A Review of the "Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel"

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Early on August 4, 2014, the Perimeter Embankment at the Mt Polley copper mine near Likely, south-central British Columbia, failed catastrophically. The loss of containment was sudden, with no warning. That failure, which released at least 25 million cubic meters of mine tailings and mine effluent mixed with stormwater into Polley Lake, Hazeltine Creek and finally stopped when it reached the deep waters of Quesnel Lake, a large, salmon-spawning, fjord-type lake.

The Cariboo Regional District declared a local state of emergency in several nearby communities, the Interior Health Authority ordered drinking water bans, and the Department of Fisheries and Oceans closed the recreational salmon fishery on the Quesnel and Cariboo Rivers.

Fortunately, there were no human fatalities or injuries. There could have been, since there was no warning of the dam failure. It just happened that no one was on or below the dam when it failed.

Why did the Mt Polley TSF Fail?

The failure of the Mt Polley Tailings Storage Facility (TSF) was reviewed shortly after the accident by an expert panel of three engineers.[1] The words of the panel itself succinctly describes what happened, and why it happened.

> *The Panel concluded that the dominant contribution to the failure resides in the design. The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation. As a result, foundation investigations and associated site characterization failed to identify a continuous GLU (Glasciolacustrine Unit) layer in the vicinity of the breach and to recognize that it was susceptible to undrained failure when subject to the stresses associated with the embankment. (p. iv)*

The tailings dam was built on top of an old, relatively small, glacial lake that contained mainly clays. The builders of the dam, Knight-Piesold Ltd., made several assumptions that led to this problem. They assumed that the extent of the clay was less widespread that it in fact was, and that the clay constituting the lake sediment (called the Upper Glasciolacustrine Unit – GLU) would not loose shear strength as the sediment was loaded by the weight of the dam, tailings, and water. These proved to be both flawed and ultimately fatal assumptions for the dam.

Figure 1 (from the Report) maps the resulting failure on top of an aerial photo of the failed dam. The increasing load due to the ongoing construction of the dam, and the load of tailings and water behind the dam, finally caused the glacial clay lake-layer to break and slide, rupturing the dam. There were no precursor warnings to the failure. The failed piece of the dam rotated down and out, letting water spill over the top of the failed segment, and in a short time washed that piece of dam away.

[1] Dr. Norbert R. Morgenstern (Chair), CM, AOE, FRSC, FCAE, Ph.D., P.Eng.; Mr. Steven G. Vick, M.Sc., P.E.; and, Dr. Dirk Van Zyl, Ph.D., P.E., P.Eng. Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel, Province of British Columbia, January 30, 2015

Figure 1: Plan Showing Direction and Extent of Mass Movements

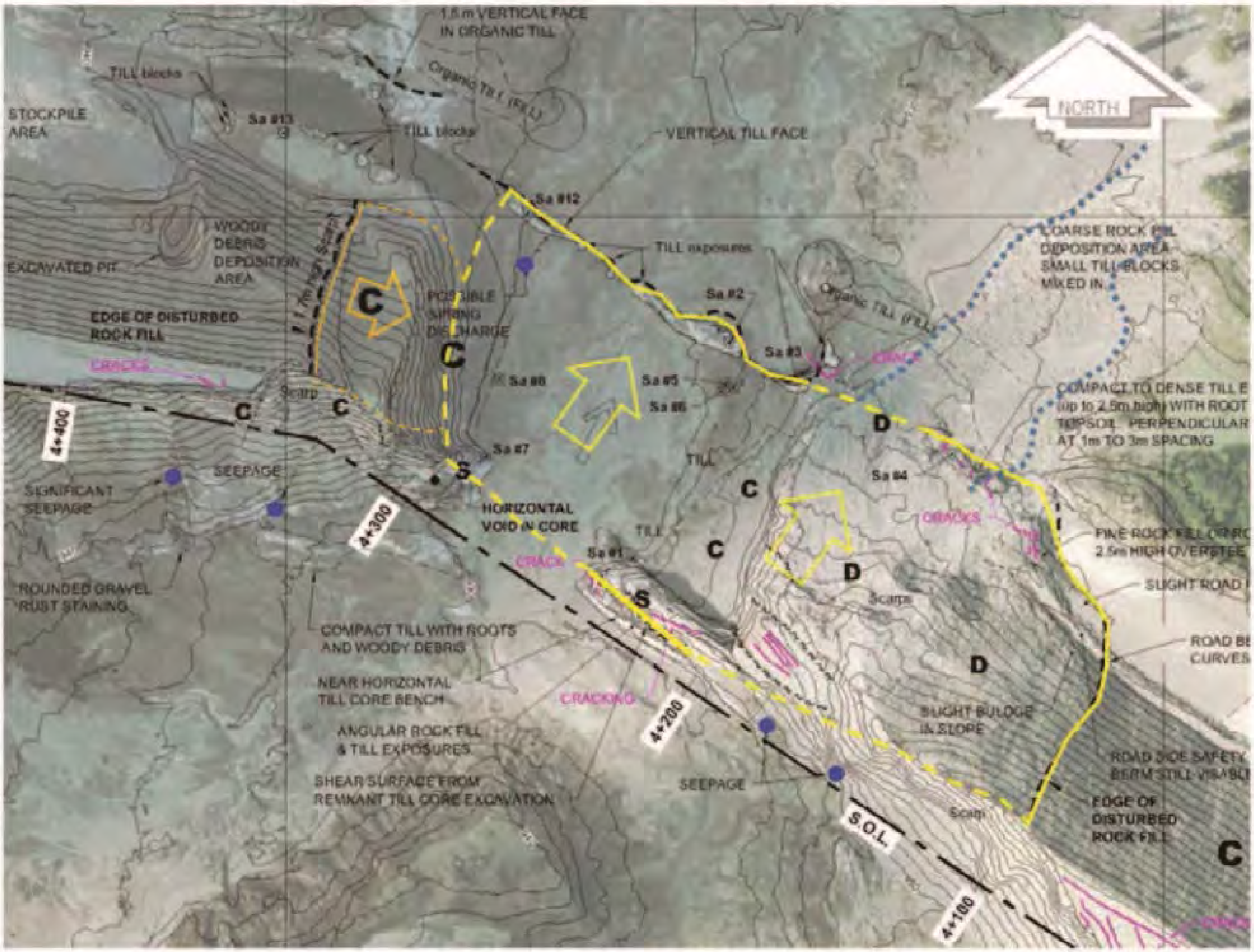


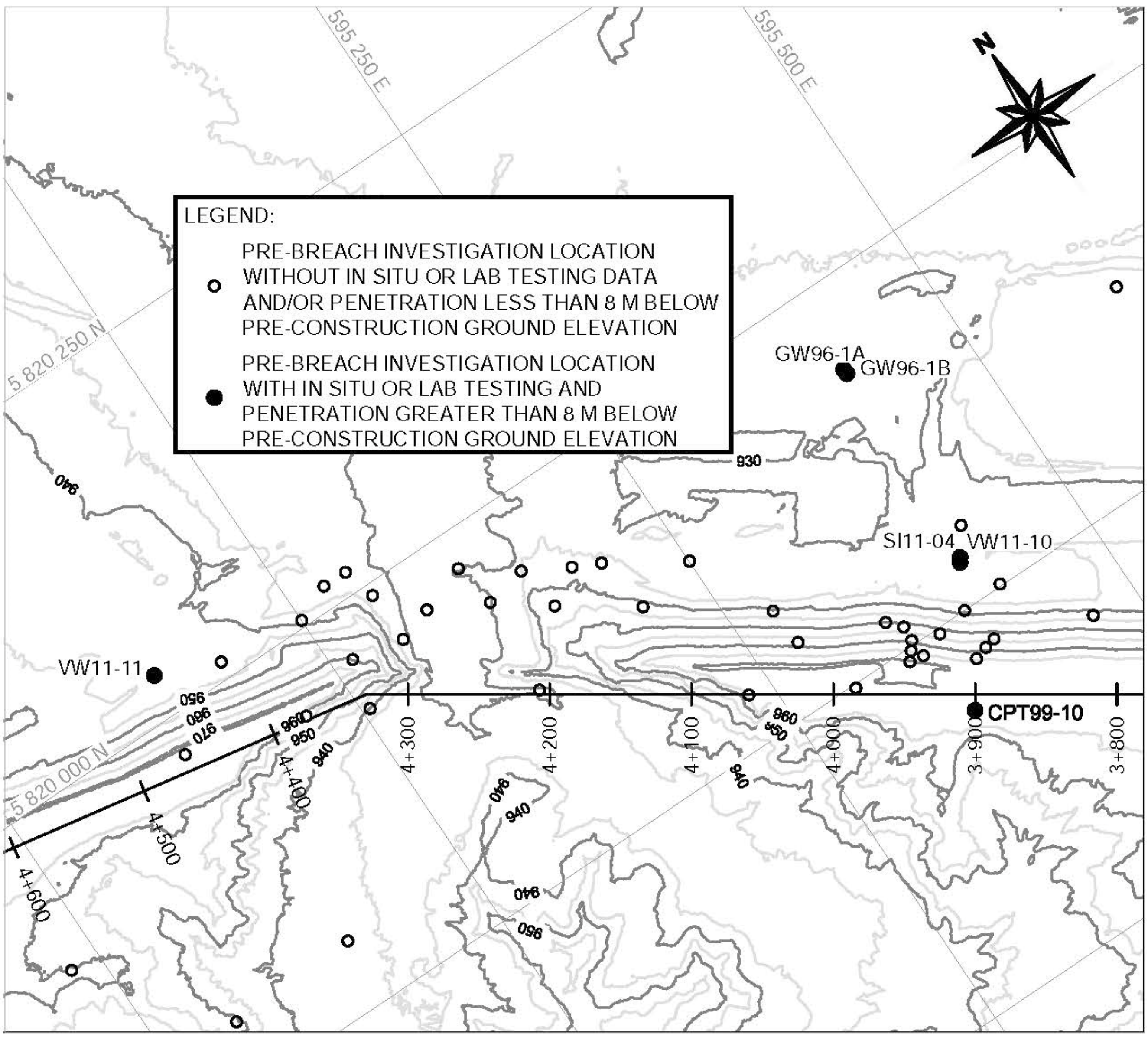
Figure 2 shows the drillholes made before the dam was built.

The drillholes depicted as solid circles in Figure 2 were drilled deep enough to intersect the Upper GLU, and clays intersected in those holes were lab tested for shear strength.

The drillholes depicted as open circles were not drilled deep enough to intersect the Upper GLU.

As can be seen in Figure 2, there are only shallow drillholes (open circles) in the area of the failed dam segment. There are no drillholes in the area of the dam failure that intersected the Upper GLU or that were lab tested for shear strength.

Figure 2: Pre-Failure Site Investigation Drillhole Locations in Breach Area



Post-failure drilling in the area of the failure, Figure 3, did intersect the Upper GLU, and lab testing of these clays clearly determined that the clay of the Upper GLU would fail under the increased pressures of the dam and tailings.

Figure 3: Joint and Panel Site Investigation Drillhole Locations

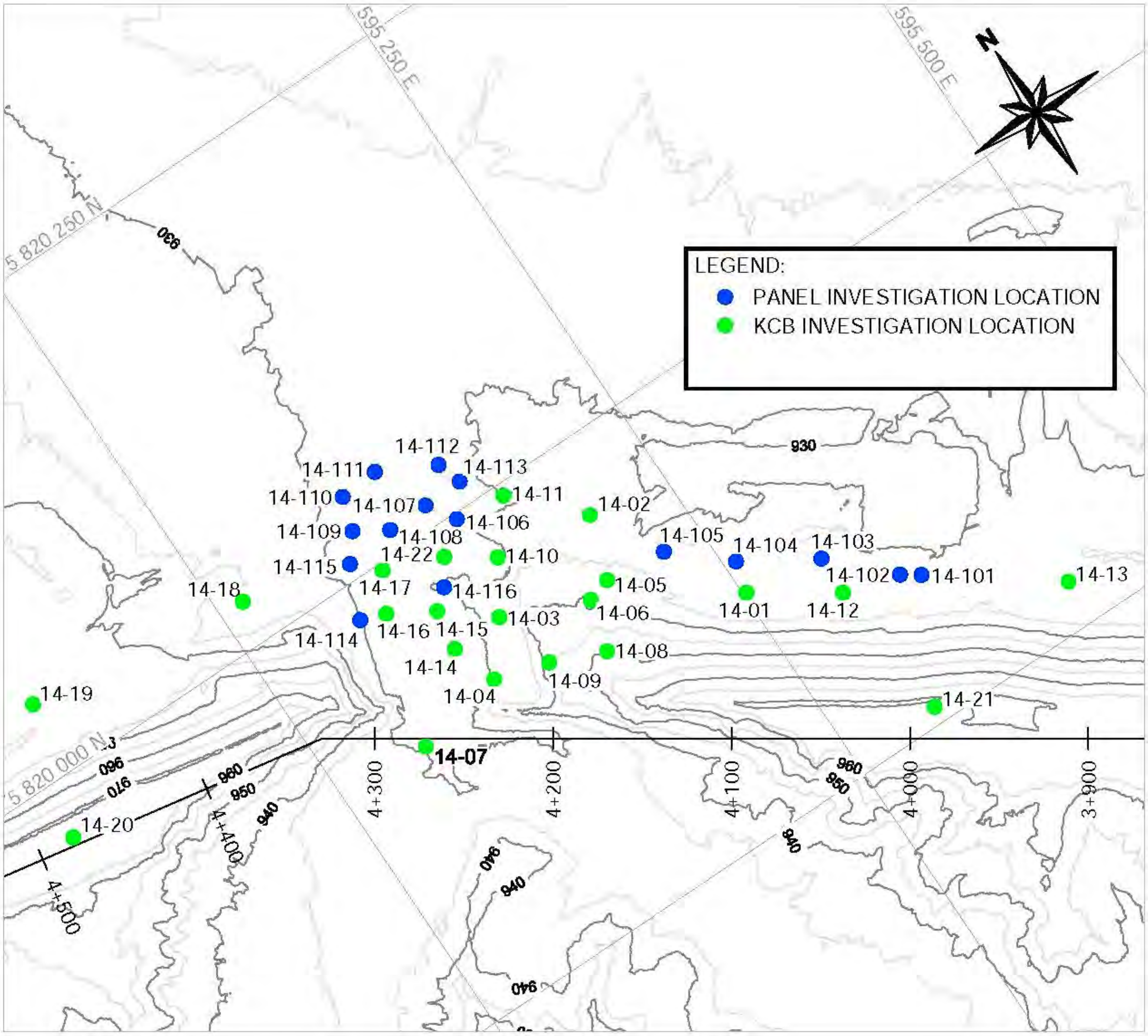
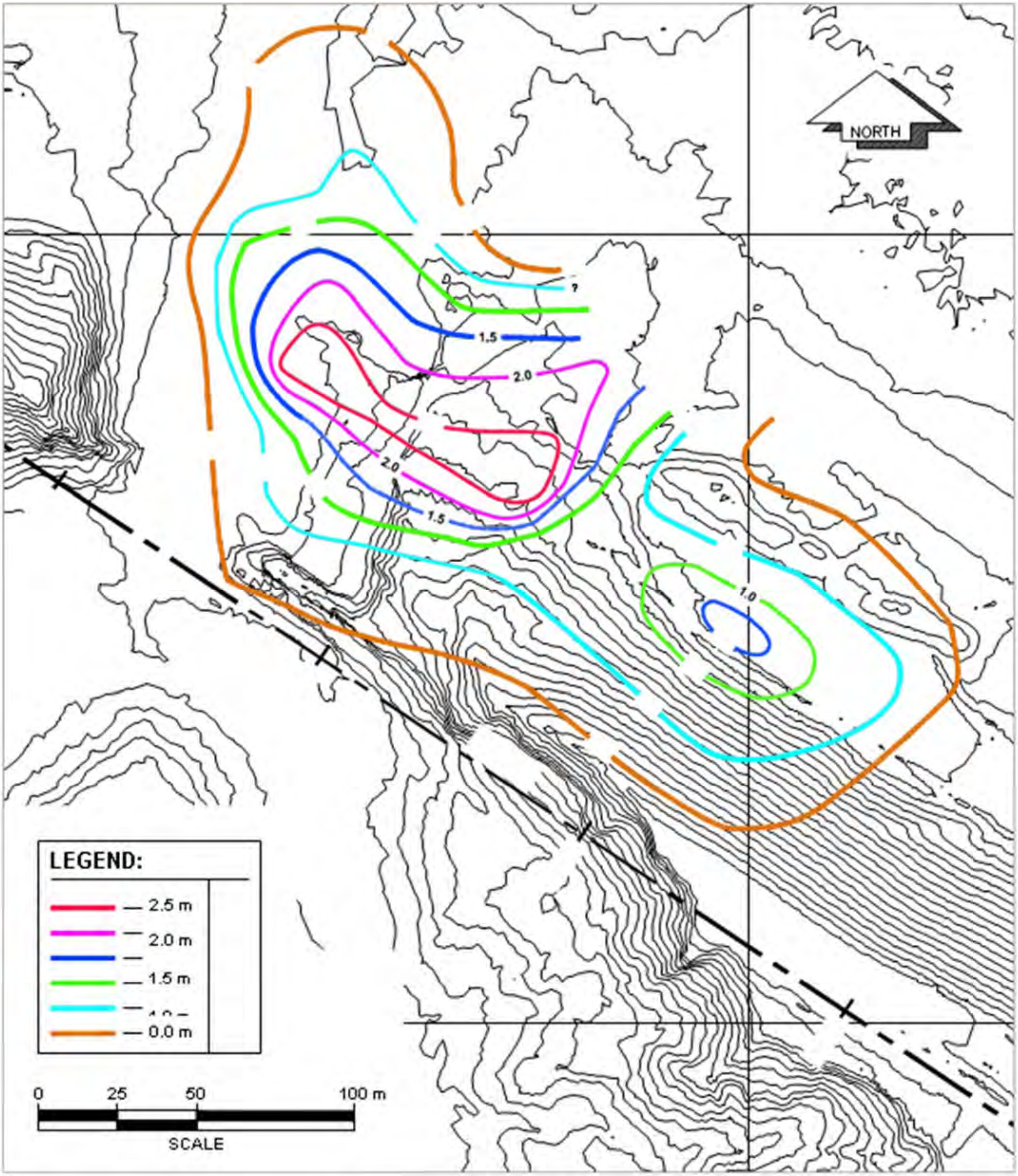


Figure 4 shows the extent and thickness of the Upper GLU – just small enough to have avoided the original deeper drillholes – but large enough to cause the catastrophe.

Figure 4: Contours of Upper GLU Thickness in Breach Area



The factors that contributed to either the dam failure, or that significantly increased the impact of the dam failure, were a bit more complex than just the inability to detect the Upper GLU. The environmental damage due to the outflow of tailings and effluent were heavily influenced by several of these other factors.

Oversteepening of the Downstream Rockfill Zone

> *The specifics of the failure were triggered by the construction of the downstream rockfill zone at a steep slope of 1.3 horizontal to 1.0 vertical. Had the downstream slope in recent years been flattened to 2.0 horizontal to 1.0 vertical, as proposed in the original design, failure would have been avoided. The slope was on the way to being flattened to meet its ultimate design criteria at the time of the incident. (p. iv)*

The plans for the dam originally called for a downstream slope of 2.0 horizontal to 1.0 vertical. Early on in the construction of the dam, which at the time of the failure had occurred in nine separately-approved construction events, a decision had been made to build the dam at a steeper slope (1.3 horizontal to 1.0 vertical) until enough construction rock became available to fill in the downstream "buttress" of the dam. The result was that that the steeper-sloped dam put more pressure on a smaller area, causing it to fail. As noted by the panel, if the dam had been constructed as designed, with a downstream slope of 2.0 horizontal to 1.0 vertical, the pressure from the dam and tailings would have been distributed over a greater area, and the dam would not have failed.

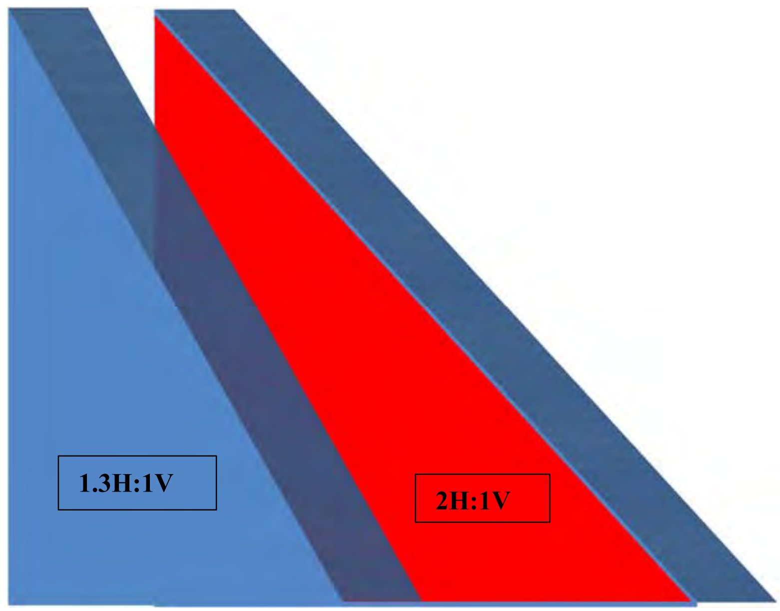


Figure 5: Tailings Dam Downstream Slopes

The panel's overall conclusion was:

> *The dominant contribution to the failure resides in its design. The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation. … Hence, the omissions associated with site characterization may be likened to creating a loaded gun. Notwithstanding the large number of experienced geotechnical engineers associated with the TSF over the years, the existence of this loaded gun remained undetected. (p. iv)*

and;

> *If constructing unknowingly on the Upper GLU...constituted loading the gun, building with a 1.3H:1V angle of repose slope over this stratum pulled the trigger. (p. 108)*

and;

> *The design was caught between the rising water and the Mine plan, between the imperative of raising the dam and the scarcity of materials for building it. Something had to give, and the result was oversteepened dam slopes, deferred buttressing, and the seemingly ad hoc nature of dam expansion that so often ended up constructing something different from what had originally been designed. (p. 75)*

Not knowing about, and accounting for, the glacial lake clay "loaded the gun" in the panel's words, and building the dam steeper than the design called for "pulled the trigger."

Other Complicitous Factors

There were a number of other factors that turned up during the course of the investigation of the dam failure which contributed materially to the fundamental cause of the accident itself. However, one did make the accident significantly worse, and two others could eventually have led to a dam failure on their own.

(1) **Tailings Pond Water Level**

At the time of the dam failure the water level in the tailings pond was just below the maximum level allowed. For some time the mine has been forced to manage water in the tailings pond at emergency levels due to higher than predicted precipitation

> *The high water level was the final link in the chain of failure events. Immediately before the failure, the water was about 2.3 m below the dam core. The Panel's excavation of the failure surface showed that the crest dropped at least 3.3 m, which allowed overflow to begin and breaching to initiate. Had the water level been even a metre lower and the tailings beach commensurately wider, this last link might have held until dawn the next morning, allowing timely intervention and potentially turning a fatal condition into something survivable. (p. 137)*

The overflow of water due to the high water level in the tailings pond caused the mass release of tailings and contaminated water. There would have been a dam breach even absent the water, but with no water there would have been little tailings release. There would probably have been minimal or no tailings release if the tailings pond were at normal levels – but it wasn't, and the tailings pond full of water led to the large release of tailings downstream.

Managing mine water was an issue because the water balance predictions were not accurate.

> *The water balance model included the site-specific information to the date of analysis, and future conditions were based on average climatic conditions. They did not account for specific wet year conditions. (p. 84)*

This is an issue that should have been apparent to both regulators and mine designers, but was either missed or ignored.

The mine had received permission to discharge treated water to resolve this problem, and a treatment plant was scheduled to begin operation in September, 2014. The accident happened on August 4, 2014.

However, earlier in 2014 the tailings pond faced a potentially catastrophic situation when water reached the top of the dam, and began to overflow. If this had continued, it too would have caused a catastrophic dam failure with concurrent release of tailings and contaminated water, much like the August accident.

Again, in order to stress the severity of the issue, here are the words of Panel:

> *For years, dam raising had managed to stay one step ahead of the rising water. But on May 24, 2014, the water caught up. With Stage 9 nearing completion, what was described as "seepage flow" was observed over the dam core. Intensive surveillance and construction activity over the following days and weeks succeeded in raising low areas around the embankment perimeter, restoring containment integrity, and saving the dam from overtopping failure. (p. 72)*

The water level in the tailings pond was a major contributing factor to the damage associated with the dam failure, although it was not related to the cause of the failure itself. But dam failure due to overtopping by water in the tailings pond was a real risk, and that almost happened on May 24, 2014.

(2) **Dam Filter Material**

Figure 6: Void in left abutment (note geo-pick for size)

The duty of the filter zone in the dam is to collect any seepage coming through the core and to prevent fines from migrating out of the core. In order for the dam to drain properly internally, the core, filter, and transition (to the buttress) zones must be carefully constructed. Much of the as-placed filter material at Mt Polley failed to meet applicable filter criteria and requirements for internal stability of its grading.

> *... in a sampling of as-placed Zone S filter gradations, the Panel found that 30% were too coarse to meet the … filter criterion … with only about 25% satisfying both filter and internal stability requirements. (p. 75)*

If the filter material is too course, it does not act as filter, but more like a drain. This can lead to voids in the core of the dam. This was essentially the cause of the Omai tailings dam failure. Had this situation been widespread it too could have led to dam failure at Mt Polley.

And, in fact, during the field work associated with the dam failure, a serious void was discovered (Figure 6), but there was no evidence of further voids discovered during the investigation. The quality control function of dam construction was obviously not working satisfactorily. This reflects poorly on both those who constructed the dam, those who were supervising the construction (this should have been an independent party), and on the standards set by regulators, which were not tight enough to detect these errors.

(3) **Inoperative Piezometers**

A piezometer is a general term used for a well drilled into the dam to measure water level and pressure. Installed in the dam were 116 piezometers. Piezometers were installed in the dam foundation, in various embankment components, such as the upstream fill, core, and downstream transition zone, in drains located in the embankment and foundation, and in the tailings upstream from the embankment.

The piezometers at the Perimeter Embankment were located too far beyond the dam toe to provide critical data, and too far in between to cover the area where the breach occurred, so they were not able to supply information on the dam failure. Piezometers, even if properly located and operating, would probably not been able to detect this type of failure. However, normally they can provide an early warning that the core of the dam is compromised, and can provide warning of impending dam failures.

As early as 2009 the functionality of these piezometers had been an issue.[2] Yet as of August 2014, there were a total of 64 operating piezometers and 52 non-operating piezometers in the dam. There were nine operating and 13 non-operating piezometers along the section of the Perimeter Embankment that failed.

[2] Knight Piésold Consulting, Tailings Storage Facility Report on 2009 Annual Inspection (Ref No VA101-1/27-1, 2011), at 7.

Allowing nearly 50% of the piezometers to be non-operational should not be acceptable either to the dam operator or the dam regulators. Non-operational piezometers take a significant safety tool away from all dam observers.

(4) TSF Management and the "Observational Method"

According to the Panel:

> *The Observational Method is a powerful tool to manage uncertainty in geotechnical practice. However, it relies on recognition of the potential failure modes, an acceptable design to deal with them, and practical contingency plans to execute in the event observations lead to conditions that require mitigation. The lack of recognition of the critical undrained failure mode that prevailed reduced the Observational Method to mere trial and error. (p. 107)*

and;

> *The Observational Method was invoked early on as the basis for design. This commonly accepted approach uses observed performance from instrumentation data for implementing preplanned design features or actions in response. (p. 77)*

However;

> *The Observational Method relies on measuring the right things in the right places. (p. 77)*

Interpreting from the Report, invoking the Observational Method allowed the dam operators, designers, and regulators to depart from implementing the planned design of the dam, most notably the allowing the Factor of Safety[3] to go from the planned 1.5 down to 1.3, by not constructing the dam buttressing on the planned schedule.

To make the Observational Method work mine designers would have to have known about the clay layer beneath the dam, but they didn't. They should have had extensive instrumentation to monitor the dam, but the instrumentation they had was not only in the wrong places, but much of it was not working.

In the view of the Panel the Observational Method was misapplied at Mt Polly. But more succinctly, the Observational Method was probably invoked at Mt Polley in order to keep mine operation on schedule. Invoking the Observational Method eventually led to the dam failure. There appears to be no regulatory guidelines as to when the Observational Method can be invoked, or what should be done to put a dam operated under the Observational Method back on its planned track.

A Way Forward

The Panel opened its recommendations by saying flatly:

> ***The Panel firmly rejects any notion that business as usual can continue. (emphasis added)***

The Panel goes on to explain what this means before rendering specific recommendations:

> *In risk-based dam safety practice for conventional water dams, some particular level of tolerable risk is often specified that, in turn, implies some tolerable failure rate. The Panel does not accept the concept of a tolerable failure rate for tailings dams. To do so, no matter how small, would institutionalize failure. First Nations will not accept this, the public will not permit it, government will not allow it, and the mining industry will not survive it. ... Tailings dams are complex systems that have evolved over the years. They are also unforgiving systems, in terms of the number of things that have to go right. Their reliability is contingent on consistently flawless execution in planning, in subsurface investigation, in analysis and design, in construction quality, in operational diligence, in*

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[3] Factor of Safety is the ratio of available strength to the strength required for equilibrium.

monitoring, in regulatory actions, and in risk management at every level. All of these activities are subject to human error. (p. 119)

…

Improving technology to ensure against failures requires eliminating water both on and in the tailings: water on the surface, and water contained in the interparticle voids. Only this can provide the kind of failsafe redundancy that prevents releases no matter what. ... ***Simply put, dam failures are reduced by reducing the number of dams that can fail.*** *(p. 120*, ***emphasis added****)*

Thus, the path to zero leads to best practices, then continues on to best technology. (p. 120)

The "*path to zero*" should not be interpreted literally to mean the Panel believes that achieving zero tailings dam failures is attainable for tailings dams or even tailings impoundments. It does mean the "goal" should be zero failures, and that in order to move toward this goal tailings impoundments need to be designed such that their stability does not depend on the structural integrity of a tailings dam.

Best Available Tailings Technology (BAT)

The goal of BAT for tailings management is to assure physical stability of the tailings deposit. This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures. (p. 121)

The implication of the statement "*… preventing the release of impoundment contents independent of … containment structures.*" are significant. This explicitly says that the tailings must have structural integrity that is independent of a containment structure.

Tailings that are saturated with water do not have any structural integrity. The Panel recommends pursuing tailings disposal methods like dry tailings and underground tailings disposal, as well as the development of new disposal technologies, the possibilities for which the Panel considers "ripe" if the right incentives are put in place.

This recommendation from the Panel is nothing short of profound. While it stops short of saying explicitly saying no more tailings dams, it couldn't get any closer without saying it. The 'physical stability of the tailings must be independent of the containment structures.' While it might be argued that a deposit of wet tailings could be made free-draining after deposition, and therefore have some structural stability, tailings are not noted for being free-draining (in fact it is often argued they are self-sealing). And even if the tailings were free-draining, the portion of the tailings next to the dam would still depend on the dam for some stability.

The Panel specifically notes that water covers (i.e. maintaining saturated and water-covered tailings in perpetuity) should be avoided, even for potentially acid generating material, because the long-term risk of dam failure is too great.

… BAT has three components that derive from first principles of soil mechanics:

1. *Eliminate surface water from the impoundment.*
2. *Promote unsaturated conditions in the tailings with drainage provisions.*
3. *Achieve dilatant conditions throughout the tailings deposit by compaction. (p. 121)*

The panel also places an emphasis on stability over preventing acid drainage/metals leaching:

No method for achieving chemical stability can succeed without first ensuring physical stability: chemical stability requires above all else that the tailings stay in one place. (p. 124)

The Panel prefers to see potentially acid generating material stored in a dry manner, even if that means a concomitant increase in the need for (perpetual) water treatment.

> *The Panel recognizes that creating dry tailings may increase the amount of water requiring treatment or storage. (p. 122)*

For the Panel more water treatment is preferable to long-term wet storage. This is sobering.

In terms of how to apply BAT, the Panel made the following recommendations:

> *Implementation of BAT is best carried out using a phased approach that applies differently to tailings impoundments in various stages of their life cycle.*
>
> - *For existing tailings impoundments. Constructing filtered tailings facilities on existing conventional impoundments poses several technical hurdles. Chief among them is undrained shear failure in the underlying saturated tailings, similar to what caused the Mount Polley incident. Attempting to retrofit existing conventional tailings impoundments is therefore not recommended, with reliance instead on best practices during their remaining active life.*
> - *For new tailings facilities. BAT should be actively encouraged for new tailings facilities at existing and proposed mines. Safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor.*
> - *For closure. BAT principles should be applied to closure of active impoundments so that they are progressively removed from the inventory by attrition. Where applicable, alternatives to water covers should be aggressively pursued. (p. 125)*

Interpreting, the Panel is saying:

- For existing impoundments – apply Best Applicable Practices (discussed below)
- For new TSFs, the recommended direction is clear – dry tailings, underground tailings disposal, or other non-wet alternatives. This raises the question of how to treat mines that are already in the proposal process, but which have not yet received regulatory approval. Reason would say that since "*… cost should not be the determining factor"* all new impoundments should be dry, but economics is still the strongest driving factor in any mine proposal. This is probably the most cogent issue associated with Panel's observation that "*The Panel firmly rejects any notion that business as usual can continue*." The Panel is saying safety, not cost, should be the determining factor in waste impoundment design.
- For closure of existing impoundments – all closure plans for existing impoundments should be for dry closure, not for water covers, even if this means increased and perpetual water treatment.

Best Applicable Practices (BAP)

Best Available Practices are more complex and detailed than Best Available Technologies. The Panel describes the situation thusly:

> *The safety of any dam, water or tailings, relies on multiple levels of defence. The Panel was disconcerted to find that, while the Mount Polley Tailings Dam failed because of an undetected weakness in the foundation, it could have failed by overtopping, which it almost did in May 2014. Or it could have failed by internal erosion, for which some evidence was discovered. Clearly, multiple failure modes were in progress, and they differed mainly in how far they had progressed down their respective failure pathways. (p. 126)*

The Panel makes a number of detailed recommendation for BAP that would impact dam designers, mine operators, and regulators. The BAP recommendation of most note is to implement Independent Tailings

Review Boards (ITRB) for all large tailings dams, and that the effectiveness of an ITRB depends on the following:

- *That it not be used exclusively as a means for obtaining regulatory approval.*
- *That it not be used for transfer of corporate liability by requesting indemnification from Board members.*
- *That it be free from external influence or conflict of interest.*
- *That there be means to assure that its recommendations are acted upon. (p. 130)*

The Panel believes that it is essential that the reports of the ITRB "*… go to senior corporate management and Regulators.*" The Panel does not include the public as one if its suggested parties to be informed. Whether this is an intentional omission, or whether the Panel assumed that since the reports would go to regulators they would then become public records, is not clear.

The Panel made a number of very insightful observations on Best Available Practices, including:

> *The Panel anticipates that this* (adopting guidelines) *will result in more prescriptive requirements for site investigation, failure mode recognition, selection of design properties, and specification of factors of safety. (p. 133)*

Here the Panel is saying that more prescriptive requirements are needed to provide guidance to tailings impoundment designers and operators. This is not a recommendation that says 'less regulation,' or 'self-regulation,' but a recommendation that clearly says more 'guidance' is needed from regulators.

With a broader view, the Panel also noted:

> *… future BAP require considerations that go beyond stability calculations. It is important that safety be enhanced by providing for robust outcomes in dam design, construction and operations. (p. 126)*

By focusing on "*…providing for robust outcomes in dam design, construction and operations.*" the Panel is saying that tailings dam design and operation must do more than just provide stability calculations. Here the Panel is again demonstrating its focus on safety (in placing emphasis on determining robust outcomes over cost (i.e. merely focusing on stability calculations for the structures that the project can afford).

The Panel notes that in its 'revised costing' approach

> *The chief reason for the limited industry adoption of filtered tailings to date is economic. Comparisons of capital and operating costs alone invariably favour conventional methods. But this takes a limited view. Cost estimates for conventional tailings dams do not include the risk costs, either direct or indirect, associated with failure potential. ... Nor do standard costing procedures consider externalities, like added costs that accrue to the industry as a whole, some of them difficult or impossible to quantify. Full consideration of life cycle costs including closure, environmental liabilities, and other externalities will provide a more complete economic picture. While economic factors cannot be neglected, neither can they continue to pre-empt best technology. (p. 123)*

If "*business as usual*" is to change, then a goal of zero failures which places a priority on conservative assumptions in dam/disposal design must take precedence. Safety in operation must take priority over mine production. From a project standpoint waste disposal costs must be driven by safety considerations, not by 'what the project can afford'.

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