The RISK, PUBLIC LIABILITY, & ECONOMICS of TAILINGS STORAGE FACILITY FAILURES

Lindsay Newland Bowker[1] & David M. Chambers[2]
July 21, 2015

1. Introduction

Prior works interpreting the history of Tailings Storage Facility (TSF) failures, 1910-2010, have concluded that the lower numbers of failures and incidents in the two most recent decades evidence the success of modern mining regulation, improved industry practices and modern technology. When examined more closely the 100 years of TSF failures shows an emerging and pronounced trend since 1960 toward a higher incidence of "Serious"[3] and "Very Serious"[4] failures. That is, the consequence of loss is becoming increasingly greater.

In a keynote address at a 2011 tailings conference Dr. A. Mac G Robertson described this trend and its implications going forward as elevating risk potential by a factor of 20 every 1/3 century. His address called a "red flag" on the current "Mining Metric" which results in ever larger and higher TSFs (Robertson 2011).

Risk potential has increased by a factor of 20 every 1/3 century. (Robertson 2011)

The Mining Metric creating this exponentially increasing consequence in the event of a tailings dam failure, is driven by continuously lower grades in identified resources and continuously falling real prices of most metals. The costs to excavate more material for a ton of end product at a lower price has been made possible through technology improvements in milling and concentration processes, bulk mining and economies of scale. There have been some new technologies e.g. dry stack and paste tailings and the more prevalent use of center line over upstream dam designs which offer the potential for lower consequence in the event of failure, and perhaps a lower overall risk of failure. However, many of the same features of modern mining that create economic feasibility in lower grades of ore also pose greater challenges for the management of mine waste and waste water. One of the manifestations of these challenges overall is a greater frequency of Very Serious tailings dam failures with significant levels of social and economic consequence, sometimes non remediable.

The modern "Mining Metric" is well mapped: higher mine production necessitated by lower grades of ore, a century of declining prices offset by declining costs per ton. The metric is to continuously develop the resource through economies of scale, larger and deeper footprints, more efficient operations, bigger and better bulk mining technology.

49% (33/67) of all recorded Serious and Very Serious failures from 1940-2010 have occurred since 1990. Of all 52[5] recorded incidents cited, 1990-2010, 17 (33%) were Serious failures, i.e. large enough to cause significant impacts or involved loss of life. Another 16 (31%), were Very Serious failures, i.e. catastrophic dam failures that released more than 1

[1] Bowker Associates Science & Research In The Public Interest, 15 Cove Meadow Rd Stonington, Maine, 04681, Email: lindsaynewlandbowker@gmail.com, Tel: 207-367-5145

[2] Corresponding Author, Center For Science In Public Participation, 224 N. Church Ave., Bozeman, Montana, 59715, www.csp2.org, Email: dchambers@csp2.org, Tel: 406-585-9854

[3] We defined Serious failures as having a release of greater than 100,000 cubic meters and/or loss of life.

[4] We defined Very Serious failures as having a release of at least 1 million cubic meters, and/or a release that travelled 20 Km or more, and/or multiple deaths (generally ≥ 20).

[5] Our study included authoritatively documented TSF failures that were not in the WISE or ICOLD inventories. See Appendix 1, TSF Failure Data Table, for a complete list of TSF incidents & failures included in our study and the basis on which they were classified.

million cubic meters of tailings and in some instances resulted in multiple loss of life. 63% of all incidents and failures since 1990 were Serious or Very Serious. The total costs for just 7 of these 16 large failures was $3.8 billion, at an average cost of $543 million per failure (See Appendix 3). These losses, according to dam committee reports and government accounts are almost all the result of failure to follow accepted practice. These failures are a direct result of the increasing prevalence of TSF's with greater than a 5 million cubic meter total capacity necessitated by lower grades of ore and the higher volumes of ore production required to attain or expand a given tonnage of finished product. We project 11 Very Serious failures 2010-2020 at total unfunded unfundable public cost of $6 billion. We estimate an additional $1 billion for 12 Serious failures this decade. These losses are uninsurable. Very few miners can simply absorb a loss at this scale without risking bankruptcy and permanent closure of a resource that has not yet been "mined out". There is no organized industry attempt to pool these losses in the context of a risk management loss prevention program, and no political jurisdiction issuing permits is large enough to prefund a low frequency high consequence loss of this scale. The inevitable result is either government pays or the damages go unremediated.

Much of our data on cost of large scale failures was sourced from court cases or proceedings where government sought unsuccessfully to recover what had been spent on remediation, compensation for damages or assigned as value for actual socio economic and natural resources loss. Shielded via wholly owned subsidiaries who can legally declare bankruptcy when liabilities exceed assets of the subsidiary (not the parent), the parent companies paid little or nothing toward most of these large losses. In countries founded on the common law tradition that all are responsible for the consequence of their actions, this gap between outcome and expectation for the most serious local impacts violates the terms and conditions of a "social license to operate" and fails to meet a standard of "polluter pays".

Miners Must Move Forward or Perish (Jones 2014)

As we have seen with Mt. Polley, very large releases do not just occur at very large mines. In comparison to the scale envisioned by mines like Pebble or KSM, the Mt. Polley TSF was relatively small, only about 35 meters high at failure with a total capacity of about 74 million cubic meters (Independent Panel 2015). In fact this is the pattern we see on close examination of Very Serious and Serious failures; older TSFs with smaller footprints are pushed to unplanned heights to accommodate additional production that was not anticipated when the tailings dams were originally designed and the permits originally issued.. Capital markets and investors don't finance clean ups. They finance production that is profitable. Smaller companies operate on tighter margins within the same overall metric affecting all miners but are less able to take advantage of and finance optimizations or achieve economies of scale that will keep production costs low enough to maintain a specific mine site as economically feasible.

Our sense of the data and the case histories we have looked to for a deeper understanding of the data is that "mining economics" plays a significant role in TSF failures and that it is important in permitting and in the regulatory process to look beyond the "mechanisms of failure" to the fundamental financials of the miner, the mine, and mega trends that shape decisions and realities at the individual mine.

Our sense of the data, and the case histories we have looked to for a deeper understanding of the data, is that "mining economics" plays a significant role in TSF failures. It is important in permitting, and in the checks and balances built into the regulatory process over the life of a TSF, to look beyond "mechanisms of failure" to the fundamental financials of the miner, the mine, and mega trends that shape decisions and realities at the level of miner and individual mine.

Taking our study of the relationship between "mining economics" and TSF failures 1910-2010 into account, it is our expectation that large failures in the near term (through 2020) will continue to come from operating mines under ownership of smaller miners first commissioned from the late 60's to the early or late 80's. These smaller older mines are producing within the Mining Metric of lower grades and now steeply rising production costs against the continuous possibility of a sharp adverse price swing but with much less capital, as compared with larger mines, to buffer contingencies or provide required levels of stewardship for TSFs from design through closure. For a mega mine like the 100 year old Bingham Canyon mine it was possible to respond to an identified threat of failure and the growing environmental problems of age. It is not clear how smaller old mines will find the funds to identify or respond in a timely fashion to threats at their facilities, or whether regulatory structures now in place will serve well enough to identify such "at risk" facilities.

If they are identified in time, it is not clear how smaller miners skating on thin balance sheets will finance the closure or improvements at TSFs and carve out the funds for new TSFs where necessary. Larger mining companies, however, are better positioned financially to manage and mitigate these threats.

This study anticipates the future trend of Serious and Very Serious TSF failures over the next decade, through 2020, and estimates the total public economic consequence of those failures, which are presently unfunded and un-fundable. We borrow the applicable elements of "loss development" in insurance rate making utilizing 100 years of data on loss and consequence and on the production levels of the mining metric producing TSF waste volumes to project an expected number of failures and an average expected loss per failure from which global estimates of expected public loss can be reasonably estimated.

Having something more like "actuarial data" to refer to is important in understanding the potential magnitude of loss from an individual dam or a permitting districts portfolio of dams and TSFs. With such low frequency high severity losses we can never assign risk to an individual TSF based on its design and receiving environment parameters. Unless it has an identified flaw that puts it at near certain risk of imminent failure, we can't say whether a given dam "will" fail. We can only say what the consequence would be in economic terms if it failed.

Satellite imagery has lead us to the realization that tailings facilities are probably the largest man-made structures on earth. Their safety, for the protection of life, the environment and property is an essential need in today's mining operations. These factors, and the relatively poor safety record revealed by the numbers of failures in tailings dams have led to an increasing awareness of the need for enhanced safety provisions in the design and operation of tailings dams. (ICOLD 2001)

2. Increasing Consequence of Failures

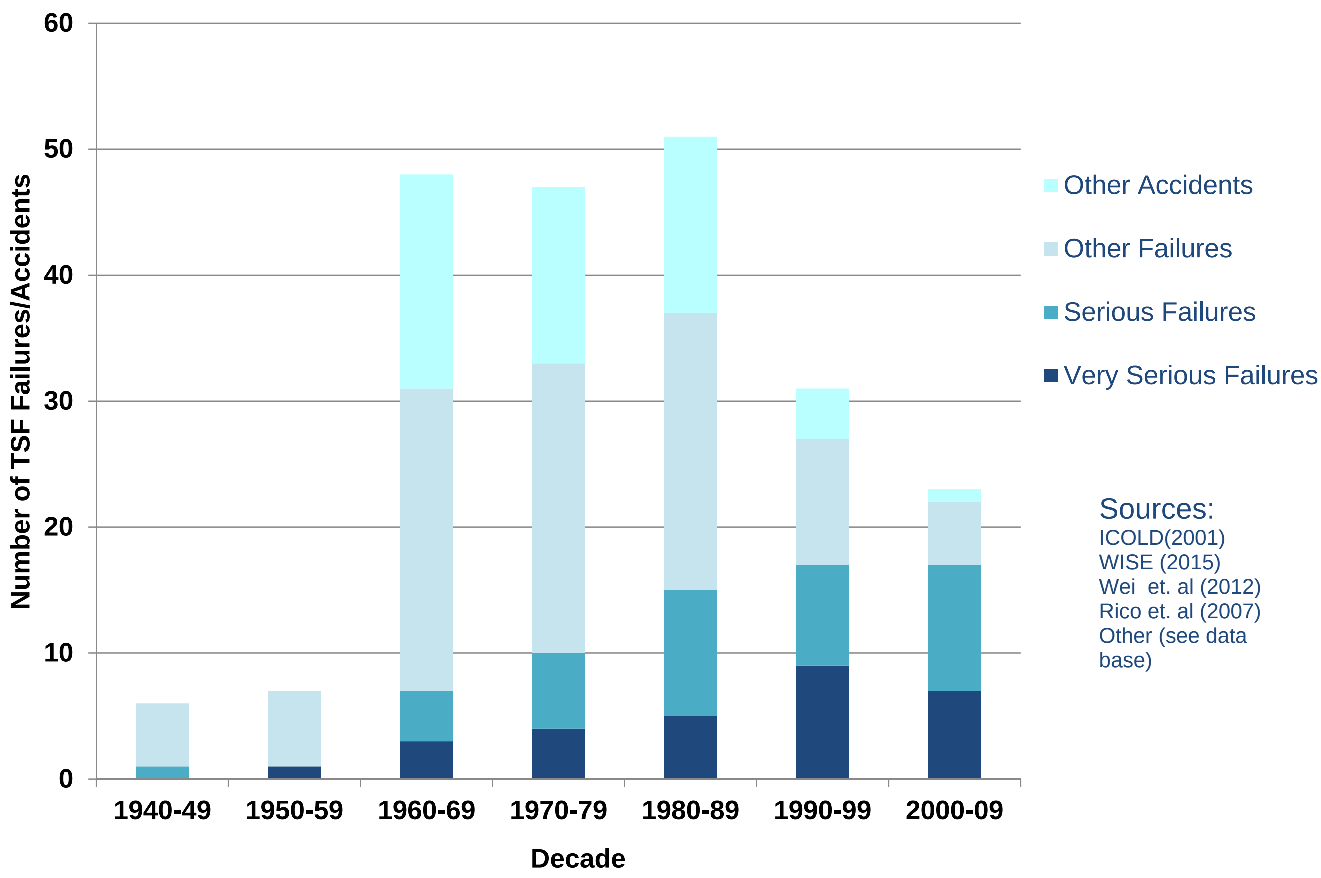
For this study we are interested primarily in the history and trend of Serious and Very Serious Failures rather than all incidents in the International Commission on Large Dams (ICOLD) or the World Information Service on Energy (WISE) compilations. These are the failures that cause consequential compromise of environmental security beyond the mine site. Serious and Very Serious failures accounted for 31% (67) of the 214 TSF failures and accidents 1940-2010, but comprise 63% (33/52) of the 52 total incidents, 1990-2010, with sufficient data for meaningful analysis.

We defined Serious failures as having a release of greater than 100,000 cubic meters and/or loss of life. 38 recorded incidents out of the 214 failures and accidents in the period 1940 to 2010 (18%) that had sufficient data for analysis met that criteria. 17 of those (45%) occurred in the last two decades.

We defined Very Serious failures as having a release of at least 1 million cubic meters, and/or a release that travelled 20 Km or more, and/or multiple deaths (generally ≥ 20). Very Serious failures comprised 14% of total historic events (29/214), but 31% (16/52) of all incidents and events in the past two decades (1990-2010). The complete list and criteria is presented in Appendix 1, TSF Failure Data Table.

This very clear trend to larger and more consequential losses is apparent in Figure 2.1 below. The clear aqua and paler blue is the distribution of incidents other than failures, most of which are very small with little or no release or consequential damage. Prior to 1980 Other Failures and Accidents (pale and aqua blue) were most prevalent. Post-1990 Serious and Very Serious failures (deep and dark blue) dominate.

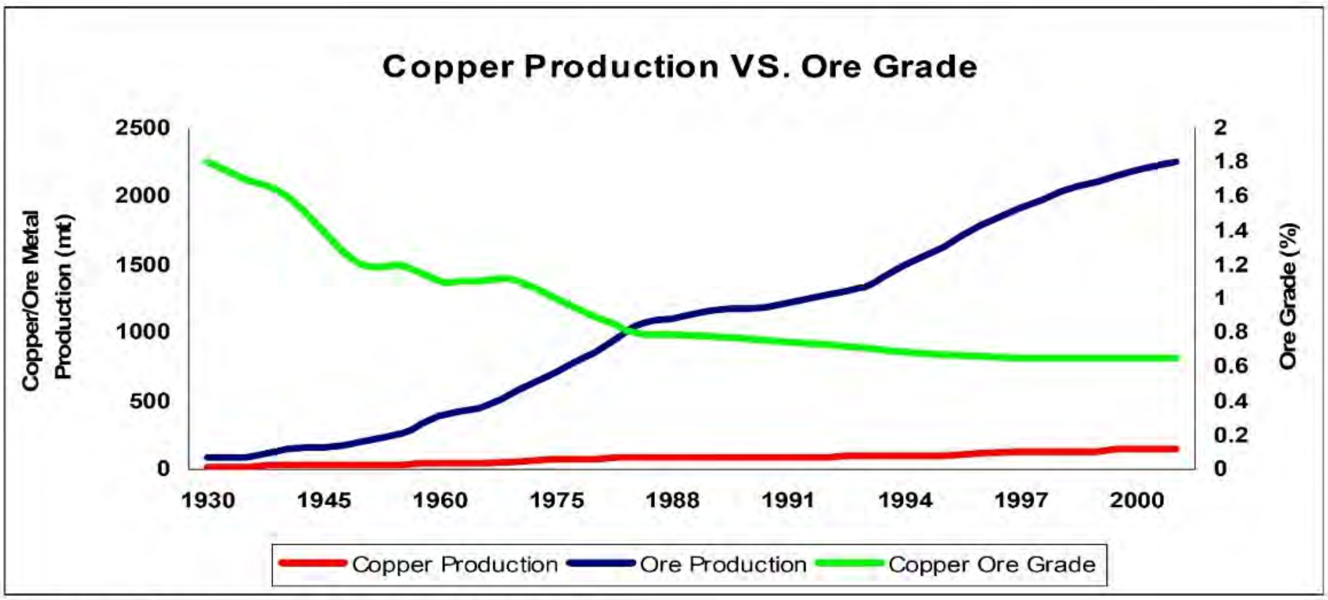
Figure 2.1 Increasing Severity of TSF Failures Globally 1940-2010



3.0 RELATIONSHIP BETWEEN LARGE FAILURES & THE MINING METRIC

Our aim was to explore the relationship between economic factors not explicitly accounted for in the permitting and regulatory oversight of mines and the observed trend toward failure incidents of greater consequence. Our data base included a count by decade of failures (Serious failures, Very Serious failures, Other failures, and Other Accidents) and a data set of variables describing the main economic trends driving mine production: price, costs to produce and grade. The following chart for copper prepared by the Raw Materials Group for the World Bank (World Bank 2006) describes the generic fundamental elements of the Mining Metric affecting all primary metals and most precious metals.

Figure 3.1. Copper Production & Ore Grade



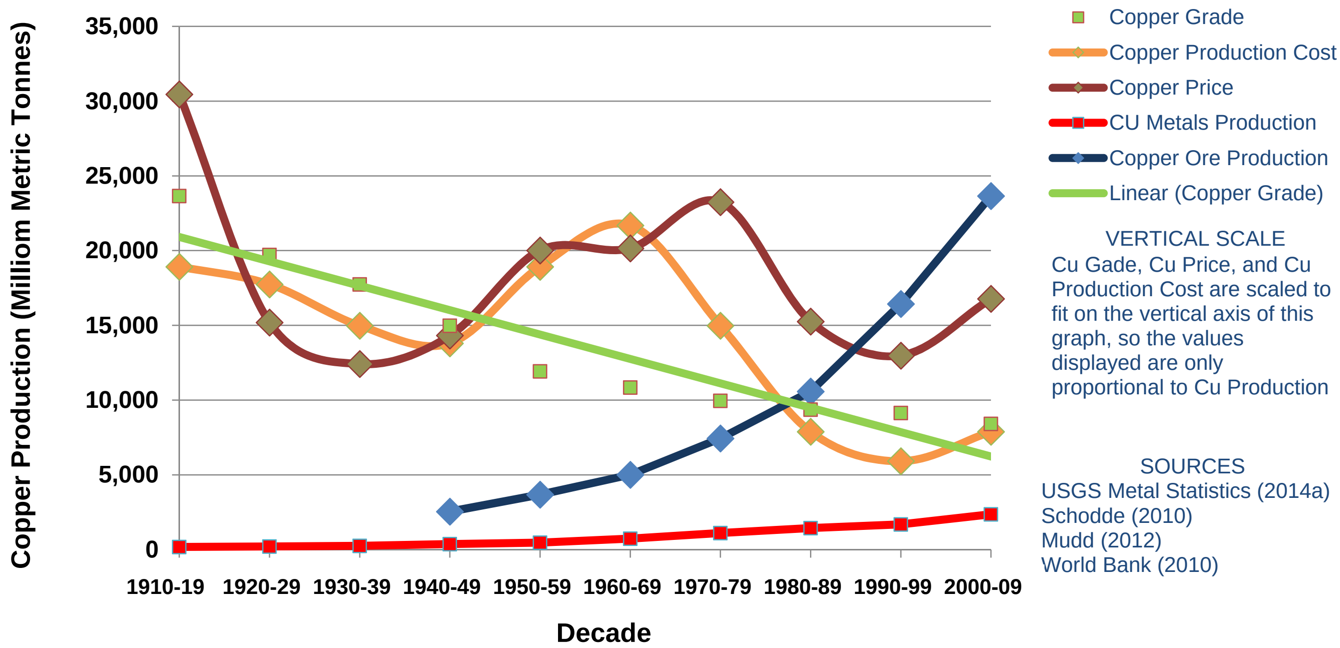
Source: Raw Materials Group, Stockholm

The chart is highlighting the very dramatic change in the relationship between metals output (the red line) which increased only 17% over the decade 1990-2000 and ore production[6] which increased 63% as grades continued to decline. The two key elements missing from this chart that explain how it was possible to "grow the resource" against a long trend of falling prices and falling grades the economic viability of these trends are the market price of the red line (the final refined product) and the costs to produce are highlighted by Richard Schodde, who noted that the declining costs to produce more than offset a century of falling prices. (Schodde 2010)

This fuller context is shown in Figure 3.2 below. That production costs have offset price is apparent through 1990.

[6] In our analysis we have used copper ore production data taken from the World Bank/Raw Materials Group graph because it is the only available published data for copper ore production. We have also done a comparison by using average copper ore grade and metal production to back-calculate to ore produced. For the back-calculation we used metal production data from Kelly & Matos (USGS 2014a), Schmitz/ABARE (Mudd 2012), the International Copper Study Group (ICSG 2014), and copper grade data from Mudd (2012). These data compared very favorably with the World Bank/Raw Materials Group data. We made several attempts to contact the Raw Materials Group through their corporate parent, SNL Metals & Mining, in an attempt to both verify the data (World Bank 2006) and the method(s) they used to develop it, but did not receive a response to these inquiries.

Figure 3.2 Mining Metric 1910-2010
Declining Prices Offset By Lower Production Costs



In correlation analysis, Table 3.1, price had a lower correlation than production cost with all failure classes. The most significant correlations with the four failure variables were with Cu Production Cost, Cu Grade and annual Cu Ore Production volume and Cu Metal Production. The correlations were only notable with the two highest failure severity categories. Cu Metal Production had higher correlations with both Very Serious failures (0.881) and Serious failures (0.826) as compared with Cu Ore Production. Cu Ore Production is more closely related, however, to TSF waste volume and also seems to distinguish between the two highest severity classes. This small difference also occurs with Cu Grade (greater negative for Serious) and Cu Production Cost (greater negative for Very Serious).

Table 3.1 Correlation Between Failure Severity and Mining Metric Indicators

	Cu Ore Production	Cu Metal Production	Cu Grade	Cu Prod Cost	Cu Price
Very Serious Failures	0.860	0.881	-0.794	-0.788	-0.427
Serious Failures	0.720	0.826	-0.884	-0.682	-0.126
Other Failures	-0.265	-0.099	0.298	0.300	0.489
Other Accidents	-0.216	-0.050	-0.312	0.281	0.485

Abbreviations:

Cu Prod Cost = Cost to produce copper concentrate from copper ore, including waste disposal

Cu Grade = grade of copper in the ore

Cu Prod = copper ore production

Other Failures = tailings dam failures and incidents other than Serious or Very Serious Failures

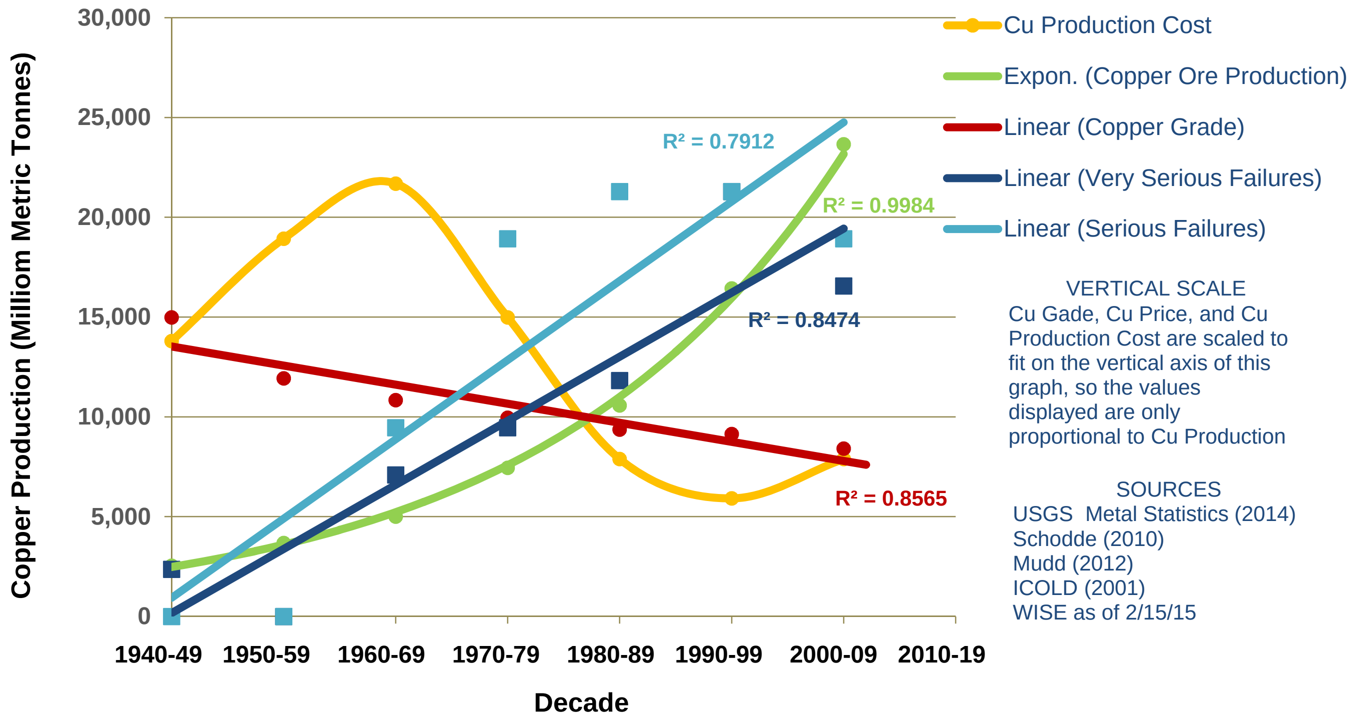
Serious Failures = Serious tailings dam failures

Very Serious Failures = Very Serious tailings dam failures

Sources: USGS Metal Statistics (2014a), Schodde (2010), ICOLD (2001), WISE (2015) & additional

Therefore, we chose Cu Ore Production, Cu Grade and Cu Production Cost to produce for further analysis. We did not include, or have a basis for deeper consideration, of copper price. These relationships are graphically presented in Figure 3.3 below.

Figure 3.3 Relationship Between Mining Metric and TSF Very Serious and Serious Failures 1940-2010



The key mining metric variable, Copper Production Cost to produce, dropped from $85/tonne in 1900 to only $15/tonne in 2000. Over this same period price dropped from $7,723/tonne to $3,292 per tonne. The largest cluster of Serious and Very Serious failures of TSFs, 88% (59/67), occurred in the long downward price trend from 1970 to 2000. 86% (25/29) of Very Serious failures and 89% (34/38) of Serious failures occurred during this period. 2000 marked the beginning of an upward trend in price but also a 33% increase in costs to produce, from $15/tonne in 2000 to $20/tonne by 2010 but with Serious and Very Serious failures still representing 71% (15/21) of all failures for the decade 2000-2010.

The dramatic shift emphasized in the World Bank/Raw Metals charts (Figure 3.1) co- occurs with an upward swing in costs to produce while grade continues to fall (Figure 3.3). This suggests a higher level of financial risk beginning in 1990, which co-occurs with the emergence of Very Serious TSF failures.

Our data suggests that the many smaller mines and miners that became part of global production of all primary and precious metals post-1950 were not as able to take full advantage of as many of the technologies and economies of scale as larger miners, and therefore remained more sensitive to price changes than larger miners, with frequent shutdowns in a small portfolio of investments as price changes made continued production unviable. Smaller miners run on thinner balance sheets with more price vulnerability in comparison to the larger miners.

Another major factor affecting stewardship for TSFs and other mining environmental liabilities, which was not mapped sufficiently for inclusion in our database, is access to capital markets. Smaller mines have always had access only to more risk tolerant markets, such as the Toronto Stock Exchange, and sometimes, as in the case of Mt. Polley, with one or two specific backers. The top miners are financed through markets with tight, well defined credit standards and an increasing underwriting emphasis on full disclosure and accounting of environmental liabilities. Smaller miners have almost no meaningful access to insurance for their environmental liabilities, whereas larger miners have more integral relationships with insurance and reinsurance markets (even though the types of risks that are insurable are no different between large and small insurers). These large market relationships create more external accountability to environmental risk management and to financial risk management for larger miners than exists for small miners, and a more rigorous ongoing process of review and reckoning. Regulatory structures don't include enough structure on assessment of financial capacity to balance that difference creating an "apparent norm" of higher financial risk in smaller mines that translates into the higher losses we see in the historical data.

Two significant changes in financial risk also weigh more heavily for smaller mines than for larger mines: a radical contraction of all capital markets for mining (Jones 2014); and, a 30% increase in costs to produce. The increase in costs to produce is across the board and attributable, according to informed market analysts, to both an increase in energy costs and also in foreign exchange rates. Chile, a major producer of copper globally, has had to commit to a major capital program to improve its mining infrastructure to maintain grade and hold its place in world concentrate markets.

While each principal base metal (iron, aluminum, copper, zinc, etc.) has its own version of the Mining Metric, the basic "shape" and slope of trend lines for production and price for all base metals are the same. The basic bottom line, vis-a-vis manifest environmental loss across all metals, is the same. All operate on close margins. Those with larger budgets, better quality assets, lower production costs and uniform corporate policies on optimization and efficiency at each site, and who can also achieve economies of scale, will generally fare better than smaller miners with tighter budgets and less access to global capital markets. The global capital markets are able to provide external checks and balances on financial/risk management relationships that hold miners to account on environmental liability management, even when regulatory structures don't – but only if the miner in question is working in the global capital market.

Copper is widely recognized as a bellwether base metal for the mining industry. Most works on mining economics use copper as the "index metal". Beyond that, the greater quality and detail of regularly produced copper commodity information over the entire last century led us to explore its use as the index metal for TSF failures, i.e. expressing TSF failures per million tons of copper production. The USGS publishes metal statistics on two of Mining Metric elements, price and mine production, but no historical data on costs to produce or grade. So copper is the only metal for which it was possible to establish a full century long "actuarial" data base on the relationship between the economics of mining and environmental loss attributable to TSF failures. Going forward it will be possible to build the data base for other metals from current and data and short term projections. In the next section we present the statistical correlation between mining economics and TSF failures.

4.0 THE STATISTICAL CORRELATION BETWEEN MINING ECONOMICS & ENVIRONMENTAL LOSS FROM TSF FAILURES

We chose Canonical Correlation Analysis (CCA) as a way of further exploring the relationship between the failure severity categories we created for this research and the main elements of the mining metric that affect all miners and all mine sites. We were interested in knowing whether there is a significant relationship and if so, whether it warrants greater attention in permitting standards and oversight of mine permits. We know from past study of TSF failures that there are many physical attributes of a TSF that influence severity as well as other often noted but so far unstudied factors such as the structure of the regulatory framework and the technical capacity available to oversight.

Canonical Correlation is a multivariate technique that aims at identifying the degree of influence of one data set with another (rather than causality). We had no pre conceived notion of what the degree of influence might be, nor did we have the data set we would like to have had. Nevertheless, the results of this exploration strongly suggest that the influence of the mining metric on frequency and severity of TSF failure is unexpectedly strong.

The First Canonical variant F1 explained 95% of the variability between the two data sets (failures v mining metrics elements). The correlations between F1 and both high severity variables are strong: Very Serious (-0.922); and, Serious (-0.995). The Wilks Lambda on F1 was 0.046 indicating a high degree of certainty that the two data sets (Failures and Mining Metric are not independent of one another). The Eigenvalue for F1, 0.903, suggests a very strong linear relationship between the two data sets (See Appendix 2, Technical Documentation on Canonical Correlation Analysis, for the data set and complete technical documentation on the Canonical Correlation).

Table 4.1 Canonical Correlation Values

	F1
Canonical Correlation	0.950
Eigenvalue	0.903
Wilks' Lambda	0.046
Correlation between:	
Very Serious failures & F1	-0.922
Serious failures & F1	-0.995

Because no other research team that we could find had explored the dimensionality of this relationship, we began with a larger set of mining metric variables beyond the 4 basic variables (Cu Production, Cu Production Cost, Cu Price and Cu Grade), and also attempted to create variables indicating the characteristics of TSF's so that the degree of influence of the mining metric variables could be compared with dam characteristics. We integrated all ICOLD/WISE recorded incidents from 1910 to 2010 into a single reconciled data set, and in the course of our research on consequence of those incidents discovered several compilations that added to WISE/ICOLD, and which also filled in gaps on our main indicators of consequence (total TSF release and release run out). We used both correlation matrix analysis and canonical correlations to find the strongest set of mining metric variables, which turned out to be tons of Cu Ore Production, Cu Production Cost, and Cu Grade. As there was only one recorded Serious failure prior to 1940 and very little information on all incidents, our final data set and analysis focused on the period 1940-2010.

Initially, none of our created synthetic variables for the Mining Metric were as strong the four main variables (copper price, production cost, grade, and copper ore production). One variable, Risk Factor, which combined cost and production volume into a single indicator actually had higher correlations with each of the two most Serious failure categories and also in linear regressions on each of the two highest severity categories. It did not perform as well in lieu of production and cost, though, in a canonical correlation. Further work is needed to evaluate Risk Factor so we are not presenting it here. Within the 4 basic variables price and cost canceled each other out, and cost was the stronger correlation, so the final data set for the Canonical Correlation was only cost, production and grade.

We were not able to develop a meaningful data set on dam characteristics for comparisons of degree of influence as between the variables of the Mining Metric and various dam characteristics (dam height, volume, etc.).

Even though these results are not conclusive, because the number of observations is very small for a CCA, they are persuasive evidence of a greater than expected and very significant influence of Mining Metric mega trends on the frequency and severity of TSF failures. Further, it is important to note that these are not "individual measurements" in the usual sense, but rather aggregations by decade of over 200 observations, and so should be afforded more consideration and weight than would normally attend such a small set of observations. The data set and the full CCA output are at Appendix 2, Technical Documentation on Canonical Correlation Analysis, along with additional technical annotation.

Although further research would be useful to shed more light on how these mega trend variables interact to affect failure, these results in our opinion support a conclusion that financial feasibility of the mine and financial capacity of the miner require greater specific consideration on permit issuance and permit oversight.

Strength of Influence of Copper Ore Production

Among the variables in the Mining Metric data set we were especially interested in the relative degree of influence/connection between copper ore volumes and the TSF failure categories especially whether it could be a reliable denominator for TSF failure rates. The conventional one to one correlations, which are a standard output of CCA in XLSTAT©, showed that both Very Serious and Serious failures were strongly correlated with copper ore production, 0.860 and 0.720 respectively. We had both production and price data on all metals 1900-2010 from the USGS metal statistics (USGS 2014a), but the correlations with aggregate all metals production and the failure variables were not nearly as strong. So the CCA output also lent support to copper ore production as the most reliable and meaningful denominator for TSF failure rates.

Although we did reasonably form an expectation that the mega trends would have a measureable and significant effect on the failure categories established (i.e. that the mega trends contribute to severity), we also know from dam committee reports and other research that many other dam specific elements have a known effect on severity of failure. The final output of a canonical correlation is a set of synthetic variables which maximize the accounting for mutual variability between the two sets of variables. Thus it is an approach which inherently recognizes that all of the information needed to explain the output of interest, the severity of failures over time, are not contained in the analysis, and further that the influence that may exist within in the expected determinant set (the mega trend variables) may result from complex interactions among the determinant data set.

While Canonical Correlation Analysis, and its focus on dimensionality rather than causality, may be the perfect tool for exploring the effect of mega trends of the Mining Metric on the trends in severity of TSF failures, many key variables that would shed more light were not available. We would hope in the future to have a more rich and complete data set, including standing TSFs that didn't fail with the same geographic distribution as those that did.

At present there is no comprehensive compilation of recent or historic tailings dam failures. This is partly understandable given the multi-national nature of the mining industry, but given the severity of the problem, coupled with the fact that it is probably not realistic to think that the problem can be solved without a full analysis of the nature of the problem, it is disappointing that someone has not stepped forward to perform this service.

5.0 Frequencies & Projections from Copper Production Volumes

The results of the correlation analyses give strong support that copper production volumes are a meaningful denominator for TSF failures. Even if there were a centrally professionally maintained inventory of TSFs it would, in our opinion, still be preferable to express TSF failures on the basis of mine production.

Copper metal production is the only reliably managed data element we have available globally that correlates directly with TSF risk potential. The analysis shows us, however, that copper ore production distinguishes more clearly between the two high severity failure categories and is a better descriptor of risk. While it is not routinely and authoritatively compiled and reported as metal production is, the World Bank/Raw Materials Group data (Figure 3.1) did give us an authoritative and reliable historical compilation. As ore production volume is more directly related to TSF waste, in our opinion Cu Ore Production is the better predictor to use. We don't have a global census inventory of standing TSFs. To be meaningful any denominator must be available for all TSFs globally as it is only through data on the global whole that meaningful expectations and comparisons can be made at the level of a nation, province or state.

Secondly, we know there is a great deal of variation in the standing operating TSFs at any point in time. Size and therefore possible maximum consequence of failure varies from small mines with a total capacity of less than 10^5 cubic meters to those over 10^7 cubic meters. Therefore, failure frequency per TSF isn't meaningful without enough attending globally available data to adjust for size and other known risk factors. Post failure it is possible to reexamine the losses more closely, taking account of the specific characteristics of the particular TSF (and eventually to recompile findings if enough new information is developed or if there is more systematic capture of these elements in WISE or other data sources).

Thirdly, we know that the risk profile of TSFs is constantly changing based on production volumes, and how the waste volumes generated from that production are managed. We know that 90% of all TSF failures in Europe (Rico et. al. 2008), to 95% in China (Wei et. al. 2012), occur during operations, as opposed to being in standby or in closure. Cu Ore Production provides an equalized basis for looking across an inventory of TSFs with highly varying size, and it is more directly tied to the phase of active life for the TSFs in which most failures occur (Rico 2008).

Table 5.1, below, shows the failure incidents data for Very Serious failures, Serious failures and Other failures by decade, expressed per million tons of copper ore production. For example, a 0.0020 rate for Other failures in 1940-1949 on 2,545 million tons of ore production describes 1 event. A 0.0006 rate on 16,437 million tons (16.44 billion) of ore production in 1980 describes 10 Other failure events.

Table 5.1 Failures per Million Tonnes Copper Mine Production 1940-2011

Decade	Cu Ore Prod (MMt)	Very Serious failures (#)	Very Serious failures rate	Serious failures (#)	Serious failures rate	Other Failures (#)	Other Failures rate	Other Accidents (#)	Other Accidents rate
1940-49	2,545	1	0.0004	0	0.0000	5	0.0020	0	0.0000
1950-59	3,680	0	0.0000	0	0.0000	7	0.0019	0	0.0000
1960-69	5,004	3	0.0006	4	0.0008	25	0.0050	17	0.0034
1970-79	7,445	4	0.0005	8	0.0011	23	0.0031	15	0.0020
1980-89	10,575	5	0.0005	9	0.0009	22	0.0021	14	0.0013
1990-99	16,437	9	0.0005	9	0.0005	10	0.0006	3	0.0002
2000-09	23,658	7	0.0003	8	0.0003	5	0.0002	1	0.0000
Total/Ave	69,344	29	0.0004	38	0.0005	97	0.0021	50	0.0010

Abbreviations:

Cu Prod = copper ore production in the decade noted in millions of metric tonnes

Very Serious failure = multiple loss of life (~20) and/or release of ≥ 1,000,000 m^3 semi-solids discharge, and/or release travel of 20 km or more.

Serious failure = loss of life and/or release of ≥ 100,000 m^3 semi-solids discharge

Other failures = ICOLD Category 1 failures other than those classified as Very Serious or Serious

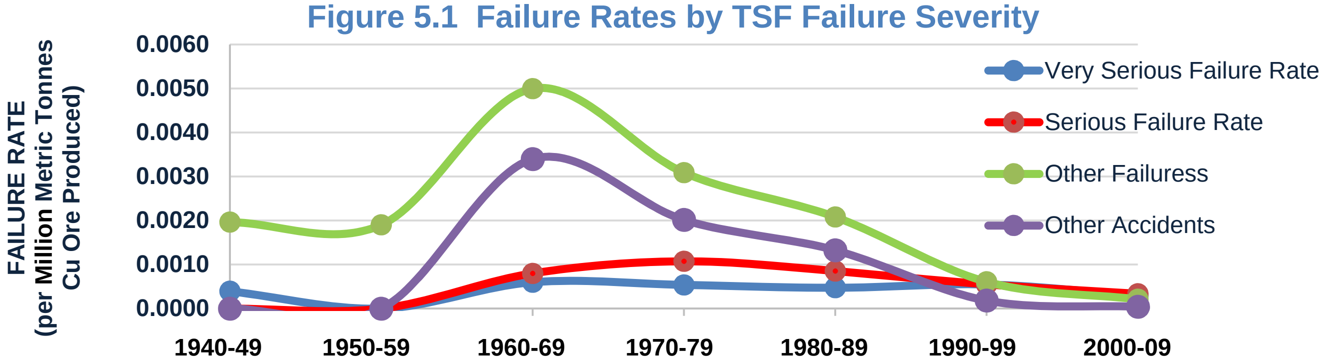
Other Accidents = ICOLD Category 2 accidents other than those classified as Very Serious or Serious

Failure Rate = number of failures per million metric tonnes (MMt) Cu Ore Produced

The overall rate of Very Serious failures and Serious failures 1940-2010 were comparable, 0 00004 and 0.0005 respectively. As expected, the higher the severity the lower the frequency. The frequency rates for all the lower severity loss categories were much lower; 0.021 Other Failures, 0.0010 for Other Accidents.

As shown in Figure 5.1 below the most dramatic change occurred with the shift from predominantly Other Failures (less Serious failure events) to predominantly more Serious failures post 1970. Across the board for each failure category, the rate of failure per ton of copper production has decreased. However, as noted in the introductory section, the severity of failures has steadily increased. More of the failures that occur are Serious or Very Serious). Our data is incomplete (we don't have actual loss data for every Serious and Very Serious failure), however it is certain that that the absolute consequence of all TSF failures has increased and is increasing substantially. This is obvious in that 55% (16/29) of all catastrophic (Very Serious failures) over the past 100 years have occurred since 1990, and that 74% (17/23) of all failure events post-2000 are Serious or Very Serious.

Figure 5.1 Failure Rates by TSF Failure Severity

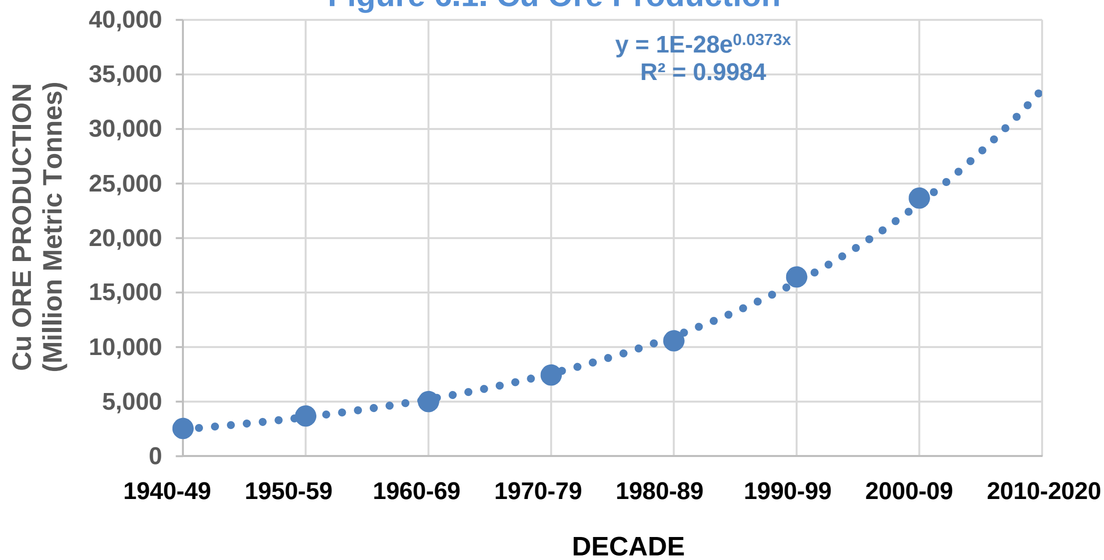


6.0 PROJECTIONS FROM COPPER MINE PRODUCTION V. FAILURE TRENDS

The heart of risk analysis is to reliably measure and forecast expected losses that are beyond control (and to hopefully finance these losses via third party transfers, i.e. insurance or risk pool). We know that will not apply to TSF failure losses, as almost without exception all losses were subject to control and prevention. The basic techniques for forecasting future losses, based on past loss experience, are nevertheless applicable to anticipating the future consequences of continuing the Mining Metric without some new forms of regulatory control and oversight which takes more adequate account of the financial viability of the deposit and the miner.

The Copper ore production estimate for this decade (2010-2019) is advanced from the equation associated with the trend line which had an extremely high R square, 0.9984. The result is 36,338 million metric tonnes, a projected increase of 54%.

Figure 6.1. Cu Ore Production



In insurance rate making the normal procedure for estimating future losses is to combine the last four years of loss data. For this data, though, each cell represents 10 years of experience data not 1, and we can see from analysis of the variables over 100 years that the events that shape loss and failure are unique to each decade, i.e. that each decade has its own pattern of determinant/loss-affecting characteristics.

Table 6.1 below compares three estimates of next decade failures based on three approaches to uses of copper production based frequencies: (1) average of last three decades; (2) last decade only; and, (3) "50-50" weighting between most recent decade and last three decades. The trended values based on failure data alone are presented in Table 6.1 in the last row of the table.

The chart values in Table 6.1 are computed from the trend line equations as they appear in Figure 6.2 (The trend lines in Figure 6.2 are linear data projections, rounded to the nearest whole number).

Very Serious failures 2020 = 0.1393*2020-271.64 = 9.746

Serious failures = 0.1643*2020-3189.6 = 12.026

Table 6.1 Predictions 2010-2020 From Historic Failure Rates

Basis	Very Serious failures Rate	Very Serious failures Pred.	Serious failures Rate	Serious failures Pred.	Other Failures Rate	Other Failures Pred.	Other Accidents Rate	Other Accidents Pred.
Last 3 Decade Ave	0.0004	15.9	0.0006	21.0	0.0010	35.1	0.0005	18.8
Last Decade	0.0003	**10.8**	0.0003	**12.3**	0.0002	7.7	0.0000	1.5
50-50 Weighting	0.0004	13.3	0.0005	16.7	0.0006	21.4	0.0003	10.1
Chart		**9.5**		**12.0**				

Rate = number of failures per million metric tonnes (MMt) ore mined

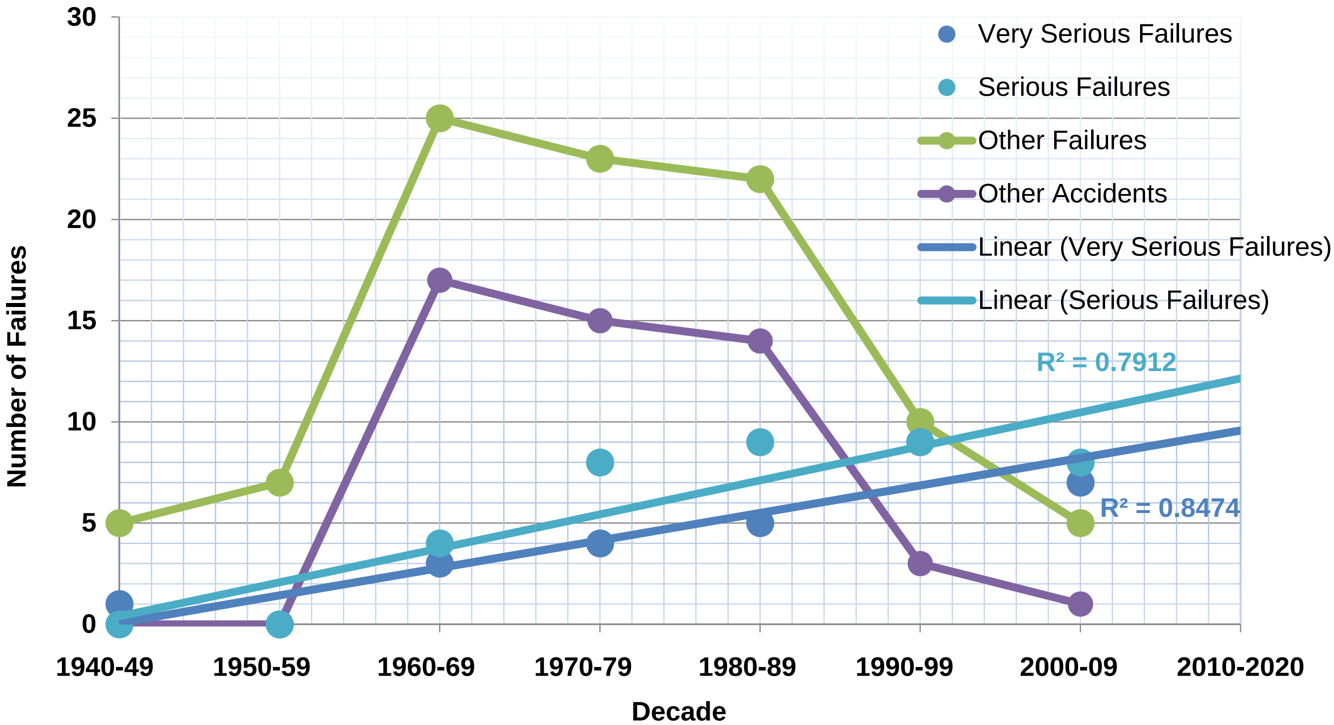
Pred = number of predicted failures in the period 2010 - 2019

The high R-squared values on the trend lines for both Serious failures and Very Serious failures indicate a "goodness of fit" that is apparent on visual inspection alone (i.e. the markers closely track the trend line). The calculated predictions by chart trend line equation most closely matches the prediction based on the most recent decade failure rates.

The canonical correlation demonstrates that the trends in the high severity failures are shaped by the entire metric (as represented in grade, cost and production). Inspection of the data set shows that the main elements of the metric as of 2009 were very different than those of either of the prior two decades. It is not likely costs will return to as low as $15 or that prices will fall to as low as they were in either of the two most recent decades. Therefore we have greater confidence in the most recent failure rate by class than we do in the either the average of the last three decades, or a 50-50 weighting between the average of the last three decades and current decade. Still there are already clear indications that this decade involves uncertainty about the direction of cost to produce, price, and perhaps even production volumes. The previous two decades both had constant costs of production against failing prices, a very different pattern with an expected higher rate of failure. Mid-decade 2010-2019 the overall environment seems to be trending toward higher financial risk, and therefore higher potential environmental liability than the 2000-2009 decade.

We are though projecting 12 Serious failures and 11 Very Serious failures for the present decade (2010–2019) relying on the failure rates of the most current decade (see Table 6.1).

Figure 6.1 Failure Predictions By Trend Line



Our dataset included 5 failures 1910-2010 that met our criteria for Very Serious that were not listed in WISE or ICOLD data bases, from a compilation of Chinese major failures and a compilation of Philippine significant tailings incidents. The frequency rate 2000-2009 was essentially the same with or without these five failures. We cannot say that whatever undercount actually exists in WISE/ICOLD data would have no bearing, however, in our view this is a conservative projection quite apart from the possible undercount issue. It makes no allowances for the possibly higher risks of price jitters on many metals (e.g. molybdenum, iron, zinc, gold), of rising production costs mostly from energy and foreign exchange rates, and the uncertainty about the roles China, Chile, and Peru (as producers, and China and India (as consumers) will play, and how that could elevate financial risks for smaller mines and smaller miners.

7.0 Projected Cost of Remediation and Non Remediable Uncontrolled releases from TSFs

We searched the historic record for what local authorities had deemed the costs of public damages from the major releases in our database, and found sufficient authoritative documentation on a total of 6 of the 14 post-1990 Very Serious uncontrolled TSF originating release incidents. Our process was to translate from foreign currency to US in the year of the incident and then to convert those $US to 2014-$US. The average cost of the 7 incidents for which we found authoritative data was $543 million (Figure 7.1). That translates to a projected public liability for remediation of 11 Very Serious releases from TSFs at cost of approximately $5 billion globally before the end of this decade (2020). We did not attempt any estimates for the expected 12 Serious failures by 2020 but a guess of an additional $1 billion is probably not unreasonable.

Usually losses are forecast from a record of homogeneous data maintained by one source over time by the entity which has actually incurred or paid out those losses (i.e. an insurer or a rating bureau like the Insurance Services Office), or a company's or agency's risk manager. That is not true of our loss history data for TSF failures. Although WISE has followed with some detail on a few cases involving litigation for recovery of outlays (e.g. for Los Frailes), descriptions of consequence are brief and narrative. There are few links to more in-depth authoritative analysis on consequence. Losses are not systematically or uniformly captured or developed as part of either the WISE or ICOLD databases. The costs data we present here is all we could find for Very Serious post-1990 failures which pertained to environmental losses, and which were cited or developed by authoritative or credible sources.

We aimed for as much homogeneity as possible in choosing amounts documented for inclusion in our loss history (i.e. to include only natural resources/environmental losses whether or not cleanup was ordered or undertaken. In one case, Omai, we used a token amount to acknowledge what farmers, fisherman, and NGOs attempted to recover, and to acknowledge what is widely agreed was environmental damage notwithstanding the governments judgments to the contrary. The token amount allocated to Omai actually lowers the overall average cost estimate but, given all the litigation and controversy that has attended, simply admitting to the extent of environmental damage we felt Omai could not simply be left off the list, even though we could not find documentation on what part of $2 billion joint damage claim was attributable to documented environmental damages to lands and waters.

While sketchily sourced and documented, the few failures which are systematically and authoritatively developed give us a high level of confidence that our average natural resource loss of $543 million for a catastrophic failure is not overstated. For example, the estimated costs to clean up the Los Frailes spill was borne primarily by the Andalusian Government as a non-remediable loss. We think that situations like this, where the actual costs are so high or cleanup costs so astronomical that losses from Very Serious TSF failures will more and more be permanent non-recoverable losses. Mt Polley is a possible example of a tailings spill into a creek and lake that will not be retrieved. Such losses will, hopefully, still have a complete accounting of value whether or not remediation is ordered, undertaken, or possible.

The data on the 7 failures forming the basis of our average loss amount of $543 million and its sources are presented in Table 7.1, below. See Appendix 3 for more detail on this chart.

Apply this to our projections of the number of Very Serious failures, 11 results in a projected unfunded unfundable public liability loss of $6.0 billion from Very Serious TSF failures for the decade 2010-2019.

Our sense of the data and case histories is that this decades' TSF failures will continue to arise mostly from standing operating TSFs, pushing older TSFs up to and past their original designs, or stretching the limits of TSFs that were not built or managed to best practices in the first place. We expect most to arise from smaller mines and miners. We see in the record an indication that in many instances releases and events suggesting fundamental problems with the structure of the TSF preceded a final catastrophe by two to four years. In the cases of Golden Cross (New Zealand), Bingham Canyon (Utah), and Mike Horse (Montana) long term issues with dam stability led to closures in time to avert catastrophe at costs that were significantly lower than the remediation costs or assessed damages would have been for a structural failure.

Table 7.1 Documented TSF Very Serious Natural Resource Losses 1990 – 2010

TSF Failure	Year	Original Currency (Millions)	Failure Year M US$	2014 M US$	Ore	Release (M m^3)	Run Out (km)	Deaths
Kingston Fossil Plant, Harriman, Tennessee, USA	2008	US 1,200	$1,200	$1,300		5.4	4.1	
Taoshi, Linfen City, Xiangfen, Shanxi Province, China	2008	US 1,300	$1,300	$1,429	Fe	0.19	2.5	277
Baia Mare, Romania	2000	US 179	$179	$246	Au	0.1	5.2	
Los Frailes, Spain	1998	EU 275	$301	$437	Zn/Cu /Pb	4.6	5	
Marinduque Island, Philippines	1996	P 180 + US 114	$123	$185	Cu	1.6	27	
Omai, Guyana	1995	US 100	$100	$156	Au	4.2	80	
Merriespruit, South Africa	1994	R 100	$29	$46	Au	0.6	2	17
				======				
		Average US$2014: $543		$3,799				

Reviewing their own role in creating and perpetuating the environment in which we have allowed TSFs at risk of consequential failure to proliferate, the International Bank for Reconstruction & Development and the International Development Association put it well:

> *"Governance should be strengthened until it is able to withstand the risks of developing major extractions. Once that has happened, the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA) can add support for the promotion of a well-governed extractive sector. Similarly, when the International Finance Corporation and the Multilateral Investment Guarantee Agency (MIGA) consider investing in an oil, gas, or mining project, they need to specifically assess the governance adequacy of the country as well as the anticipated impacts of the project and then only support projects when a country's government is prepared and able to withstand the inherent social, environmental, and governance challenges." (IFC 2003)*

Our study has provided a very conservative estimate of future unfunded public liabilities for standing, already operating, and permitted TSFs globally. We know globally that every one of those failures can be prevented for a cost much less than $6.0 billion for just the 11 Very Serious failures we are predicting by 2020.

We know globally, and in Canada and the US, the regulatory structure is not presently in place to identify and correct these at-risk TSFs before they fail, and we know many of them are operated by companies whose balance sheets are too thin to fund repairs and closure where necessary.

We hope our work will begin a collaborative and highly focused multi-disciplinary dialogue to prevent the materialization of these $6.0 billion in public losses by 2020.

8.0 SUMMARY & CONCLUSIONS

The advances in mining technology over the past 100 years which have made it economically feasible to mine lower grades of ore against a century of declining prices have not been counterbalanced with advances in economically efficient means of managing the exponentially expanding volume of associated environmental liabilities in waste rock, tailings and waste waters. In fact those new technologies which do offer better management of mine wastes usually add significant cost and are often detrimental to bottom line financial feasibility. This is evidenced in a post-1990 trend toward un-fundable environmental losses of greater consequence. This interdisciplinary review of TSF failures 1910-2010 establishes a clear and irrefutable relationship between the mega trends that squeeze cash flows for all miners at all locations, and this indisputably clear trend toward failures of ever greater environmental consequence.

The implication of our findings is that a continuation of the present Mining Metric is not environmentally or economically sustainable, and that regulatory systems must begin to understand and address financial capacity of the miner, and the financial feasibility of mining itself, both in permitting criteria and in oversight of mine water management over the life of the mine.

Our findings point toward undocumented and unstudied risks of failure in the standing operating already permitted mines of smaller miners globally where cash flow pressures have led to an avoidance of best practices in waste management, and where political pressures have led to avoided close scrutiny of decades of neglect and shortfalls.

We have not identified an existing statutory or regulatory system anywhere that has the authority and capacity to identify and prevent the $6 billion in losses we estimate the public globally will be liable for by the end of this decade.

#####

9.0 References & Bibliography

Advani 2011. Advani, Sameer "Real Historical Copper Price", May 30,2011, Sameer Advani's Instablog http://seekingalpha.com/instablog/946411-sameer-advani/182708-real-historical-copper-price

Azam & Li 2010. Azam, Shahid Li, Quiran "Tailings Dam Failures: A Review of the Last 100 Years", Geotechnical News December 2010 http://www.infomine.com/library/publications/docs/Azam2010.pdf

Bertram 2010. Bertram, Geoff "Mining Economics & The Conservation Estate" Royal Forest & Bird Protection Society of New Zealand Inc., September 2010 accessed November 2014 http://www.geoffbertram.com/fileadmin/Mining%20Economics%20and%20the%20Conservation%20Estate%20main%20text.pdf

Boswell & Sobkowicz 2011. Boswell, Jeremy, Sobkowicz, John "Duty Of Care Applied To Tailings Operations", Proceeding Tailings & Mine Waster, Vancouver B.C. Nov 6-9 2011 http://www.infomine.com/library/publications/docs/Boswell2011.pdf

BCMM 2013. British Columbia Ministry of Mines " Provincial Summary Exploration and Mining In British Columbia 2013" http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/InformationCirculars/Documents/IC_2014-01.pdf

BCOAG 2011. British Columbia, Office of the Auditor General "An Audit of the Enviornmnetal Assessments Office Oversight of Certified Projects, July 2011 http://www.bcauditor.com/pubs/2011/report4/audit-bc-environmental-assessment-office-EAO

Caldwell 2006. Caldwell,Jack "British Columbia Tailings Failure at The HB Mine Near Salmo, British Columbia", TechnoMine July 6, 2006 http://technology.infomine.com/articles/1/8455/tailings.failure.canada/british.columbia.tailings.aspx

COAG 2014. Canada, Office of the Auditor General "Implementation of the Canadian Environmental Assessment Act, 2012, 2014 Fall Report of the Commissioner of Environment and Sustainable Development http://www.oag-bvg.gc.ca/internet/English/parl_cesd_201410_04_e_39851.html

Chambers & Higman 2011. Chambers, David M., Higman, Bretwood "Long Term Risks Of Tailings Dam Failure," October 2001, accessed November 2014 at http://www.csp2.org/technical-reports

Davies et. al. 2002. Davies, Michael, Martin,Todd and Peter Lighthall "Mine Tailings Dams: When Things Go Wrong," AGRA Earth & Environmental Limited, Burnaby, BC 2002 http://www.infomine.com/library/publications/docs/Davies2002d.pdf

Davies & Martin 2009. Davies, Michael, Martin,Todd "Mining Market Cycles and Tailings Dam Incidents," AMEC Earth & Environmental, Vancouver, British Columbia, Proceeding of the Thirteenth International Conference on Tailings and Mine Waste, November 1, 2009, Banff, Alberta, Canada accessed November 2014 at http://www.infomine.com/library/publications/docs/Davies2009.pdf

EGN 2014. Ecology Global Network "Population Estimates: Year 1 to 2050" accessed November 2014 at http://www.ecology.com/population-estimates-year-2050/

ICMM 2012. International Council on Mining & Metals, "Trends in the Mining & Metals Industry" Mining's Contribution To Sustainable Development October 2012. Accessed November 2014 at http://www.icmm.com/document/4441 M

ICOLD 1995. International Commission on Large Dams, "Dam Failures Statistical Analysis," Bulletin 99, 1995

ICOLD 2001. International Commission on Large Dams and the United Nations Environmental Programme (UNEP) Division of Technology, Industry and Economics (DTIE), "Tailings Dams Risks of Dangerous Occurrences Lessons Learned From Practical Experiences," Bulletin 121, 2001

ICSG 2014. International Copper Study Group, Copper production statistics, November 13, 2014.

IFC 2003. Striking a Better Balance, the World Bank Group and Extractive Industries, the Final Report of the Extractive Industries Review, International Finance Corporation, December 2003

Independent Panel 2015. Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel, Province of British Columbia, January 30, 2015

Jakubekl et. al. 2013. Jakubekl, Jaret , Clayon, Russel, Guest Alan R., "Mudrush Risk Evaluation" CIM Journal 2013 accessed November 2014 at http://www.srk.com/files/pdfs/mudrushriskevaluation_paper_cim_journal_fnl_20130322_jj.pdfailings

Jones 2014. Jones, Sam Jordan, Editor/Compiler "Global Mining Finance Guide 2014" Aspermont Media 2013 accessed November 2014 at http://www.mayerbrown.com/files/Publication/3e2dc5e3-878a-40a2-8b06-cb75f8d632ba/Presentation/PublicationAttachment/86b233d1-beb2-4f47-9b85-cd4793b90b92/global_mining_finance_guide_jan14.PDF

Kelly & Matos 2013. Kelly, T.D., and Matos, G.R., comps., 2013, Historical statistics for mineral and material commodities in the United States (2013 version): U.S. Geological Survey Data Series 140, accessed November 2014, at http://minerals.usgs.gov/minerals/pubs/historical-statistics/.

Knight Piesold 2011. Knight Piesold Ltd., Mount Polley Mining Corporation Mt Polley Mine Storage Facility Report of 2010 Annual Inspection", Prepared for Mt. Polley Mining Corporation, January 25, 2011 http://www.scribd.com/doc/241108453/Mount-Polley-Mine-Tailings-Storage-Facility-Report-on-2010-annual-inspection-by-Knight-Piesold

Kossoff et. al. 2014. Kossoff, D. Dubbin, W.E.Porter, Edwards, S.J. , Macklin, M.G., Hudson Edwards, K.A. "Mine Tailings Dams: Characteristics, Failure, Environmental Impacts, and Remediation", Applied Geochemistry V.51, 2014 PP 229-245 accessed November 2014 at http://dx.doi.org/10.1016/j.apgeochem.2014.09.010

Mudd et.al. 2012. Gavin M. Mudd, Zhehan Weng, and Simon M. Jowitt, A Detailed Assessment of Global Cu Resource Trends and Endowments, Economic Geology, v. 108, pp. 1163–1183, August 30, 2012

Porter & Beliwas 2003. Porter,Kenneth E., Beliwas ,Donald I., Physical Aspects Of Waste Storage From a Hypothetical Open Pit Porphyrry Operation, U.S. Department of the Interior, U.S. Geological Survey, 2003, accessed November 2014 at http://pubs.usgs.gov/of/2003/of03-143/of03-143.pdf

Repetto 2014. Repetto, Robert "Silence is Golden, Leaden and Copper Disclosure of Material Environmental Information in the Hardrock Mining Industry" Yale School Of Forestry & Environmental Studies, July 2004 accessed November 2014 at http://environment.research.yale.edu/documents/downloads/o-u/repetto_report_execsum.pdf

Rico et al. 2007. Rico, M., Benito, G., Díez-Herrero, A. "Floods From Tailings Dam Failures" Geological Hazards Unit, Spanish Geological Survey (IGME), Madrid, Spain, October 2, 2007 http://digital.csic.es/bitstream/10261/12706/3/MayteRico_10.pdf

Rico et al. 2008. Rico, M. Benito, G., Salgueriro, A. Diez-Herrero, A. & Pereira, H.G. Reported Tailings Dam Failures: A review of the European Incidents in the Worldwide Context, Journal of Hazardous Materials 152 (2008), pp. 846–852, http://digital.csic.es/bitstream/10261/12716/3/MayteRico_08.pdf

Robertson 2011. "Mine Waste Management in the 21st Century Challenges & Solutions Beyond Incremental Changes" Andrew Macgregor Robertson, Key Note Address Tailings & Mine Waste, Vancouver B.C., 2011, http://www.infomine.com/library/publications/docs/Robertson2011c.pdf

Samis et. al. 2012. Samis, M., Martinez, L., Davis, G. A., and Whyte, J. B., "Using Dynamic Discounted Cash Flow and Real Option Methods for Economic Analysis in NI 43-101 Technical Reports." in the Valmin Seminar Series 2011-12 Proceedings, The Australian Institute of Mining and Metallurgy, Publication Series No 3/2012, 149-160 accessed December 2014 at http://inside.mines.edu/~gdavis/Papers/ValMin.pdf

Schodde 2010. Schodde, Richard "The Key Drivers Behind Resource Growth: An Analysis of the Copper Industry For the Last 100 Years", Mine EX Consulting, 2010 MEMS Conference Minerals and Metals Over the Long Term, Phoenix Arizona, March 3, 2010 . http://www.slideshare.net/RichardSchodde/growth-factors-for-copper-schodde-sme-mems-march-2010-final

Stano 2011. Stano, Maya "Rave Mine: A Regulatory & Fiscal Black Hole" Environmental Law Centre, Spring 2011 http://www.elc.uvic.ca/publications/documents/2010-02-03-RavenMine-RegulatoryandFiscalBlackhole_Stano-REVISEDJul2011.pdf

Troncosco et. al. 1993. Troncosco, J.H. , Avendano, A. Vergara, A. "The Seismic Failure of Barahona Tailings Dam" Procedings: 3rd International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper # 2.56, Accessed November 2014 at https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/33917/P%201473-%20The%20Seismic%20Failure%20of%20Barahona%20Tailings%20Dam.pdf?sequence=1

USGS 2014a. U.S. Geological Survey "Historical Statistics for Mineral and Material Commodities in the United States" Thomas D. Kelly and Grecia R. Matos, with major contributions provided by David A. Buckingham, Carl A. DiFrancesco, Kenneth E. Porter, and USGS mineral commodity specialists. Data Series 140, April 2014. Accessed November 2014 at http://minerals.usgs.gov/minerals/pubs/historical-statistics/#copper

USGS 2014b. U.S. Geological Survey "Iron Ore Statistics" Compiled by T.D. Kelly (retired), W.S. Kirk (retired), J.D. Jorgenson (retired), and C.A. Tuck. Data Series 140 2014 Accessed November 2014 at http://minerals.usgs.gov/minerals/pubs/historical-statistics/#copper

USGS 2014c. U.S. Geological Survey "Zinc Statistics" April 2014 Compiled By DiFranceso, C.A. Plachy, J., Gabby P.N., Bleiwas,D.I., Tolcin, A.C. Data Series 140 April 2014 http://minerals.usgs.gov/minerals/pubs/historical-statistics/#copper

Utah 2011. State of Utah, "Groundwater Quality Discharge Permit UGW350011 Kennecott Utah Copper, Magna Utah, January 2011, Accessed November 2014 at http://www.waterquality.utah.gov/GroundWater/gwpermits/kennecott-tailings/kennecott-tailingsSOB.pdf

Valero et. al. 2011. Valero, Alicia, Valero, Antonio and Domiguez, Adriana "Trends of Energy Costs and Ore Grade in Global Mining", Centre Of Research Energy Resources & Consumption (CIRCE), Spain, 2011, Accessed November 2014 at http://teide.cps.unizar.es:8080/pub/publicir.nsf/codigospub/0751/$FILE/cp0751.pdf

Vick 1996. Vick, Steven G. Failure of the Omai Storage Dam Geotechnical News, September 1996, Accessed November 2014 at https://ejatlas.s3.amazonaws.com/docs/omai-gold-mine-tailings-dam-guyana/Failure_of_the_Omai_Tailings_Dam.pdf

Vogt 2013. Vogt, Craig, International Assessment of Marine & Riverine Disposal of MineTailings Final Report Adopted By The International Maritime Organization, London Convention.Protocol, October 18, 2013 http://www.craigvogt.com/links/Mine_Tailings_Marine_and_Riverine_Disposal.pdf

Wei et. al. 2012. Wei, Zuan, Yin, Guangszhi, Wang J.G, Ling, Wan, Guangzhi, Li "Design Construction and Management of Tailings Storage Facilities For Surface Disposal In China: Case Studies of Failures" Waste Management An Research Vol 31 p 106-112 Sage Publications October 11,2012 http://wmr.sagepub.com/content/31/1/106.full.pdf+html

WISE 2015. World Information Service on Energy Uranium Project, Chronology of Major Tailings Dam Failures, from 1960, updated 18 May 2015, http://www.wise-uranium.org/mdaf.html

Witt & Schonhardt 2004. Witt, K.J. Schonhardt M. Editors Tailings Management Facilities, Risk &Reliability, TAILSAFE September 2004 http://www.tailsafe.bam.de/pdf-documents/TAILSAFE_Risk_and_Reliability.pdf

World Bank 2006. World Bank Group, Oil Gas Mining & Chemicals Group, Background Paper The Outlook For Metals Markets Prepared For G-20 Deputies Meeting Sydney 2006, September 2006 http://siteresources.worldbank.org/INTOGMC/Resources/outlook_for_metals_market.pdf

APPENDIX 1

TSF Failure Data Table

TSF FAILURE DATA TABLE LEGEND

	Very Serious	30	Very Serious = multiple loss of life (~20) and/or release of ≥ 1,000,000 m3 semi-solids discharge, and/or release travel of 20 km or more
	Serious	38	Serious = loss of life and/or release of ≥ 100,000 m3 semi-solids discharge
	Other Failures	98	Other Failures = ICOLD Category 1 failures other than those classified as Very Serious or Serious
	Other Accidents	50	Other Accidents = ICOLD Category 2 accidents other than those classified as Very Serious or Serious
	Non-Dam Failure	10	Non-Dam Failures = groundwater, waste rock, etc.
		=======	
	Total	226	

SOURCES:

(1) ICOLD. International Committee on Large Dams, Bulletin 121 "Tailings Dams Risks of Dangerous Occurrences Lessons Learned From Practical Experiences"

(2) WISE. World Information Service on Energy Uranium Project (http://www.wise-uranium.org/mdaf.html) as of December 10, 2014

(3) Rico, M., Benito, G., Díez-Herrero, A. "Floods From Tailings Dam Failures" Geological Hazards Unit, Spanish Geological Survey (IGME), Madrid, Spain http://digital.csic.es/bitstream/10261/12706/3/MayteRico_10.pdf

(4) Wei, Zuoan, Yin, Guangszhi, Wang J.G, Ling, Wan, Guangzhi, Li "Design Construction and Management of Tailings Storage Facilities For Surface Disposal In China: Case Studies of Failures" Waste Management An Research Vol 31 p 106-112 Sage Publications October 11,2012 http://wmr.sagepub.com/content/31/1/106.full.pdf+html

(5) Repetto, Robert "Silence is Golden, Leaden and Copper Disclosure of Material Environmental Information in the Hardrock Mining Industry" Yale School Of Forestry & Environmental Studies, July 2004 accessed November 2014 at http://environment.research.yale.edu/documents/downloads/o-u/repetto_report_execsum.pdf

(6) Piplinks. "Chronology of Tailings Dam Failures In The Philippines (1982-2007)," accessed January 2015 at http://www.piplinks.org

(7) Tailings.info. Tailings Related Accidents - Failures, Breaches and Mudflows, http://www.tailings.info/knowledge/accidents.htm

(8) United Nations, Department of Economic & Social Affairs, International Expert Group Meeting on Indigenous Peoples And Protection of the Environment, "Case Study of the Impact of Mining & Dams on the Environment and Indigenous Peoples in Benguet, Cordillera, Philippines," Aug 27-29, 2007

DAM TYPE Key		DAM FILL MATERIAL Key		INCIDENT TYPE Key			INCIDENT CAUSE Key	
US	Upstream	**T**	Tailings	**1A**	Failure	Active Impoundment	**SI**	Slope instability
DS	Downstream	**CST**	Cycloned sand ta	**1B**	Failure	Inactive Impoundment	**SE**	Seepage
CL	Centerline	**MW**	Mine waste	**2A**	Accident	Active Impoundment	**FN**	Foundation
WR	Water retention	**E**	Earthfill	**2B**	Accident	Inactive Impoundment	**OT**	Overtopping
NR	Not reported	**R**	Rockfill	**3**	Groundwater		**ST**	Structural
							EQ	Earthquake
							MS	Mine subsidence
							ER	Erosion
							U	Unknown, or
							NR	Not Reported

GENERAL NOTE

We found small variations source to source on total release, run out, deaths and other details, but we found no ambiguities or inconsistencies that precluded a clear classification as "Serious" or "Very Serious".

Overall we found much more detailed accounts of "consequence" in local compilations or regional or national studies. WISE & ICOLD occasionally including details on consequence, or linked to sources detailing consequence. Our bibliogtaphy includes a more extensive list of materials related to the consequence of TSF failures

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Karamken, Magadan Region, Russia					1A	29-Aug-09	1,200,000		1		WISE, MACE	11 houses lost, 1 death (Karamken Update - MACE 2012-02-10)
	Huayuan County, Xiangxi Autonomous Prefecture, Hunan Province, China					1A	14-May-09	50,000		3		WISE	3 killed, 4 injured
	Kingston fossil plant, Harriman, Tennessee, USA					1A	22-Dec-08	5,400,000	4.1			WISE	5.4 million cubic yards (1.09 billion gallons) of fly ash was released (http://www.sourcewatch.org/index.php?title=TVA_Kingston_Fossil_Plant_coal_ash_spill#TVA_Reaction)
	Taoshi, Linfen City, Xiangfen county, Shanxi province, China	US		50.7	290,000	1A	8-Sep-08	190,000	2.5	277		WISE	At least 254 dead and 35 injured.
	Glebe Mines, UK		E			1B-OT	22-Jan-07	20,000				HSE Report	Initial Report of the HSE investigation into the Glebe Mines Stony Middleton dam failure 2007, HSE Central Division - Nottingham, UK, 23Feb07
	Miliang, Zhen'an County, Shangluo, Shaanxi Province, China					1A	30-Apr-06		5	17		WISE	17 missing
	Pinchi Lake, BC, Canada	WR	E	12		2A-ER	30-Nov-04	6,000-8,000				WISE	Mercury contaminated tailings into Pinchi Lake
	Riverview, Florida, USA					1A	5-Sep-04	227,000				WISE	
	Partizansk, Primorski Krai, Russia					1A	22-May-04	166,000				WISE	
	Malvési, Aude, France					1A	20-Mar-04	30,000				WISE	Uranium slurries elevated nitrate in river
	Cerro Negro, near Santiago, Chile, (5 of 5)	US	T			1A-ER	3-Oct-03	80,000	20			WISE	
	El Cobre, Chile, 2, 3, 4, 5	US	T			1B-OT	22-Sep-02	8,000				Villavicencio (2014)	
	San Marcelino Zambales, Philippines, Bayarong dam (9/11/02)				47,000,000	1B	11-Sep-02					WISE, Piplinks	Sep. 11: low lying villages flooded with mine waste; 250 families evacuated;
	San Marcelino Zambales, Philippines, Camalca dam (8/27/02)					1B	27-Aug-02					WISE, Piplinks	Aug. 27: some tailings spilled into Mapanuepe Lake and eventually into the St. Tomas River.
	El Cobre, Chile	US	T			1B-OT	11-Aug-02	4,500				Villavicencio (2014)	
	Sebastião das Águas Claras, Nova Lima district, Minas Gerais, Brazil					1A	22-Jun-01		8	2		WISE	2 killed, 3 missing. Tailings 8 km downstream the Córrego Taquaras stream, mud affected an area of 30 hectares
	Nandan Tin mine, Dachang, Guangxi					1A	18-Oct-00			28		WISE, Wei	WISE:15 killed, 100 missing, 100 houses destroyed

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Inez, Martin County, Kentucky, USA					1A	11-Oct-00	950,000	120		Table 1	ICOLD, WISE	
	Aitik mine, near Gällivare, Sweden	DS	MW & E	15	15,000,000	1A-ER	8-Sep-00	1,800,000	5.2		Table 1	ICOLD, WISE	
	Baia Mare, Romania Esmerelda Exploration	DS then US	T	A few m	800,000	1A-ST	30-Jan-00	100,000	>100		221	ICOLD, WISE, Rico	Killed tonnes of fish and poisoned drinking water of more than 2 million people in Hungary
	Borsa, Romania					1A	2000	22,000t			Table 1	ICOLD, WISE	Company: Remin SA
	Surigao Del Norte Placer, Philippines (#3 of 3)					1A	26-Apr-99	700,000 t	12	4	Table 1	ICOLD, Piplinks	
	Toledo City (Philippines)					1B	1999	5,700,000				Piplinks	Drainage tunnel blowout
	Huelva, Spain					1A	31-Dec-98				Table 1	ICOLD, WISE	Fertiberia phosphate mine
	Los Frailes, near Seville, Spain	WR	R	27	15,000,000	1A-FN	25-Apr-98	6,800,000	41		209	ICOLD, WISE, Rico	
	Zamboanga Del Norte, Sibutad Gold Project					1A-OT	6-Nov-97					Piplinks	
	Pinto Valley, Arizona, USA					1B	22-Oct-97	230,000			Table 1	ICOLD, WISE	
	Amatista, Nazca, Peru					1A-EQ	12-Nov-96	300,000				WISE	due to M6.4 earthquake
	El Porco, Bolivia					1A	29-Aug-96	400,000	300		Table 1	ICOLD, WISE	300 km of Pilcomayo river contaminated
	Marcopper, Marinduque Island, Philippines(3/24) (#2 of 2)					1A-ST	24-Mar-96	1,600,000	26		208	ICOLD, WISE, Piplinks	Drainage tunnel plug failed. 26 km of the Makulaquit and Boac river systems filled with tailings rendering them unusable; US$ 80 million in damage
	Sgurigrad, Bulgaria	US	T	45	1,520,000	1A-SI	1996	220,000	6		220	ICOLD, Rico	
	Negros Occidental, Bulawan Mine Sipalay River					1A	8-Dec-95					Piplinks	
	Golden Cross, Waitekauri Valley, New Zealand		R	25-30	3,000,000	1A-FN	Dec-95	9,999			207	ICOLD	
	Surigao del Norte Placer, Philippines (#2 of 3)	WR	E	17		1B-SI	2-Sep-95	50,000		12	206	ICOLD, WISE	
	Omai Mine, Tailings dam No 1, 2, Guyana	WR	R	44	5,250,000	1A-ER	19-Aug-95	4,200,000	80		205	ICOLD, WISE, Rico	80 km of Essequibo River declared environmental disaster zone
	Middle Arm, Launceston, Tasmania	CL	E	4	25,000	1A-OT	25-Jun-95	5,000			204	ICOLD	
	Riltec, Mathinna, Tasmania	CL	E	7	120,000	2A-SE	Jun-95	40,000			203	ICOLD	
	Hopewell Mine, Hillsborough County, Florida, USA					1A	19-Nov-94	1,900,000				WISE	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Payne Creek Mine, Polk County, Florida, USA					1A	2-Oct-94	6,800,000				WISE	
	Merriespruit, near Virginia, South Africa, Harmony 2, 3	US paddock	T	31	7,040,000	1B-OT	22-Feb-94	600,000	4	17	202	ICOLD, WISE, Rico	
	Olympic Dam, Roxby Downs, South Australia					3	14-Feb-94	5,000,000				WISE	Designed groundwater leakage from unlined tailings impoundment into groundwater
	Minera Sera Grande: Crixas, Goias, Brazil	DS then US	CST	41	2.25Mt	2A-SI	Feb-94	None			214	ICOLD	
	Fort Meade, Florida, Cargill phosphate (#3 of 3)					1A	2-Jan-94	76,000				WISE	
	Longjiaoshan, Daye Iron Ore mine, Hubei					1A	1994			31		Wei	
	Marcopper, Marinduque Island, Mogpog Philippines(12/6) (#1 of 2)					1B	6-Dec-93			2		Piplinks	Siltation dam failure. Mogpog River and Mogpog town flooded.
	TD 7, Chingola, Zambia	US	T&E	5		1A-OT	Aug-93	100 t			200	ICOLD	
	Itogon-Suyoc, Baguio gold district, Luzon, Philippines					1A-OT	26-Jun-93				199	ICOLD, Piplinks	
	Marsa, Peru					1A-OT	Jan-93			6		WISE	
	Kojkovac, Montenegro	WR	E		3,500,000	2B-ER	Nov-92	none			198	ICOLD	
	Saaiplaas, South Africa, 2		CST			1A-IS	19-Mar-92				Table 1	ICOLD	3 separate events within 4 days
	Maritsa Istok 1, Bulgaria		Ash	15	52,000,000	1A-ER	1-Mar-92	500,000			218	ICOLD, WISE	
	Tubu, Benguet, No.2 Tailings Pond, Padcal, Luzon, Philippines				80,000,000	1A-FN	2-Jan-92	80,000,000			197	Piplinks	
	Iron Dyke, Sullivan Mine, Kimberley, BC, Canada	US		21		1A-SI	23-Aug-91	75,000			196	ICOLD	
	Soda Lake, California, USA	US	E	3		2A-EQ	17-Oct-89				111	ICOLD	
	Silver King, Idaho, USA	DS	E	9	37,000	2A-OT	5-Aug-89	Small			108	ICOLD	
	Big Four, Florida, USA	CL	E			2A-FN	1989				14	ICOLD	
	Cyprus Thompson Creek, Idaho, USA	CL	CST	146	27,000,000	2A-SE	1989				34	ICOLD	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Southern Clay, Tennessee, USA	WR	E	5		1A-SE	1989	300			112	ICOLD	
	Stancil , Maryland, USA	US	E	9	74,000	1A-SI	1989	38,000	0.1		116	ICOLD, Rico	
	Unidentified, Hernando, County, Florida, USA #2	US	E	12	3,300,000	1A-OT	Sep-88	4,600			163	ICOLD	
	Jinduicheng, Shaanxi Province., China	US		40		1A-OT	30-Apr-88	700,000		~20	195	ICOLD, WISE	
	Consolidated Coal No.1, Tennessee, USA,	DS	MW	85	1,000,000	2A-ST	19-Jan-88	250,000			121	ICOLD, WISE	
	Rain Starter Dam, Elko, Nevada, USA	WR	ER	27	1,500,000	3-	1988				98	ICOLD	
	Unidentified, Hernando, County, Florida, USA	DS	E	12		2A-FN	1988				164	ICOLD	
	Surigao Del Norte Placer, Philippines (#1 of 3)					1A	9-Jul-87					Piplinks	
	Montcoal No.7, Raleigh County, West Virginia, USA					1A	8-Apr-87	87,000	80			WISE	tailings flow 80 km downstream
	Bekovsky, Western Siberia	US	Argillite, aleurolite	53	52,000,000	1A	25-Mar-87	None			212	ICOLD	
	Xishimen, China	US	T	31		1A-SI	21-Mar-87	2,230			194	ICOLD	
	Montana Tunnels, MT, USA	DS	MW	33	250,000	3-	1987				87	ICOLD	
	Marianna Mine #58, PA,	US	E	37	300,000	2A-SI	19-Nov-86				77	ICOLD	
	Mankayan, Luzon, Philippines, No.3 Tailings Pond		E			1A-ST	17-Oct-86				193	ICOLD, Piplinks	Siltation of the Abra River which affected 9 municipalities
	Lepanto, Mankayan, Benguet, Philippines					1A	17-Oct-86					Piplinks	Siltation of the Abra River which affected 9 municipalities
	Pico de Sao Luis, Gerais, Brazil		T	20		1A-ER	2-Oct-86				192	ICOLD	
	Rossarden, Tasmania	WR	E	7.5	200,000	1B-OT	16-May-86				190	ICOLD	
	Story's Creek, Tasmania	Valley side		17	30,000	1B-OT	16-May-86	Minimal			191	ICOLD	
	Itabirito, Minas Gerais, Brazil	Gravity	Masonry	30		1A-ST	May-86	100,000	12	7	189	ICOLD, WISE, Rico	
	Mineral King, BC, Canada	CL	CST	6	Small	1B-OT	20-Mar-86				188	ICOLD	
	Huangmeishan, China					1A	1986			19		WISE	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Spring Creek Plant, Borger, Texas, USA			5	30,000	1A-OT	1986				114	ICOLD	
	Bonsal, North Carolina, USA	WR	E	6	38,000	1A-OT	17-Aug-86	11,000			17	ICOLD	
	Stava, North Italy, 2, 3	US	CST	29.5	300,000	1A-SI	19-Jul-85	200,000	8	269	117	ICOLD, WISE, Rico	
	La Belle, Pennsylvania, USA	DS	MW	79	1,230,000	2A-FN	17-Jul-85				68	ICOLD	
	Cerro Negro No. (4 of 5)	US	CST	40	2,000,000	1A-EQ	3-Mar-85	500,000	8		30	ICOLD WISE, Rico	
	Veta de Agua	US	T	24	700,000	1A-EQ	3-Mar-85	280,000	5		178	ICOLD, WISE, Rico	
	El Cobre No. 4	DS	CST	50		2A-EQ	3-Mar-85				44	ICOLD	
	Niujiaolong, Shizhuyuan Non-ferrous Metals Co., Hunan					1A	Jan-85	731,000	4.2	49		Wei	
	Marga, Chile					1B-OT	1985				76	ICOLD	
	Ollinghouse, Nevada, USA	WR	E	5	120,000	1A-SE	1985	25,000	1.5		91	ICOLD, Rico	
	Texasgulf 4B Pond, Beaufort, Co., North Carolina, USA	WR	T	8	12,300,000	2A-SI	Apr-84				122	ICOLD	
	Mirolubovka, Southern Ukraine	US	E&T	32	80,000,000	2A-SI	15-Jan-84	-			210	ICOLD	
	Battle Mt. Gold, Nevada,	DS	E	8	1,540,000	2A-SI	1984				11	ICOLD	
	Virginia Vermiculite, Louisa County, Virginia, USA	WR	E	9		1A-ST	1984				179	ICOLD	
	Clayton Mine, Idaho, USA	CL	T	24	215,000	2A-ST	2-Jun-83				32	ICOLD	
	Golden Sunlight, MT, USA	CL	CST			3-	5-Jan-83				51	ICOLD	
	Grey Eagle, California, USA	DS	E			3-	1983				53	ICOLD	
	Vallenar 1 and 2					1B-OT	1983				175	ICOLD	
	Sipalay, Philippines, No.3 Tailings Pond	WR	MW		37,000,000	1A-FN	8-Nov-82	28,000,000			187	ICOLD, WISE, Piplinks	Dam failure, due to slippage of foundations on clayey soils. Widespread inundation of agricultural land up to 1.5 m high
	Royster, Florida, USA	US	T	21		1A-FN	1982				102	ICOLD	
	Ages, Harlan County, Kentucky, USA					1A	18-Dec-81	96,000	163	1		WISE	
	Dixie Mine, Colorado, USA					1B-U	Apr-81				39	ICOLD	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Balka Chuficheva, Russia	US	CST	25	27,000,000	1A-SI	20-Jan-81	3,500,000	1.3		211	ICOLD, WISE	
	Texasgulf No. 1 Pond, Beaufort Co., North Carolina, USA	WR	E		24,700,000	2A-SI	1981				123	ICOLD	
	Veta de Aqua A					1A-EQ	1981				176	ICOLD	
	Veta de Agua B					1A-EQ	1981				177	ICOLD	
	Tyrone, New Mexico, Phelps-Dodge	US	CST	66	2,500,000	1A-SI	13-Oct-80	2,000,000	8		94	ICOLD, WISE, Rico	
	Sweeney Tailings Dam, Longmont, Colorado, USA			7		1A-SE	May-80				119	ICOLD	
	Kyanite Mining, Virginia, USA			11	430,000	2A-OT	1980				67	ICOLD	
	Churchrock, New Mexico, United Nuclear	WR	E	11	370,000	1A-FN	16-Jul-79	370,000	110		173	ICOLD, Wikipedia, Rico	
	Union Carbide, Uravan, Colorado, USA	US	T	43		2A-SI	Mar-79				172	ICOLD	
	Incident No. 1, Elliot, Ontario, Canada	WR	E	9		3-	1979				35	ICOLD	
	Suncor E-W Dike, Alberta, Canada	WR	MW	30		2A-SI	1979				118	ICOLD	
	Arcturus, Zimbabwe	US	T	25	1.7-2.0 Mt	1A-OT	31-Jan-78	39,000	0.3	1	185	ICOLD, WISE, Rico	
	Mochikoshi No. 1, Japan (1 of 2)	US	T	28	480,000	1A-EQ	14-Jan-78	80,000	8	1	84	ICOLD, WISE, Rico	Dam failure due to earthquake
	Norosawa, Japan	DS		24	225,000	2B-EQ	14-Jan-78				90	ICOLD	
	Hirayama, Japan	DS		9	87,000	2B-EQ	1978				56	ICOLD	
	Mochikoshi No. 2, Japan (2 of 2)	US	T	19		1A-EQ	1978	3,000	0.15		85	ICOLD, Rico	dam failure due to aftershock
	Syncrude, Alberta, Canada	CL	T			2A-FN	1978				120	ICOLD	
	Madison, Missouri, USA	WR	E	11		1A-OT	28-Feb-77				74	ICOLD	
	Homestake, N. Mexico, USA	US	T	21		1A-ST	Feb-77	30,000			59	ICOLD	
	Pit No. 2, Western	US	T	9		1A-SI	1977				96	ICOLD	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Unidentified, Hernando, County, Florida, USA	CL	E	6		2A-FN	1977				162	ICOLD	
	Western Nuclear, Jeffrey City, Wyoming, USA #2					1A-SI	1977	40			180	ICOLD	
	Kerr-McGee, Churchrock, New Mexico, USA	WR	E	9		1A-FN	Apr-76				64	ICOLD	
	Zlevoto No. 4, Yugoslavia	US	T	25	1,000,000	1A-SI	Mar-76	300,000			184	ICOLD, WISE	
	Dashihe. China	US		37		2A-EQ	1976				36	ICOLD	
	Unidentified, Idaho, USA	DS	E	34		2A-SI	1976				149	ICOLD	
	Cadet No. 2, Montana,	CL	E	21		2A-SI	Sep-75				18	ICOLD	
	Madjarevo, Bulgaria	US	T	40	3,000,000	1A-ST	1-Apr-75	250,000			219	ICOLD	
	Carr Fork, Utah, USA			10		1A-ST	Feb-75				22	ICOLD	
	Dresser No. 4, Montana,	CL	E	15		1A-FN	1975				40	ICOLD	
	Keystone Mine, Crested Butte, Colorado, USA					1B-U	1975				65	ICOLD	
	Mike Horse, Montana, USA	US	T	18	750,000	1B-OT	1975	150,000			79	ICOLD	
	PCS Rocanville, Saskatchewan, Canada	US	T	12		3-	1975				92	ICOLD	
	Unidentified, Green River, Wyoming, USA	WR	E	18		3-	1975				161	ICOLD	
	Heath Steele main dam, Brunswick, Canada	WR	R,E	30		2A-FN	1975				186	ICOLD	
	Bafokeng, South Africa	US	T	20	13,000,000	1A-SE	11-Nov-74	3,000,000	45	12	7	ICOLD, WISE, Rico	
	Golden Gilpin Mine, Colorado, USA			12		1B-U	Nov-74				50	ICOLD	
	Deneen Mica Yancey County, North Carolina, USA	US	CST	18	300,000	1A-SI	Jun-74	38,000	0.03		37	ICOLD	
	Silver King, Idaho, USA	DS	E	9	37,000	1A-OT	16-Jan-74	6,000			109	ICOLD	
	Galena Mine, Idaho, USA #2	US	MW	9		1A-OT	15-Jan-74	3,800	0.61		49	ICOLD, Rico	
	Berrien, France	US	R	9		1A-SE	1974				10	ICOLD	
	GCOS, Alberta, Canada	US	T	61		2A-SI	1974				47	ICOLD	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Unidentified, Mississippi, USA #2	US	T	20		2A-FN	1974				153	ICOLD	
	Unidentified, Canaca, Mexico	US	T	46		1A-OT	1974				159	ICOLD	
	Ray Mine, Arizona, USA inc #2	US	T	52		2A-SI	5-Feb-73				101	ICOLD	
	(unidentified), Southwestern USA	US	E	43	500,000	1A-SI	1973	170,000	25		169	ICOLD, WISE, Rico	noted as "Southwestern US" in WISE
	Earth Resources, N M,	US	T	21		1A-OT	1973				41	ICOLD	
	Ray Mine, Arizona, USA	US	T	52		1A-SI	2-Dec-72				100	ICOLD	
	Buffalo Creek, West Virginia, USA					1A	26-Feb-72	500,000	64.4	125	Table 1	ICOLD, WISE, Rico	Tailings traveled 27 km downstream, 125 people lost their lives, 500 homes were destroyed. Property and highway damage exceeded $65 million
	Galena Mine, Idaho, USA	US	E	14		2A-ER	1972				48	ICOLD	
	Cities Service, Fort Meade, Florida, phosphate					1A	3-Dec-71	9,000,000	120		31	WISE, Rico	
	Pinchi Lake, BC, Canada	WR	E	13		2A-ER	1971				95	ICOLD	
	Western Nuclear, Jeffrey City, Wyoming, USA					1A-ST	1971				181	ICOLD	
	Mufulira, Zambia			50	1,000,000	1A-MS	Sep-70	68,000		89	88	ICOLD, WISE	Saturated slime tailings deposited in a TSF #3 over subsidence feature flowed into an underground mine killing 89 miners.
	Maggie Pye, United Kingdom, clay	US	T	18		1A-SI	1970	15,000			75	ICOLD, WISE	
	Park, United Kingdom	WR	T	3		1A-OT	1970				93	ICOLD	
	Portworthy, United Kingdom	DS	R	15		1A-ST	1970				97	ICOLD	
	Unidentified, Mississippi, USA	US	T	15		1A-OT	1970				152	ICOLD	
	Williamsport Washer, Maury County, Tennessee, USA			21		1A-U	1970				182	ICOLD	
	Bilbao, Spain					1A-SI	1969	115,000	0.035	?	15	ICOLD, WISE	
	Monsanto Dike 15, TN,	DS	E	43	1,230,000	2A-SE	1969				86	ICOLD	
	Stoney Middleton, UK					1A-SI	8-Feb-68				217	ICOLD	
	Hokkaido, Japan	US	T	12	300,000	1A-EQ	1968	90,000	0.15		57	ICOLD, WISE, Rico	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Agrico Chemical, Florida, USA					1A-U	1968				1	ICOLD	
	IMC K-2, Saskatchewan, Canada	US	T	30		3-	1968				60	ICOLD	
	Climax, Colorado, USA					1A-U	2-Jul-67	12,000			33	ICOLD	
	Mobil Chemical, Fort Meade, Florida, phosphate					1A	1-Mar-67	2,000,000			83	ICOLD, WISE	250,000 m3 of phosphatic clay slimes, 1.8 million m3 of water. Spill reaches Peace River, fish kill reported
	Unidentified, United Kingdom	DS		20		1A-SI	1967				144	ICOLD	
	Unidentified, United Kingdom #3	DS	MW	14		2A-SI	1967				145	ICOLD	
	Unidentified, United Kingdom #2	DS	E	30		2A-SE	1967				146	ICOLD	
	Alberfan, Wales						21-Oct-66	112,000		144		Wikipedia	Coal tip (waste rock pile) failure
	Mir mine, Sgorigrad, Bulgaria	US	T			1A-U	1-May-66	450,000	8	488	81	ICOLD, WISE	Tailings wave traveled 8 km to the city of Vratza and destroyed half of Sgorigrad village 1 km downstream, killing 488 people.
	Williamthorpe, UK		MW			1A-OT	24-Mar-66				183	ICOLD	
	Unidentified, Texas, USA	US	T	16		1A-SE	1966	130,000			154	ICOLD, WISE	
	Gypsum Tailings Dam (Texas, USA)	UP		11	7,000,000	1A-SE	1966	85,000	0.3			WISE, Rico	Summary of Research on Analyses of Flow Failures of Mine Tailings Impoundments, J. K. Jeyapalan, J. M. Duncan, and H. B. Seed
	Derbyshire, United Kingdom	DS		8		1B-FN	1966	30,000			38	ICOLD	
	Williamthorpe, UK #2					1A-FN	1966				216	ICOLD	
	Tymawr, United Kingdom Inc#2			12		1A-OT	29-Mar-65				125	ICOLD, WISE	
	Bellavista. Chile	US	T	20	450,000	1A-EQ	28-Mar-65	70,000	0.8		12	ICOLD	The tailings failures of March 28, 1965, were from La Ligua, Chile, earthquake. This accounts for a significant part of the large number of earthquakes in the period of 1960-1970. About half of the failed dams were abandoned, and half were located at operating mines. (see Villavicencio et al, 2014)
	Cerro Blanco de Polpaico, Chile	WR	R	9		2A-EQ	28-Mar-65				26	ICOLD	
	El Cerrado, Chile	US	T	25		2B-EQ	28-Mar-65				42	ICOLD	
	El Cobre New Dam	DS	CST	19	350,000	1A-EQ	28-Mar-65	350,000	12		43	ICOLD, WISE	
	El Cobre Old Dam	US	T	35	4,250,000	1A-EQ	28-Mar-65	1,900,000	12	>200	45	ICOLD, WISE, Rico	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Hierro Viejo, Chile	US	T	5		1A-EQ	28-Mar-65	800			55	ICOLD	
	La Patagua New Dam,	US	T	15		1A-EQ	28-Mar-65	35,000	5		69	ICOLD, Rico	
	Los Maquis No. 1	US	T	15		2B-EQ	28-Mar-65				70	ICOLD	
	Los Maquis No. 3	US		15	43,000	1A-EQ	28-Mar-65	21,000	5		71	ICOLD, Rico	
	Ramayana No. 1, Chile	US	T	5		1A-EQ	28-Mar-65	150			99	ICOLD	
	Sauce No. 1, Chile	US	T	6		2A-EQ	28-Mar-65				104	ICOLD	
	Sauce No. 2, Chile	US	T	5		2B-EQ	28-Mar-65				105	ICOLD	
	Sauce No. 3, Chile	US		5		2B-EQ	28-Mar-65				106	ICOLD	
	Sauce No. 4, Chile	US	T	5		2B-EQ	28-Mar-65				107	ICOLD	
	Cerro Negro No. (1 of 5)	US	T	46		2B-EQ	28-Mar-65				27	ICOLD	Cracking due to EQ
	Cerro Negro No. (2 of 5)	US	T	46		2B-EQ	28-Mar-65				28	ICOLD	Cracking due to EQ
	Cerro Negro No. (3 of 5)	US	T	20	500,000	1A-EQ	28-Mar-65	85,000	5		29	ICOLD WISE, Rico	Dam failed due to EQ
	El Cobre Small Dam	US	T	26	985,000	2B-EQ	28-Mar-65				46	ICOLD	
	American Cyanamid, Florida #2					1A-U	1965				4	ICOLD	
	N'yukka Creek, USSR	WR	E	12		2A-FN	1965				89	ICOLD	
	Unidentified, Idaho, USA	DS	E	18		2A-SI	1965				150	ICOLD	
	Alcoa, Texas, USA			19	4,500,000	1A-U	Oct-64				2	ICOLD	
	Utah construction, Riverton, Wyoming, USA					2A-OT	16-Jun-63				174	ICOLD	
	Mines Development, Edgemont, South Dakota, USA					1A-U	11-Jun-62	100			80	ICOLD	
	Huogudu, Yunnan Tin Group Co., Yunnan	US				1A	1962	3,300,000	4.5	171		Wei	
	American Cyanamid, Florida					1A-U	1962				3	ICOLD	

COLOR CODE	MINE/PROJECT & LOCATION	DAM TYPE	DAM FILL MATERIAL	DAM HEIGHT (meters)	STORAGE VOLUME (cu. meters)	ICOLD TYPE	INCIDENT DATE	RELEASE VOLUME (cu. meters)	RUNOUT (km)	DEATHS	Source Color Code	SOURCES	NOTES
	Unidentified, Peru					1A-EQ	1962				135	ICOLD	
	Union Carbide, Maybell, Colorado, USA					1A-U	6-Dec-61	280			171	ICOLD	
	Tymawr, United Kingdom					1A-U	Dec-61				124	ICOLD	
	Lower Indian Creek, MO,	US	E			2A-SI	1960				72	ICOLD	
	Union Carbide, Green River, Utah, USA					1A-OT	19-Aug-59	8,400			170	ICOLD	
	Grootvlei, South Africa	US	T			1A-SI	1956				54	ICOLD	
	Unidentified, Peace River, Florida, USA 3/52	WR	E	8		1A-SI	Mar-52				168	ICOLD	
	Unidentified, Alfaria River, Florida, USA	WR	E	8		1A-SI	Feb-52				156	ICOLD	
	Unidentified, Peace River, Florida, USA 9/51	WR	MW	6		1A-SE	Sep-51				165	ICOLD	
	Unidentified, Peace River, Florida 7/51	WR	MW	30		1A-SE	Jul-51				166	ICOLD	
	Unidentified, Peace River, Florida, USA2/51	DS	E			1A-SE	Feb-51				167	ICOLD	
	Kimberley, BC, Canada, iron	US	T			1A-SI	1948	1,100,000			66	ICOLD	
	Castle Dome, Arizona, USA	US	T			1A-SE	29-Sep-47	150,000	0.1		25	ICOLD	
	Hollinger, Canada	US	T	15		1A-FN	1944				58	ICOLD	
	Captains Flat Dump 3, Australia		T			1A-U	1942	40,000			20	ICOLD	
	Kennecott, Utah, USA	US	T			1A-FN	1942				63	ICOLD	
	Kennecott, Garfield, Utah, USA	US	T			1A-SI	1941				62	ICOLD	
	St. Joe Lead, Flat Missouri, USA	US	T	15		1A-OT	1940				115	ICOLD	
	Captains Flat Dump 6A, Australia	US	T			1A-SI	1939				21	ICOLD	
	Simmer and Jack, South Africa	US	T			1A-SI	1937				110	ICOLD	
	Barahona, Chile	US	CST	61	20,000,000	1A-EQ	Oct-28	2,800,000			9	ICOLD	
	Unidentified, South Africa					1A-U	1917				136	ICOLD	

APPENDIX 2

Technical Documentation on Canonical Correlation Analysis

TECHNICAL DOCUMENTATION ON CANONICAL CORRELATION ANALYSIS

CANONICAL CORRELATION ANALYSIS (CCA)

Canonical correlation considers the relationship between two data sets one normally considered a "criteria" data set the other and "explanatory" data set. For our CCA analysis the criterion data set (Y1) were the Very Serious Failure and Serious Failures. The explanatory data set (Y2) were the three mining metric variables shown to have the highest correlation with these failure categories copper ore production (Cu prod), copper grade (Cu grade), and copper cost to produce (Cu cost).

Table A2.1 - Input Data Set

Decade	Very Serious Failures	Serious Failures	Other Failures	Other Accident	Non-Dam Failures	All Failures	Cu prod (K tonnes)	Cu grade (%)	Cu cost $/tonne	Cu price $/tonne
1940 – 49	0	0	5	0	0	6	2,545	1.52	$35	$3,633
1950 – 59	1	0	7	0	0	7	3,680	1.21	$48	$5,076
1960 – 69	3	4	25	17	2	51	5,004	1.10	$55	$5,112
1970 – 79	4	8	23	15	3	53	7,445	1.01	$38	$5,895
1980 – 89	5	9	22	14	4	54	10,575	0.95	$20	$3,871
1990 – 99	9	9	10	3	1	32	16,437	0.93	$15	$3,292
2000 – 09	7	8	5	1	0	21	23,658	0.85	$20	$4,256
	======	======	======	=======	=======	======	======	=====	======	=======
Total/Ave	29	38	97	50	10	224	69,344	1.54	$33	$4,448

Abbreviations:

Cu Price = Copper price ($/tonne)
Cu Prod Cost = Cost to produce copper concentrate from copper ore, including waste disposal ($/tonne)
Cu Grade = grade of copper in the ore (%)
Cu Prod = copper ore production (thousand metric tonnes)
Other Failures = tailings dam failures and incidents other than Serious or Very Serious Failures
Serious Failures = Serious tailings dam failures
Very Serious Failures = Very Serious tailings dam failures

Sources: USGS (Metal Statistics) 2014, Schodde 2010, ICOLD 2001, WISE 2015 & additional

DEVELOPMENT AND VETTING OF INPUT DATA

These final selections were based on a rigorous and thorough exploration of the structure of the data within each set and of the inter-relationships among data elements. After settling on the above data set it was vetted against two criteria for proper use and meaningful interpretation of CCA: Multivariate Normality and Multicollinearity.

We had pre-determined CCA to be the best multivariate analysis technique for our consideration of how the "Mining Metric" affects TSF failure frequency and severity globally. We were not looking at this relationship on a time series basis but on a criteria and explanatory basis for which CCA was specifically developed. CCA is used mostly for looking at whether and how intentional or known environmental conditions or interventions affect a given set of observed conditions. (E.g. and more typically, whether the elements of a diet and exercise program, as a program, have more positive effect on measures of health and which elements are most strongly related to the desired or expected outcome.) At least one major economic study (Malacarne 2014) published in the Mathematica

Journal also employed CCA. That study explored whether and to what extent behavior of the major stock exchanges of developed nations influenced the behavior of the exchanges of developing nations.

CCA is perfectly suited to our study because although price is the fixed element against which all mines must perform, the other elements of the Mining Metric are subject to miner control and or have great variability one mine to another within the expressed averages, including how much production to undertake at a given head grade and mine specific cost of production, and how much cash flow is available for nonrevenue generating parts of the operation like waste and waste water management.

DEVELOPMENT OF INPUT VARIABLES

The main defining criteria for severity classifications are apparent on a sort by Release Volume (column L) and Run Out (column M) (See Appendix I), or even a visual inspection. The category Very Serious Failures has had clarity in all analysis from the outset in its relationship to the key Mining Metric variables, and much stronger alone than in combinations we experimented with. Similarly, combinations of coding for other incidents didn't have the clarity we finally found in these final 5 major failure groups. Among these 5 groups (classifications) as shown in the correlation matrix in Table 3.1 only the two high severity codes had significant correlations with Mining Metric variables.

Similarly with the Mining Metric variables we found that the original raw data had greater clarity than any combinations we formulated. For example, on noting the lower correlation of price with failures variables, we created a variable called "price cycle" that coded each decade on the basis of length of trend up or down. Since cumulative production is a surrogate for the exponential growth in global accumulated tailings volume we initially focused on that but found that cumulative production had consistently lower correlations with any coding of failure categories, and so settled on using production as reported by the USGS metal statistics. We tried to improve correlations with various other formulations. But in all cases the actual raw measurements of cost, grade and production were found to have the highest correlations with high severity failures events.

We also had explored an "all metals" basis in lieu of using Cu only and found that no combination of all metals had the same strength of correlation as Cu production alone. (Possibly because Cu production so closely tracks Global GDP). USGS Metal Statistics (2014) includes price, but there were no other comparable sources for average head grade or average production costs. Only Cu afforded the possibility of looking at the interrelationships over the entire century 1910-2010.

For almost any analysis there were too many empty cells for a complete Y1 and Y2 set prior to 1940. Therefore we ended up with a workable data set of only two Y1 variables and three Y2 variables for only 7 decades out of the 10 in the century. At the outset, therefore, we knew that our workable data set was much smaller than what is normally considered the minimum for CCA, and that that would limit the statistical significance of conclusions, but not preclude a meaningful glimpse into the relational behavior of the two data sets.

APPROPRIATE AGGREGATION LEVEL OF FAILURE DATA

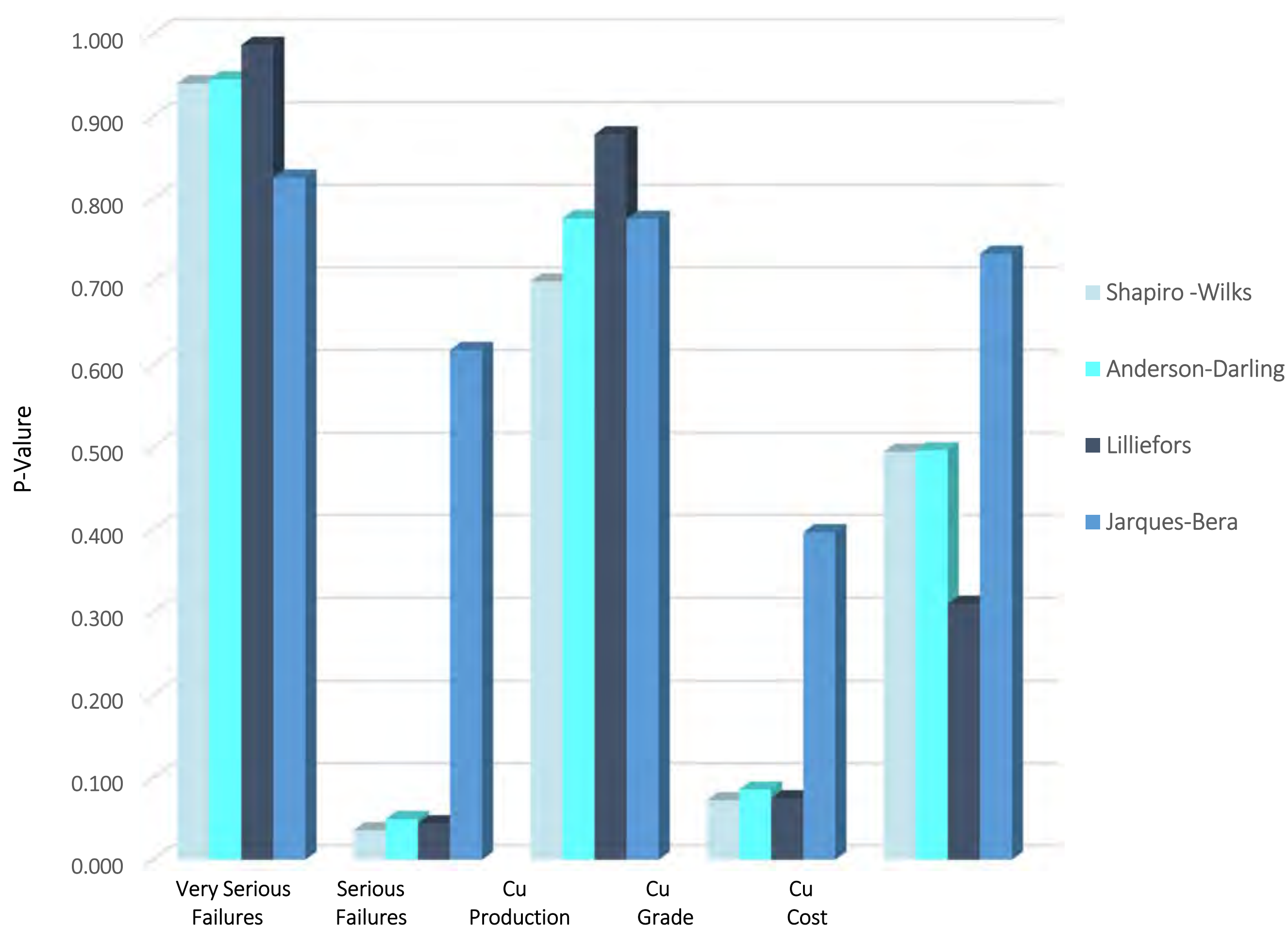
To determine the most appropriate level of aggregation for the failure data sets we looked at aggregations by 1, 2, 5 and 10 years building from the earliest year, 1910. The decade 1910-1920 is the earliest recorded ICOLD TSF incident. We found that the clarity of inter relationships was not apparent at aggregations below 5 years and was most clear at aggregations by decade.

Ideally, there should be 20 observations for each variable which would have required aggregations of 3 years or less. This is also true of the U.S. Census or any other phenomenon that looks at small incremental changes or incidents over a long period of time and the interrelationship with other inter-census changes. These changes would not be apparent or meaningful at smaller levels of aggregation as the many elements of population change (age, ethnicity, household size) have constant small changes day-by-day, month-by-month, which don't reveal the magnitude of net effect or net change until a meaningful level of aggregation is established. Ten years happens to be the apparent optimum level of aggregation for analysis of frequency and severity of TSF failures and reportable incidents.

VETTING OF INPUT DATA SET ON REQUIREMENTS FOR CCA

The proper use of CCA for descriptive analysis requires no assumptions of distribution. To test the significance of the relationships between canonical variates, however, the data should meet the requirements of multivariate normality (MVN). We were not able to conduct a full multivariate normality as it was not an option in XLSTAT©. The normality of each variable within the data set is not a proof of MVN, but all elements of a data set that does meet the requirements of MVN must meet univariate tests of normality. We therefore used the results of univariate tests on each of the 5 input variables as an approximation of MVN as did Malacarne (2014). XLSTAT© automatically gives output for 5 different normality tests and is presented in Figure A2.1, below: P values at 95% confidence intervals are presented for each test on each variable. (The higher the P value the more likely the sample/observation set is drawn from a population with a normal distribution.) The alpha level was 0.05 (95% confidence limits). The closer to 0.05 alpha value the P value is the less certainty that the data set is from a population with a normal distribution. Each test involves different assumptions and approaches to testing for a normal distribution.

Figure A2.1 Tests of Normality
Comparisons on Major Measures By Variable



These results are being presented as a point of interest to get some insight to the data set. All of these measures are known to be robust with very small data sets and normally 20 is the smallest data set they should be performed on. Interesting and not unexpected to note that all 5 variables satisfied only the Jarques-Bera that is most often the case with econometric data sets. Jarques-Bera, alone requires no known mean or standard deviation and is based on skewness and kurtosis. It is interesting to note that "Serious Failures" and "Cu Grade" satisfied the criteria for normality only on the Jarques-Bera. In the case of "Serious Failures" that could be due to its "curvature". (See Figure 3.2) In the case of Cu Grade it may be due to the small difference min to max. Despite the results, this is not conclusive of MVN but strongly suggests that and supports that our use of CCA for exploration is reasonable.

Multicollinearity must not exist for meaningful use and interpretation of CCA Each data set was also tested via principal Component Analysis for Multicollinearity and the eigenvalues for each were very high, 1.880 for the failures data set accounting for 94.013 % of variability and 2.546 for the mining metric data set accounting for 84.8% of variability. Again there is a tendency to robustness in small data sets with very strong linearity. We are concluding only that the data set seems to satisfy the requirement for no Multicollinearity.

All of these results support that CCA is a suitable analytic tool for this Y1, Y2 data set and that the results can be meaningfully interpreted, albeit with acknowledged limitations on affirming statistical significance.

Table A2.2 – Failures Data Eigenvalues

	F1	F2
Eigenvalue	1.880	0.120
Variability (%)	94.013	5.987
Cumulative %	94.013	100.000

Table A2.3 – Mining Metric Data Set Eigenvalues

	F1	F2	F3
Eigenvalue	2.546	0.377	0.077
Variability (%)	84.859	12.570	2.571
Cumulative %	84.859	97.429	100.000

Our aim was not statistical significance, but a better understanding of the nature and structure of the relationship between the high severity failures and the mining metric variable affecting all mines and all miners. CCA offered that and is particularly well suited to exploration of relationships within complex systems and complex multi causal effects.

TSF failures resist any efforts to definitively map what specific combinations of events will result in failure, but we can meaningfully explore the contribution of various elements.

Our data set of "causes" most often associated with failure is itself raggedly incomplete and not systematically recorded for every failure. CCA allows analysis of the relationships between any two sets of system known to be much more complex than just the effects studied through CCA. It allows an open exploration of inter relationships and their intensity without in any way discounting other factors that may contribute as much or more to both likelihood of failure and severity of failure.

OUTPUTS OF CCA

Canonical Correlation Analysis (CCA) is most usually and almost universally defined as "the problem of finding two sets of basis vectors, one for data set Y1 and the other for data set Y2, such that the correlations between the projections of the variables onto these basis vectors are mutually maximized."

CCA seeks a pair of linear transformations, one for each of the sets of variables such that when the set of variables are transformed the corresponding co-ordinates are maximally correlated. The linear transformations are synthetic variables. One "synthetic variable" or canonical variate is create for each data set.

CCA is in some respects similar in principal to dimensional analysis in engineering employed to statistically explain or explore the complex relationships producing observed measurements. CCA similarly "discovers" the relationships that may not otherwise be apparent in univariate correlation analysis or which may be understated or not detected at all in univariate analysis (because of interrelationships within and between the two sets)

UNIVARIATE CORRELATION MATRIX

The univariate correlation matrix is a standard CCA output and presents the relationships in the entire data set, and is used to assess both the degree of independence and the degree of individual variable to variable relationships across all variables in the selected arrays Y1 (the severity of failure array) and Y2 (the Mining Metric array). These values are the same as those shown in Table 3.1 for the full original data set. This data set was pre-selected for the CCA for the strength of the correlations between the two failure severity classes (Y1) and the three selected mining metric variables (Y2).

Table A2.4 – CCA Output Correlation Matrix

		Y1		Y2		
		Very Serious Failures	Serious Failures	Cu prod	Cu cost	Cu grade
Y1	Very Serious Failures	1	0.880	0.860	-0.788	-0.794
	Serious Failures	0.880	1	0.720	-0.682	-0.884
Y2	Cu prod	0.860	0.720	1	-0.782	-0.756
	Cu cost	-0.788	-0.682	-0.782	1	0.497
	Cu grade	-0.794	-0.550	-0.756	0.497	1

EIGENVALUES

The principal output of a canonical correlation analysis are the canonical functions (variates) which seek to maximize explained variability between the two arrays (Y1 and Y2). Each function produced is an equation (similar to the equations created in regression analysis) but instead of explaining the relationships in terms of causality, it seeks to define the dimension (strength) of the relationship between (or in larger data sets among) the arrays. Essentially it asks are these arrays independent of one another, or does there appear to be an influence of the two arrays on one another. As many canonical functions are produced as there are variable sets

The first exploration of these canonical functions is the eigenvalue which measures how much variability is explained by each of the canonical functions. The closer the eigenvalue is to zero the less likely the two arrays form a diagonal matrix, i.e. have a linear correlation to one another which might therefore be suitable for linear modeling (regression analysis).

Table A2.5 – Eigenvalues

	FAILURES DATA EIGENVALUES	
	Canonical Function 1	Canonical Function 2
Eigenvalue	0.903	0.528
Variability (%)	63.1	36.9
Cumulative %	63.1	100.000

In this case the Eigenvalue for the first canonical function, F1, 0.903 strongly indicates a diagonal matrix. F1 explains explained 93.9% of the total variability between the two arrays indicating a very strong diagonal matrix. The second function, F2, calculated to be maximally independent of the first, in our data set also contributes to explaining 36.9% of the relationship between the two arrays.

We would expect any two data sets with similar within set patterns to produce very high eigenvalues but this FI result is higher than any produced from randomly generated arrays with similar slope and range for each variable. So this does add to our understanding of the strength of the linear relationship between Y1 and Y2.

WILKS LAMBDA

Wilks' Lambda is a test of the null hypothesis that the data sets are independent of one another as measured via the canonical coefficients. The lower the Wilk's Lambda, the less likely that the data sets Y1 and Y2 are independent. The following results means it is unlikely that the two data sets are independent of one another.

Table A2.6 – Wilks' Lambda Test

	Lambda	F	DF1	DF2	Pr > F
F1	0.046	2.451	6	4	0.202
F2	0.937				

F-Value

The value of the F approximation (a probability distribution) for testing the significance of the Wilks' Lambda corresponding to this row and those below it. If F is an approximation, as here, it is generated as appropriate to the test. Similar F values were XLSTAT generated for the actual (4.6) and the control (4.58) data sets. The first F-value tests the significance of the 1st and 2nd canonical correlations.

DF1

The numerator degrees of freedom of the above F-ratio.

DF2

The denominator degrees of freedom of the above F-ratio.

PR>F (Probability Level)

This is the probability value for the above F statistic. A value near zero indicates a significant canonical correlation. A cutoff value of 0.05 or 0.01 is often used to determine significance at the 95%h of 99% level.

This result is below a 95% confidence level (0.05) but is still strong (92%) I.e., if we accepted the null hypothesis that the two data sets are independent of one another there is a 92% chance we'd be wrong.

Again any data sets with similar variable ranges and slopes would also produce similarly strong results, but several trials with made up data sets did not yield results as strong as the actual data sets. For example, the data set in Table A2.5 below produced lower eigenvalues and higher Wilks Lambdas than the actual data (although the Wilks result in the control set is significant at a higher level than the actual data set).

The data set in Table A2.5 has very similar slope and pattern to the actual failures and mining metric data sets. The synthetic data are plotted in Figure A2.2.

The very high R-Squared as for the actual data set. The eigenvalue not as high and the Wilk's Lambda not as low.

The real data shows a strength of relationship that is not present in synthetic data sets with similar dimensionality and slope for each of the 5 variables.

Table A2.7 – Synthetic Data Set

Decade	Synthetic Very Serious Failures	Synthetic Serious Failures	Synthetic Cu Grade	Synthetic Production Cost	Synthetic Cu Production
1	46.8	49.95	70.14	66.0	50.00
2	39.0	42.18	65.13	52.8	51.55
3	31.2	57.72	46.76	24.2	53.15
4	46.8	43.29	33.40	17.6	54.80
5	54.6	53.28	31.73	13.2	56.49
6	54.6	62.16	30.06	8.8	58.25
7	62.4	57.72	20.04	6.6	60.05
8	54.6	65.49	18.37	6.6	61.91
9	70.2	61.05	15.03	4.4	63.83
10	62.4	69.93	5.01	4.4	65.81
11	70.2	68.82	3.34	6.6	67.85
12	62.4	69.93	1.67	11.0	69.95

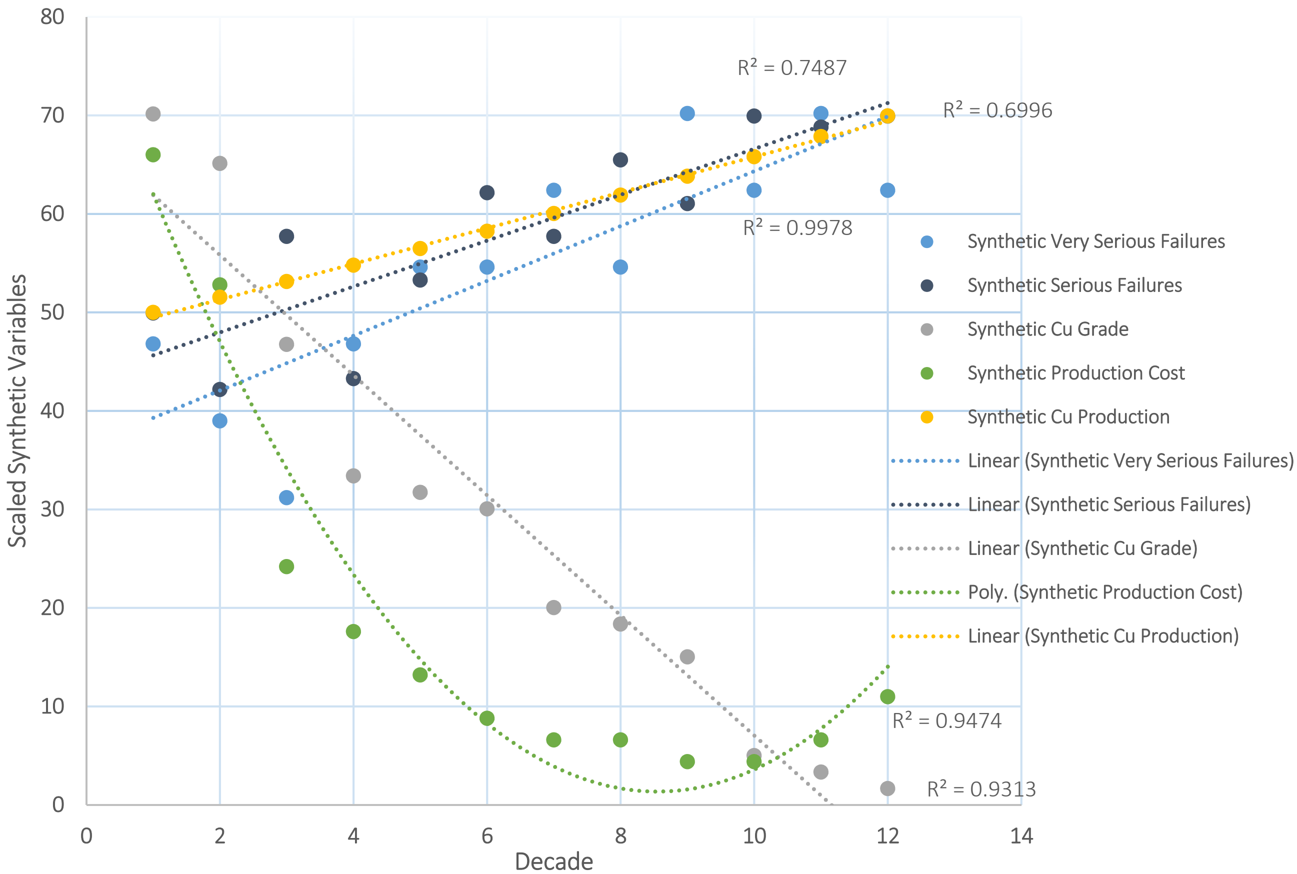
Table A2.8 – Synthetic Data Set Wilks' Lambda Test

	Lambda	F	DF1	DF2	Pr > F
F1	0.114	4.583	6	14	0.009
F2	0.932				

Table A2.9 – Synthetic Data Set Eigenvalues

	Canonical Function 1	Canonical Function 2
Eigenvalue	1.880	0.120
Variability (%)	94.013	5.987
Cumulative %	94.013	100.000

Figure A2.2 – Graph of Synthetic Values



Canonical Correlations

The canonical correlations (also called variates) are the two synthetic variables resulting from the projections of each data set onto a base vector maximizing the mutual variability between the two data sets. The result for each function, F1 and F2 describes the amount of variability accounted for. The higher the value the greater the amount of variability explained by the functions. Function F1 explained 95% of the variability.

Table A2.10 – Canonical Correlation Values

	F1	F2
Canonical Correlation	0.950	0.727
Eigenvalue	.903	0.528
Wilks' Lambda	0.046	0.472

Correlation Between F1 Canonical Variate And Data Set Variables

The aim of CCA is to discover whether dimensions of relationship exist between y1 and y2 variables that were not apparent in the graphs, charts and univariate analysis vis-a-vis one to one correlations. The correlations are shown below between both correlations (F1 and F2), and each variable in each data set, Y1 and Y2. They reveal a stronger influence of grade and cost to produce and reaffirmed the primary dominant relationship with production volume on both categories of failure severity. It also brought out stronger relationships in general between Serious Failures and the Mining Metric variables than were revealed in univariate and graphic analysis. The relationship between Serious Failures and the mining metric may be via cost of production.

Very Serious Failures had a much stronger and opposite correlation with F2 than did Serious Failures, - 0.388 v. - 0.096. The main component in F2 is ore production (-0.588) with cost also strong, 0.450.

In F1 which is much more strongly correlated with Serious Failures, grade is the principal element, 0.929. (While the second variate, F2 does not have the Wilks and Eigen Values of F1, it does it does illustrate that serious failures is a distinctive and separate failure severity group despite its many commonalities with very serious failures. As the possibility of larger data sets grow going forward (i.e. more information from 2000 onward) it may be possible to explore those differences more fully.

The first canonical variate, F1, had very strong correlations with all variables in each of the two data sets (Y1, failures and Y2, mining metric elements. Both of the failure variables and production volume had very strong negative correlations with F1: -0.922, -0.995. Cu Ore Production (-0.802). Cu Cost (0.755) and Cu Grade (0.929) were also highly correlated with F1. F1 is a therefore a nearly complete expression of the very strong relationship between the two data sets with each of the mining metric elements.

Table A2.9 - Input and Canonical Variable Correlations

Correlations between input variables and canonical variables (Y1):

	F1	F2
Very Serious Failures	-0.922	-0.388
Serious Failures	-0.995	0.096

Correlations between input variables and canonical variables (Y2):

	F1	F2
Cu Production	-0.802	-0.558
Cu Cost	0.755	0.072
Cu Grade	0.929	0.368

References & Bibliography

Dehon, Catherine, Filzmoser, Peter, and Christophe Croux, “Christoper Robust Methods for Canonical Correlation Analysis” accessed March 27 at http://www.statistik.tuwien.ac.at/public/filz/papers/namur00.pdf

Korkmaz, Selcuk; Goksuluk, Dincer; and, Zararsiz, Gokmen. “MVN: An R Package for Assessing Multivariate Normality” 2015 Accessed March 27, 2015 at http://cran.r-project.org/web/packages/MVN/vignettes/MVN.pdf

Malacarne 2014. Malacarne, Rodrigo Loureiro, Canonical Correlation Analysis, The Mathematica Journal v.16, 2014. Accessed March 27 at http://www.mathematica-journal.com/2014/06/canonical-correlation-analysis/

NCSS Statistical Software “Canonical Correlation Analysis” Accessed March 27 at http://ncss.wpengine.netdna-cdn.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Canonical_Correlation.pdf

http://faculty.arts.ubc.ca/dwhistler/325ClassNotes/chapNorTest.pdf

APPENDIX 3

Documented TSF Very Serious Natural Resource Losses

1990 - 2010

Documented TSF Very Serious Natural Resource Losses 1990 – 2010

TSF Failure	Year	Original Currency (Millions)	Failure Year M US$	2014 M US$	Ore	Release (M m^3)	Run Out (km)	Deaths	Source
Kingston Fossil Plant, Harriman, Tennessee, USA	2008	US 1,200	$1,200	$1,300		5.4	4.1		http://www.sourcewatch.org/index.php/TVA_Kingston_Fossil_Plant_coal_ash_spill
Taoshi, Linfen City, Xiangfen, Shanxi Province, China	2008	US 1,300	$1,300	$1,429	Fe	0.19	2.5	277	Wei, Yin, Wang Ling,Wan(2012), http://wmr.sagepub.com/content/31/1/106.full.pdf+html
Baia Mare, Romania	2000	US 179	$179	$246	Au	0.1	5.2		(1) http://www.wise-uranium.org/mdafbm.html (2) http://viso.jrc.ec.europa.eu/pecomines_ext/docs/bmtf_report.pdf
Los Frailes, Spain	1998	EU 275	$301	$437	Zn/Cu/Pb	4.6	5		http://www.wise-uranium.org/mdaflf.html
Marinduque Island, Philippines	1996	P 180 + US 114	$123	$185	Cu	1.6	27		(1) http://www.slideshare.net/no2mininginpalawan/major-tailings-dam-disasters-in-the-philippines-alyansa-tigil-mina-atm-april-2011-7819384Philippines (2) http://newsinfo.inquirer.net/479345/marinduque-folk-lose-case-vs-mine-firm (3) http://opinion.inquirer.net/63421/marinduque-is-pushed-to-the-wall (4) http://www.slideshare.net/jillentot/environmental-damages-and-health-hazards-caused-by-marcopper?related=1 (5) Bennagen, 1998
Omai, Guyana	1995	US 100	$100	$156	Au	4.2	80		(1) http://www.thefreelibrary.com/Cambior+Inc.+Announcement.-a055509330 (2) http://www.monitor.net/monitor/9-18-95/eyewitness.html (3) http://ejatlas.org/conflict/omai-gold-mine-tailings-dam-guyana (4) http://www.multinationalmonitor.org/hyper/issues/1995/11/mm1195_04.html
Merriespruit, South Africa	1994	R 100	$29	$46	Au	0.6	2	17	http://floodlist.com/africa/merriespruit-tailings-dam
	Average US$2014: $543			====== $3,799					

NOTES:

A. HISTORICAL CURRENCY CONVERTERS

(1) http://unix4.outcoursing.com/currency-converter/us-dollar-usd_zar-south-african-rand.htm/1994

(2) http://www.x-rates.com/historical/

2005-2015 selected currencies

(3) http://fxtop.com/en/currency-converter-past.php?A=275&C1=EUR&C2=USD&DD=01&MM=01&YYYY=1998&B=1&P=&I=1&btnOK=Go%21

Converts from any one currency to another for any given date 1953-2015

(4) http://www.usinflationcalculator.com/

Advances value of $US from any year from 1913 to any year up to 2015

B. DOCUMENTED TSF VERY SERIOUS NATURAL RESOURCE LOSSES

(1) **TAOSHI, LINFEN CITY, XIANGFEN COUNTY, SHANXI PROVINCE**

US2008 $1,300 million = US2014 $1,429 million

This failure released approximately "1.9 × 105 m^3 tailings. The tailings flowed as far as 2.5 km downstream and covered about 35 hectares of land. … The tailings destroyed many houses, caused 277 deaths, 33 injuries, and caused about US$ 1.3×10^7 in direct losses. The failure also resulted in very serious social impacts."

Source:
(a) http://wmr.sagepub.com/content/31/1/106.full.pdf+html

(2) **BAIA MARE**

US2000 $179 million = US2014 $246 million

Operated by AURUL, a joint-venture between Esmeralda Exploration of Australia and REMIN the Romanian state owned mining company.

"On Dec. 16, 2000, Tom Garvey, the head of a European Union task force investigating the spill said there is no doubt the mine was at fault and is responsible for the environmental disaster." No doubt whatever it was a direct result of a hundred tonnes plus of cyanide going into the Pau, the Somas and the Tisza River and killing everything in its wake," he said.

The investigation concluded that the accident was caused by the inappropriately designed tailings dams, the inadequate monitoring of the construction and operation of those dams and by severe - though not exceptional - weather conditions. (Australian Broadcasting Corporation Dec. 16, 2000) (1)

Excerpts from the Baia Mare International Task Force Investigation

"As a result, it is the conclusion of the BMTF that the accidents were caused:

- Firstly, by the use of an inappropriate design of the TMF;
- Secondly, by the acceptance of that design by the permitting authorities; and
- Thirdly, by inadequate monitoring and dam construction, operation and maintenance"(2)

"Furthermore there was a problem in the case of Baia Mare with the stability of the embankment walls themselves. This arose because the Baia Mare facility used a recognized technique of embankment or dam wall construction (called 'construction by operation') which called for the gradual deposition of tailings of sufficiently coarse grade on the starter walls to ensure stable and continuous growth of the height of the embankment walls.

However, the mix of tailings used did not have the ratio of coarse to fine grades stipulated in the design and, in addition, the hydrocyclones used to distribute the tailings within the pond could not operate in the very low temperatures experienced before the accident. As a result the embankment wall construction was interrupted at a critical time, leading to a reduction in the 'freeboard', and consequently to wall breaching and overflow." (2)

"In effect, these were two accidents waiting to happen, waiting for the necessary trigger of adverse weather conditions which was bound to come sooner or later." (2)

On July 11, 2000, the Hungarian Government lodged a $179 million compensation claim against Esmeralda Exploration. (1)

Sources:

(a) http://www.wise-uranium.org/mdafbm.html
(b) http://viso.jrc.ec.europa.eu/pecomines_ext/docs/bmtf_report.pdf

(3) **LOS FRAILLES**

EU1998 €275 million = US1998 $301.4 million = US2014 $437 million

Operated by Boliden Ltd. Sweden via subsidiary Boliden-Apirsa

On November 20, 2001, the Andalusian Government and the Spanish Environmental Ministry announced to sue for damages. Both Administrations have spent more than Pesetas 40,000 million (Euro 240 million / US$ 210 million) for the clean-up of the spill. (El País Nov. 21, 2001)

On December 14, 2001, Boliden Apirsa signed agreements with the Regional Government of Andalucía and with the workers council and unions regarding environmental restoration plans and severance payments. The mining company had presented a plan of environmental restoration and abandonment of the mine valued in 8,269 million pesetas (EUR 50 million / US$ 45 million). The workers council, however, estimated that at least an additional 5,000 million pesetas (EUR 30 million / US$ 27 million) were required. I.e. future work estimated by regional government of Andalusia at $72 million (beyond what was sent as of 11/21/2001)

In the agreement obtained, the Regional Government had to accept the payment with assets of the company for lack of sufficient funds available. But it reserved the right to claim from Apirsa's Swedish parent company Boliden Ltd any additional funds that might be required in the future. (El País Dec. 15, 2001)

The environmental group Ecologistas en Acción has decided to draw the case on the penal responsibility for the tailings dam failure before the Constitutional Court. (El País Feb. 1, 2002)

On April 23, 2002, the advisor of Environment, Fuensanta Coves, indicated that the legal services of the Regional Government are completing the statements of civil claims against Boliden-Apirsa, to demand a part of the funds used to repair the damages of the accident. The Andalusian Administration has invested more than 152 million Euros (around 25,000 million Pesetas) in the recovery, and it anticipates to spend another 10 million Euros in 2002. El País April 24, 2002) (i.e. total costs as of 2002 put at $162 EU)

On July 2, 2002, the Environmental Council of the Andalusian Government approved the initiation of civil actions against the mining company to try to recover part of the 152 million Euros (25,000 million pesetas) spent to decontaminate the affected zone. (El País July 3, 2002)

On July 31, 2002, the Environment Council of the Andalusian Government concluded the removal of the 10,000 cubic meters of muds that still were stored in the river basin of the Guadiamar. The Environment Council furthermore announced that it will come to the reforestation of the affected zone in October 2002. (El País August 1, 2002)

On August 2, 2002, the Council of Ministers imposed a penalty of 45 million Euros on Boliden, the highest ever by environmental damages in Spanish history. Nevertheless, the fine covers only about one sixth of the cleanup cost of 276 million Euros spent by the administrations so far. (El País / El Mundo, August 3, 2002)

Boliden announced it is not willing to pay a single cent. (ABCe August 5, 2002)

The Andalusian Government plans to impose another penalty of 86 million Euros on Boliden to recover the cost it has spent on the cleanup. (El País August 6, 2002)

Boliden claims damages from the Spanish construction company Dragados: Boliden's Spanish subsidiary Boliden Apirsa has filed a notice of litigation against Dragados y Construcciones S.A., a member of the construction company Dragados S.A., listed in Spain, in connection with the failure of the tailings dam at the Los Frailes mine, Spain, in 1998. Boliden´s claim against Dragados amounts to a minimum of **1 billion SEK (107 million Euro).** The formal claim will be presented to a Spanish court in October. (Boliden Sep 26, 2002)

On Nov. 16, 2002, the regional government of Andalusia filed a civil suit to recover from Boliden 89.8 million euros ($89.9 million) in damages and cleanup costs. (Reuters Nov. 22, 2002)

On Jan. 2, 2003, the Primera Instancia número 11 court of Seville rejected the civil demand of the regional government of Andalusia against Boliden. (ABCe Jan. 4, 2003)

The regional government of Andalusia now has decided to demand from Boliden recovery of 89.9 million euros in damages by the administrative route. (ABCe Nov. 5, 2003)

"As previously announced, Boliden's Spanish subsidiary Boliden Apirsa filed a notice of litigation against the Spanish company Dragados y Construcciones S.A. Now Boliden Apirsa has filed the final claim in a court in Madrid. Boliden's claim against Dragados amounts to around EUR 115 million." (Boliden Jan. 23, 2004)

Source:

(a) http://www.wise-uranium.org/mdaflf.html

(4) **OMAI**

US1995 $100 million = US2014 $156 million

Operator: Cambior, subsidiary Golden Star Resources in partnership with INVESCOR of Denver, via subsidiary Omai Mines Ltd in which Guyana Government had 4% interest.

Class Action Lawsuit for $2B dismissed against Cambior & claimants ordered by Guyana court to pay all defense costs of all named mining interests and their insurers. (3) The dismissal and general outcome viz a viz environmental damages is widely considered a failure of environmental justice. There has been no systematic accounting of actual damages by the Guyana Government or any NGO only the imposition of a $100 million fine.

"Several months before the disaster, the company told the government that because it had underestimated the amount of waste it would produce, it would need to build a second tailings dam and partly because of the cost would be unable to pay any royalties and taxes to the government until the year 2002, just three years before the mine's is expected to close. The news had reportedly caused dismay in government circles. As Omai is the largest open pit gold mine in South America, the government expected it to contribute substantially to its revenues." (2)

"The disaster only added fuel to an already difficult relationship. Instead of being a source of revenues, the mine is now a cause of more environmental expenditures for the government, whose foreign debt sometimes consumes as much as 70 percent of its tax revenues.

"There have been warnings of a disaster in the making for months. In March, the operators of the mine warned that disposal of the waste water was a problem, and prophetically suggested the mine might need to close in August if no other way was found to deal with the waste. A small spill occurred in May and in June the government announced an investigation into whether company plans to discharge effluent into the river were environmentally sound.

"Roger Moody, the Mining Advisor to the Amerindian People's Association of Guyana (APA) and the author of several works assessing the socio-economic impact of mining projects, was invited to Guyana last December by the APA, who expressed concern about earlier reported pollution incidents at Omai.

"He was unable to get permission to visit the site. He told American Reporter News Bureau yesterday that "the mine was hastily built, ill planned and an example of greed masquerading as the hope of a poor country." The mine is a subsidiary of Invesco, Inc., a Denver, Colorado-based mutual fund giant. Among that company's outside directors is the CEO of Atlanta 1996 Olympic Games. The Canadian engineering company Knight Piesold hired by Omai Gold Mine to build the tailings dam say they were very embarrassed by being associated with the failure.

"The company has built hundreds of tailings dams and this is the first time something has happened like this," a company spokesman said. However, the firm believes that Omai further developed the tailings dam after Knight Piesold left the project, raising the walls from the 25 metres state Knight Piesold had designed to a height of 45 metres.

"The initial cyanide spill in May was reported as being due to a power failure which had prevented sluice gates from being closed. This suggests that the gates were already open at the time of the failure, perhaps for a deliberate controlled discharge of effluent.

"Such a deliberate release is entirely plausible. Omai Mines had intended from the very first to release overflows from the polluted tailings dam into the river in its original Environmental Impact Statement to the previous Guyanese government. The current government apparently inherited a tacit agreement to this controlled release, along with a five percent equity share in the mine.

"A major force in bringing the mine to reality was Canadian mining investor Robert Friedland, who at the time was reeling from a gold mine's tailings dam disaster at Summitville, Indiana, the most expensive such failure in the U.S. in recent times.

"The Environmental Protection Agency (EPA) has estimated that the final cost of clearing up the cyanide and heavy metal pollution at the Summitville mine will be about $120 million. Friedland is still wanted for questioning by the EPA.

"After the Summitville disaster, Friedland invested in Omai Gold Mines Ltd. through Golden Star Resources, the subsidiary of Canadian-based Cambior, Inc. and Invesco, which operates a $9 billion mutual fund specialized in high-risk securities from "emerging nations." Golden Star Resources is now a 35 participant in the mine. Friedland is now believed to have sold his holding in the Omai mine and to have moved on to establishing one of the world's largest new gold mines on Lihir Island in Papua New Guinea." (2)

"The Québec Superior Court dismissed the case in August 1998, on the grounds that the courts in Guyana were in a better position to hear the case. A lawsuit against Cambior was filed in Guyana, but it was dismissed by the High Court of the Supreme Court of Judicature of Guyana in 2002. A new suit was filed against Cambior in 2003 in Guyana again seeking damages for the effects of the 1995 spill. In October 2006, the High Court of the Supreme Court of Judicature of Guyana ordered the dismissal of the 2003 action and ordered the plaintiffs to pay the defendants' legal costs. (3)

"In August 1998, within the three-year limitation period, a similar Representative Action was filed in Guyana. OMAI has now been served with the Action claiming to represent some 23,000 individuals in Guyana and seeking US $100 million as compensation for damages. The Action remains open to challenge in numerous respects, and Cambior and OMAI have instructed their attorneys to contest it vigorously" (1)

Sources:

(a) http://www.thefreelibrary.com/Cambior+Inc.+Announcement.-a055509330
(b) http://www.monitor.net/monitor/9-18-95/eyewitness.html
(c) http://ejatlas.org/conflict/omai-gold-mine-tailings-dam-guyana
(d) http://www.multinationalmonitor.org/hyper/issues/1995/11/mm1195_04.html
(e) https://ujdigispace.uj.ac.za/handle/10210/7295

(5) **MARINDUQUE**

Natural Damage Rehabilitation:

Tailings rehabilitation: Dredging of Boac River (Bennagen, 1998, Table 13)

US1996 $114 million = US2014 $172 million (www.usinflationcalculator.com)

Socioeconomic Loss:

Present Value of Current and Future Foregone Income for 10 years = P1996 $180 million
(At a discount rate of 15%, see Bennagen, 1998, Table 7)

P1996 $180 million = US1996 $8.77 million (www.x-rates.com/historical)

US1996 $8.77 million = US2014 $ 13.23 million (www.usinflationcalculator.com)

TOTAL: US1996 $122.8 million = US2014 $185 million

Operator Placer Dome Subsidiary Marcopper Mining

"This may be the amount used in some or all of the claims filed against Marcopper by fisher folk & other private citizens (which was not sustained). These damages are clearly not about clean up and only partly about loss of the rivers other functions in the ecosystem. We have therefore treated them as an amount separate from the $100 million government suit against Placer.

Background & Summary Notes

"The banks of the Boac River still hold tall mounds of tailings that were left to continuously pump acid and heavy metals into the river after another catastrophic dam failure filled that river with mine waste in 1996. These contaminated rivers no longer support the livelihood and economic activities of nearby villages, as they once did. Placer Dome, which had managed two copper mines in Marinduque, fled the Philippines in 2001, leaving the mess behind.

In spite of a long legal struggle with competent American lawyers, on Sept. 17 Marinduque provincial administrator Eleuterio Raza told the Inquirer that Barrick had offered the province around $20 million, take it or leave it." (4)

The cleanup of mine waste in contaminated sites around the world indicates that rehabilitation on a scale that is required in Marinduque can easily run into hundreds of millions of dollars. (4)

"Numerous independent scientific studies of the ravages of mining on Marinduque, including by the United States Geological Survey, confirm the ongoing toxic impacts of uncontained mine waste and unrehabilitated rivers and coastal areas. Furthermore, numerous dams and structures have not been maintained since the mine ceased operations in 1996. Placer Dome's own consultants, Canada's Klohn Crippen, warned in a 2001 report, leaked just before Placer Dome fled the Philippines, of "danger to life and property" related to inadequate mine structures holding back waste." (4)

The incident resulted in the release of 1.6 million cubic meters of tailings along a 27km span of the river system and coastal areas near the river mouth of the island province. The impact on the river eco system was extensive. The devastating effects of the pollution on the river and costal ecosystems was of such a magnitude that a UN Assessment Mission declared the accident an environmental disaster. Boac River was left virtually dead. The onrush of tailings downstream displaced the river water, which in turn flooded low lying areas destroying crop farms and vegetable gardens along the banks and clogging the irrigation waterways to rice fields."

Oxfam, an international development and humanitarian aid agency with projects in the Philippines was approached by Marinduque community members for help. Oxfam Australia's Mining Ombudsman took their case and released a report. The report calls on Placer Dome to complete an environmental clean-up, adequately compensate affected communities, and take steps to prevent future disasters. The report updates similar findings made by the United States Geological Survey in July 2004. As of 2005 Placer Dome (which ran the mine at the time of the disaster) was the sixth largest gold mining company in the world and was listed on the Toronto Stock Exchange, but was acquired by Barrick Gold in 2006. At the time of the incident Marinduque was identified as among the 44 poorest of the 80 provinces in the Philippines

On October 4, 2005, the provincial government of Marinduque sued Marcopper's parent company, Placer Dome, for $100 million in damages.

Sources:

(a) http://www.slideshare.net/no2mininginpalawan/major-tailings-dam-disasters-in-the-philippines-alyansa-tigil-mina-atm-april-2011-7819384Philippines
(b) http://newsinfo.inquirer.net/479345/marinduque-folk-lose-case-vs-mine-firm
(c) http://opinion.inquirer.net/63421/marinduque-is-pushed-to-the-wall
(d) http://www.slideshare.net/jillentot/environmental-damages-and-health-hazards-caused-by-marcopper?related=1
(e) Bennagen, 1998. Estimation of Environmental Damages from Mining Pollution: The Marinduque Island Mining Accident, Ma. Eugenia Bennagen, Economy and Environment Program for Southeast ASIA, November, 1998

(6) **MERRIESPRUIT**

R1995 R100 million = US1995 $29 million = US2014 $46 million

Operator Harmony Gold

Despite the well documented and oft cited magnitude of loss, an entire village and many lives, and despite a judicial inquest there was no authoritative estimate of the economic value of that damage. The R100 cited above gave no source and no details and clearly is a significant under accounting of damage from a run out of this volume and length.

"Little attention was given to the environment. The identified need in this study was therefore to investigate the consequences of the disaster on the environment, a need which derives from the uniqueness of this particular disaster and its consequences. The Department of Minerals and Energy require the submission of an Environmental Management Program Report (EMPR) on all prospecting and mining operations. It is clear that, in the compilation of such an EMPR, Harmony Gold Mine neglected to establish a Management Plan to regulate the physical impact of the disaster on the environment, mainly because no attention was given to disasters in the Aide-Memoir."

Damages were estimated at R100 million (1)

The year before the disaster, a leak was reported, so all deposition was cancelled in to that particular compartment. Extra water was filtered into another compartment. Before the dam failed, the conditions were considered unsafe and unfit. The freeboard (which contained the extra water) did not have the ability to hold half a metre of extra water. But still, nothing was done. (1)

Management failures at Merriespruit:

- The inquest judge laid the blame for the disaster at the doors of the contractor, the mine, and certain of the contractor's and mine's employees. Failings of these parties that were illuminated at the inquest were as follows:
- There was no review process for the operation of the storage that involved an independent reviewer. The mine's and contractor's familiarity with the chronic problems of the storage resulted in complacency about their seriousness.
- The only involvement of a trained geotechnical engineer in the problems of the storage was that of an employee of the contractor, who became involved occasionally, only by request, and whose roles and responsibilities were ill defined.
- There were regular meetings between the mine and the contractor. However, decisions were poorly recorded, which led to confusion about responsibilities and agreed actions.
- The contractor's office at the mine did not keep the head office adequately informed of happenings at the storage. The head office was ignorant of problems and potential problems at the site and could thus not take corrective action.
- The contractor's local office was aware that water was being stored in the storage by the mine, but it took no action and did not inform either head office or seek the advice of its geotechnical engineer.
- Although the contractor had operated the storage since its inception, he had never been requested to upgrade the facilities of the storage and so bring it in line with acceptable practice, as spelled out in the industry guideline. (Chamber of Mines of South Africa 1979, 1983). Thus, the storage continued to be operated without a return-water pond. This necessitated storing water in the storage.
- Remedial measures taken to restore the stability of the northern wall were ad hoc and not the result of an adequate geotechnical investigation and design. (3)

Source:

(a) https://ujdigispace.uj.ac.za/handle/10210/7295
(b) http://floodlist.com/africa/merriespruit-tailings-dam
(c) https://books.google.com/books?id=OdFp3wKyxJoC&pg=PA453&dq=merriespruit+slimes+dam+1994&source=gbs_toc_r&cad=4#v=onepage&q=merriespruit%20slimes%20dam%201994&f=false

(7) **TENNESSEE FOSSIL PLANT**

US2008 $1,200 million = US2014 $1.3 billion

Owner Operator Tennessee Valley Authority

On December 22, 2008, a retention pond wall collapsed at Tennessee Valley Authority's (TVA) Kingston plant in Harriman, Tennessee, releasing a combination of water and fly ash that flooded 12 homes, spilled into nearby Watts Bar Lake, contaminated the Emory River, and caused a train wreck. Officials said 4 to 6 feet of material escaped from the pond to cover an estimated 400 acres of adjacent land. A train bringing coal to the plant became stuck when it was unable to stop before reaching the flooded tracks.

Originally TVA estimated that 1.7 million cubic yards of waste had burst through the storage facility. Company officials said the pond had contained a total of about 2.6 million cubic yards of sludge. However, the company revised its estimates on December 26, when it released an aerial survey showing that 5.4 million cubic yards (1.09 billion gallons) of fly ash was released from the storage facility.

The TVA spill was 100 times larger than the Exxon Valdez spill in Alaska, which released 10.9 million gallons of crude oil. Cleanup was expected to take weeks and cost tens of millions of dollars.

According to reports filed with the EPA by the Tennessee Valley Authority, the 2008 TVA Kingston Fossil Plant coal ash spill resulted in a discharge of 140,000 pounds of arsenic into the Emory River -- more than twice the reported amount of arsenic discharged into U.S. waterways from all U.S. coal plants in 2007. (1)

In April 2009, TVA Chairman Bill Sansom said the company is facing "upward pressure" on its rates, stemming from several challenges, including the Kingston coal ash spill. TVA has already spent $68 million on cleanup, and it estimates the final cost could surpass $800 million, not including fines and lawsuits. The Associated Press reported on April 11 that TVA had already spent over $20 million purchasing 71 properties tainted by the coal-ash spill and is negotiating to buy more.

Although falling fuel prices have enabled TVA to cut much of a 20 percent rate increase that took effect in October 2008, the company is considering another increase in October 2009 to mitigate these expenses. TVA will set its fiscal 2010 budget and rate changes in August.

In September 2011, it was reported that TVA estimated the total cost of the cleanup will be $1.2 billion. The utility is self-funding, so ratepayers in the seven-state region are paying the tab with higher electric bills. (1)

On August 23, 2012, U.S. District Judge Thomas Varlan ruled that "TVA is liable for the ultimate failure of North Dike which flowed, in part, from TVA's negligent nondiscretionary conduct." The litigation involves more than 60 cases and more than 800 plaintiffs, and will allow their claims of negligence, trespass, and private nuisance to move to Phase II proceedings, meaning each plaintiff must prove the elements of his or her respective negligence, trespass, and/or private nuisance claims by a preponderance of the evidence.

In a Sep. 27, 2010 report, TVA's inspector general Richard Moore said poor coal ash control practices and the Tennessee Valley Authority management culture led to the huge December 2008 spill. The report on the inspector general's website describes the giant spill of coal sludge laden with selenium, mercury, and arsenic as "one of the largest environmental disasters in U.S. history." TVA said the description of the event as one of the largest disasters is "not supportable." Moore refused to change. (1)

(ATLANTA – May 18, 2010) The U.S. Environmental Protection Agency (EPA) Region 4 today has approved the Tennessee Valley Authority's (TVA) selected cleanup plan for the next phase of coal ash removal at the TVA Kingston site in Roane County, Tenn. The cleanup plan, one of three alternatives proposed to the public earlier this year, requires TVA to permanently store on site all of the ash being removed from the Swan Pond Embayment, which includes land and bodies of water adjacent to the TVA coal ash disposal area. The embayment area will then be restored to conditions that protect human health and the environment. (2)

Sources:

(a) http://www.sourcewatch.org/index.php/TVA_Kingston_Fossil_Plant_coal_ash_spill
(b) http://yosemite.epa.gov/opa/admpress.nsf/2ac652c59703a4738525735900400c2c/106c22e4bc722561852577270062c9de!OpenDocument
(c) http://www.epakingstontva.com/default.aspx