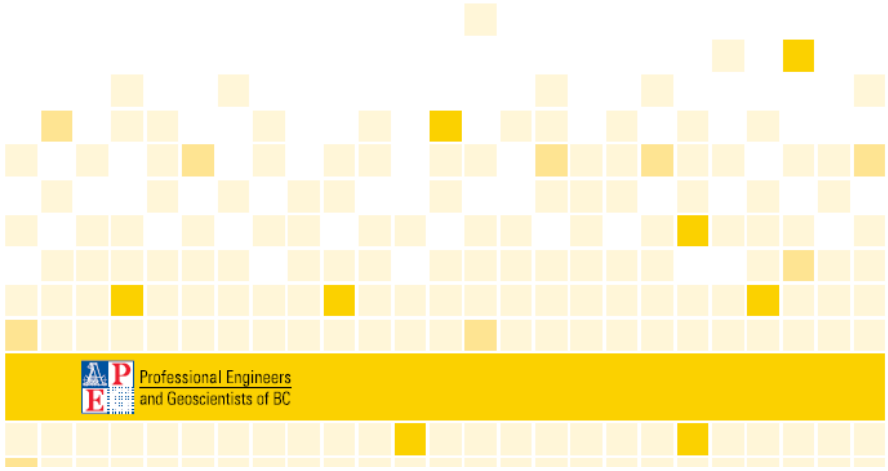
MONTANA
STATE UNIVERSITY
Mountains & Minds

Infrastructure

SITE CHARACTERIZATION FOR DAM FOUNDATIONS IN BC

APEGBC PROFESSIONAL PRACTICE GUIDELINES

V1.0



How to avoid failure

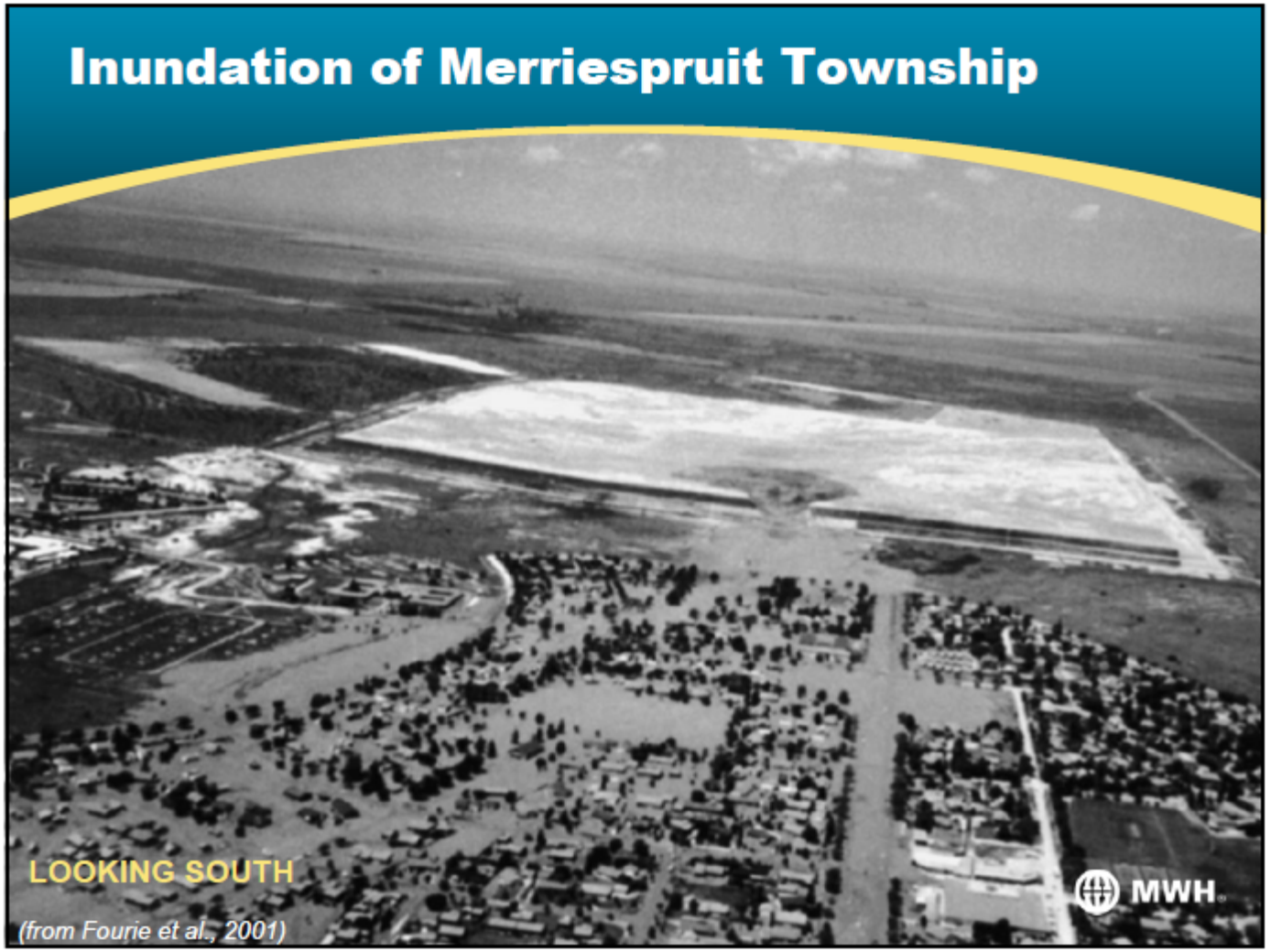
A few controversial ideas

Human Habitation

- Rule: No tailings facilities upstream of human habitation or sensitive environments.

- Violations re Human Habitation:
  - Stava
  - Merrispruit
  - Samarco
- Violations re Sensitive Environments:
  - Mount Polley

Inundation of Merriespruit Township

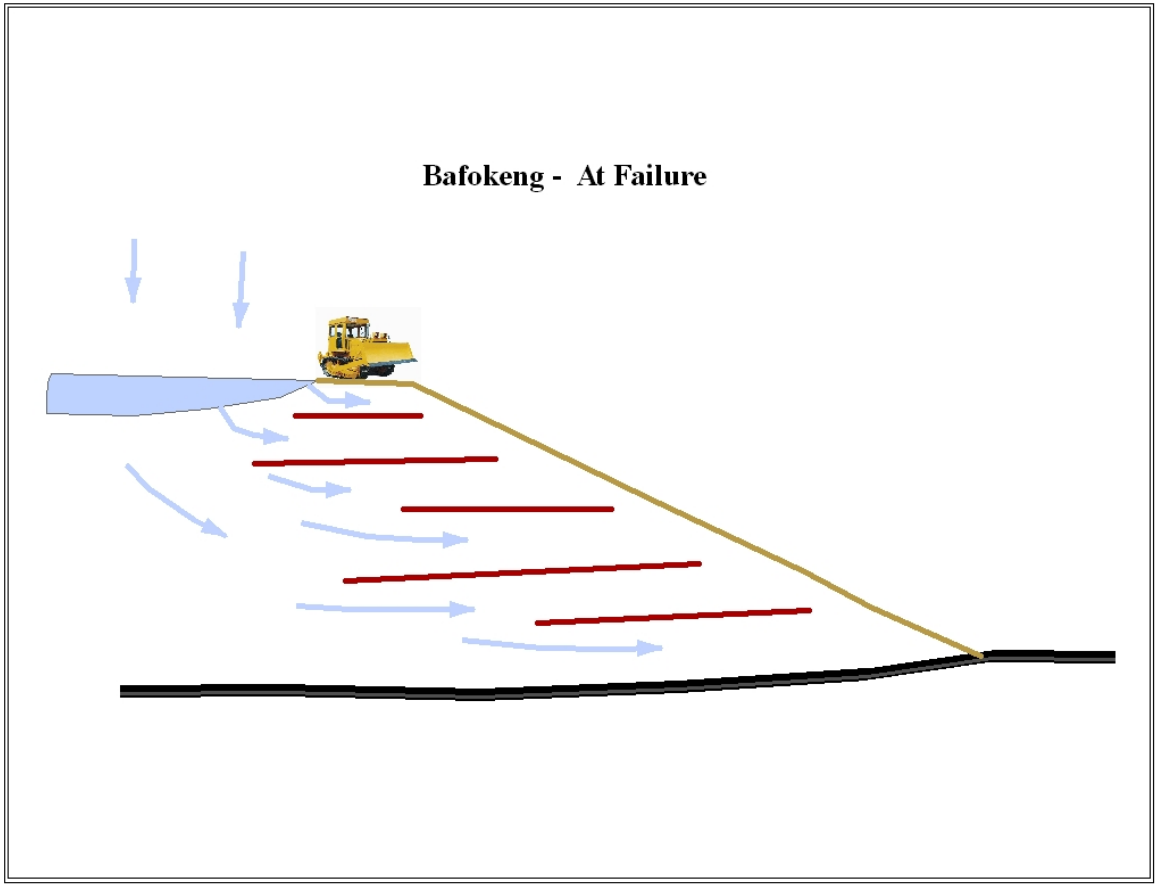


No Slimes Near the Perimeter

- Rule:
  - No slimes near the perimeter or in the zone of potential slope failure.

- Violations:
  - Bafokeng – Piping through sand between slimes layers
  - Samarco
    - Promoted horizontal deformation leading to loose sands
    - Impede free drainage leading to saturated sands?

Bafokeng – at Failure



No Cascading Dams

- Rule:
  - No cascading tailings dams.

- Violations:
  - Stava: one failed causing the other to fail
  - Merrispruit: flow from upper to lower exceeded storage capacity

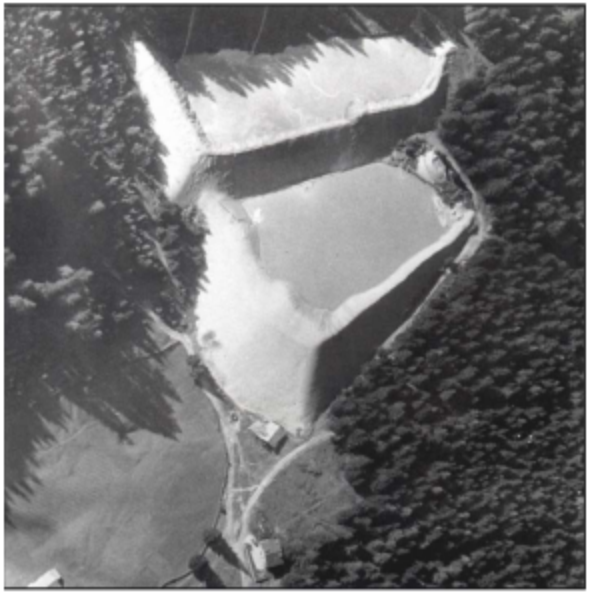


Fig. 5. Aerial view of the basins in October 1973, nearly two years after the construction of upper basin; in this one is in progress the raising of the embankment from the orographic left side (photo Impresa Rossi, Brescia).

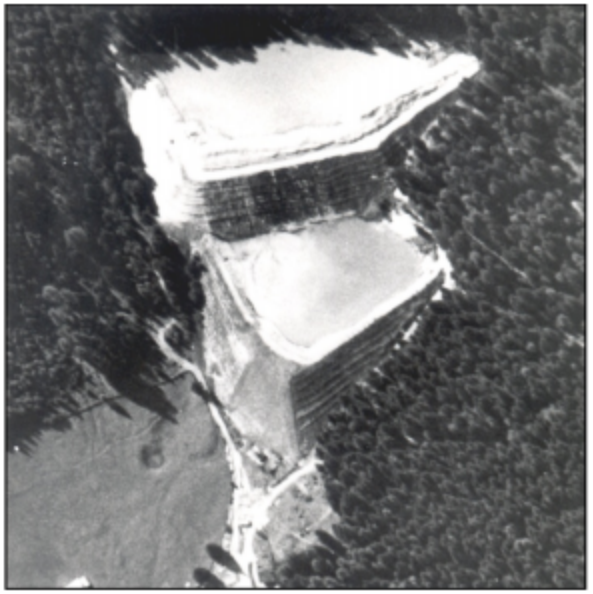


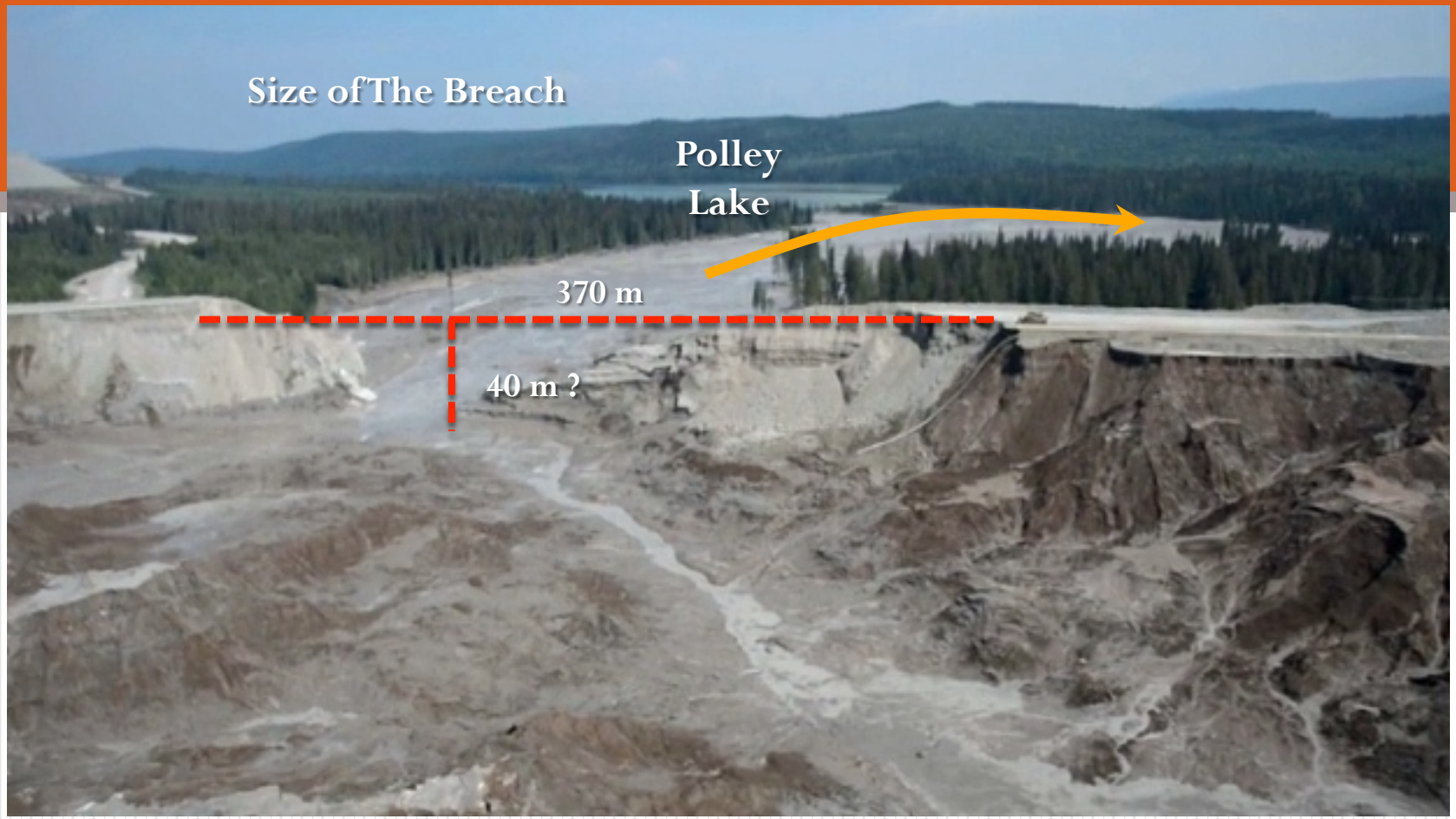
Fig. 6. The decantation basins photographed in September 1978. The geometry of the upper basin seems altered with respect to the previous photo: works to raise the embankment according to the scheme "upstream" are clearly in progress (photo Impresa Rossi, Brescia).

No Clay Foundations

- Rule:
  - Limit or avoid clay in the foundations.

- Violations:
  - Bafokeng and other Rustenburg Dams: foundation failure when reached 30-m high
  - Mount Polley:
    - Failure to locate clay layer
    - Complex clay behavior not understood

MOUNT POLLEY



Fonte: CBCNEWS, 2014.

No Water on Top Deck

- Rule:
  - No or very small pool; or
  - Pool distance from crest = 5 x embankment height

- Violations:
  - Bafokeng: pool at crest
  - Mount Polley:
    - No freeboard exacerbated failure consequences


7 km

Low Slope Embankments

- Rule:
  - Tailings embankments slopes of 5H:1V
  - Rockfill embankments as rockfill permits

- Non-Violations:
  - UMTRA: all piles reconfigured to 5:1
  - Cannon Mine: good-quality, compacted rockfill at 1.73:1

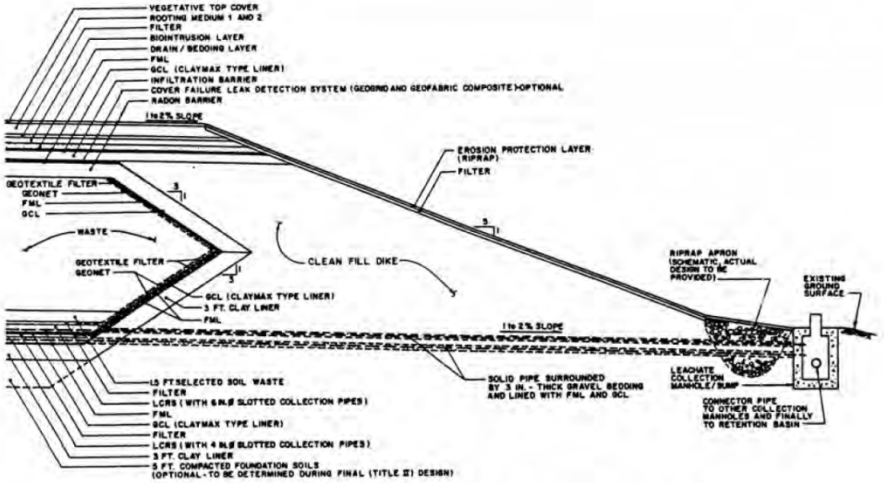


Fig. 4. Schematic section of disposal cell with various components.

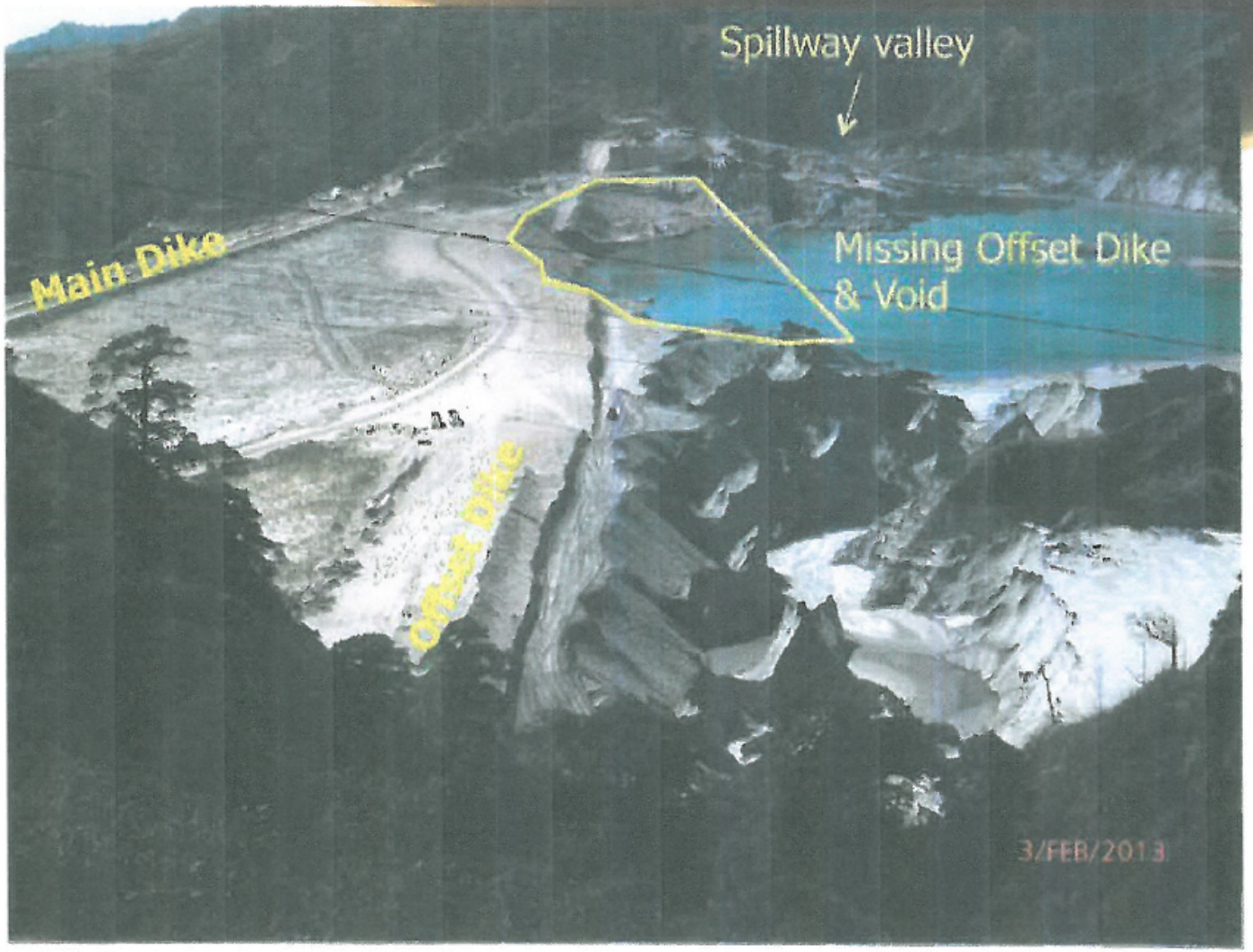
No Penstocks

- Rule: No penstocks through tailings or adjacent abutments

- Violations:
  - Bafokeng: cavitation in penstock suspected as main or contributory cause
  - Padcal: Pipe break lead to large tailings loss

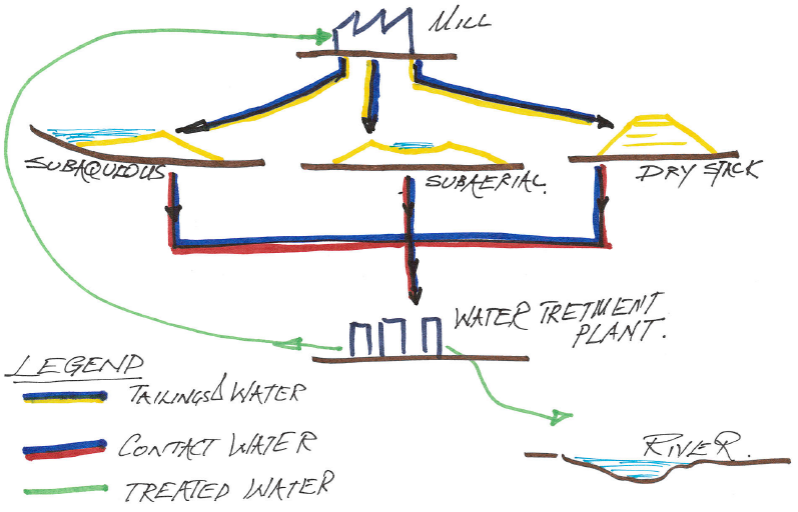
TSF3 ON SUNDAY

PHILEX MINING CORPORATION



Risk Assessment

- FACTS:
  - People make mistakes
  - Human systems fail to function
- Mining Association of Canada Guidelines:
  - Apply Risk Management
  - Mine Manager responsible by law

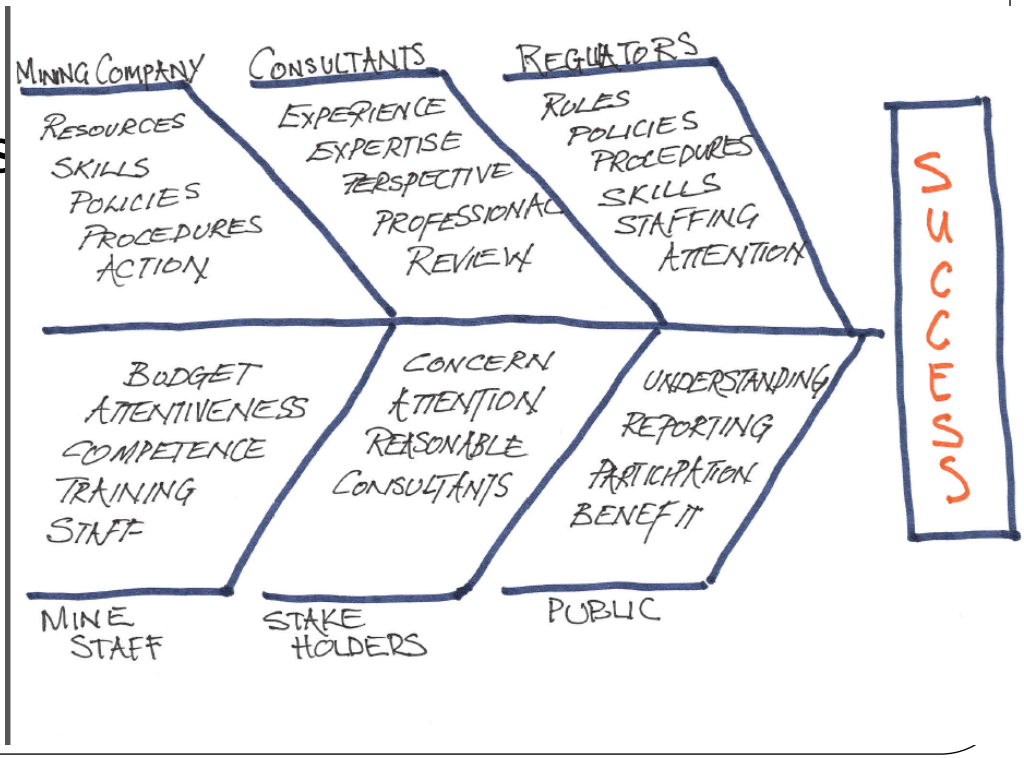


Tolerable Risks

- Rule: If dam break consequences tolerable, proceed.
  - Other wise change design or do not construct

Lots of People

- Competent Responsible Engineer
- Intelligent ITRB
- Engaged Staff
- Committed Management
- Educated Regulators
- Informed Stakeholders



Tailings Stewardship

- Identify potential design or operational issues or concerns;
- Manage liabilities (reduce risk);
- Identify opportunities to improve operational efficiencies, and reduce costs;
- Provide input into design, construction, and operations throughout the life of the facility (including closure and post-closure);
- Provide operators contemporary, "state of the practice" training;
- Improve data management;
- Provide a standardized review process; and
- Prepare for upset conditions (emergency preparedness).

Higher Factor of Safety

- Rule:
  - More than 1.5
  - Greater depending on:
    - Site complexity
    - Structure complexity
    - Site knowledge
    - Past performance of similar facilities

Break these Rules, IF

- More conferences
- More papers
- More courses
- More education
- More wisdom

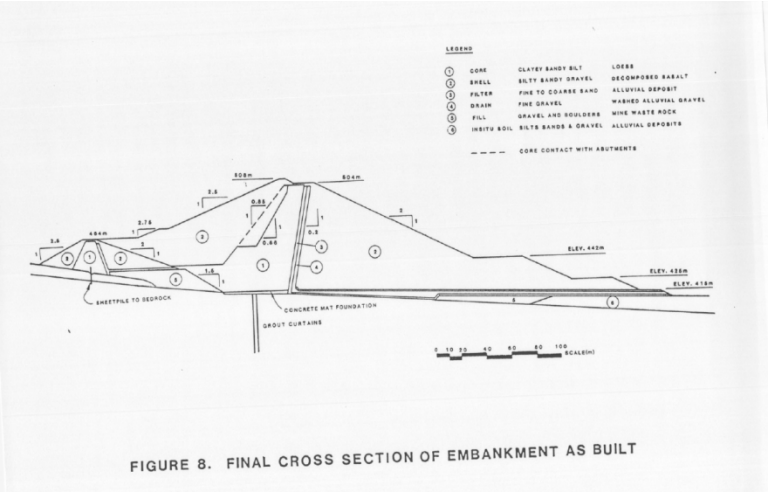


FIGURE 8. FINAL CROSS SECTION OF EMBANKMENT AS BUILT