

Permanent submergence : the long-term challenge and commitment of keeping the genie in the bottle

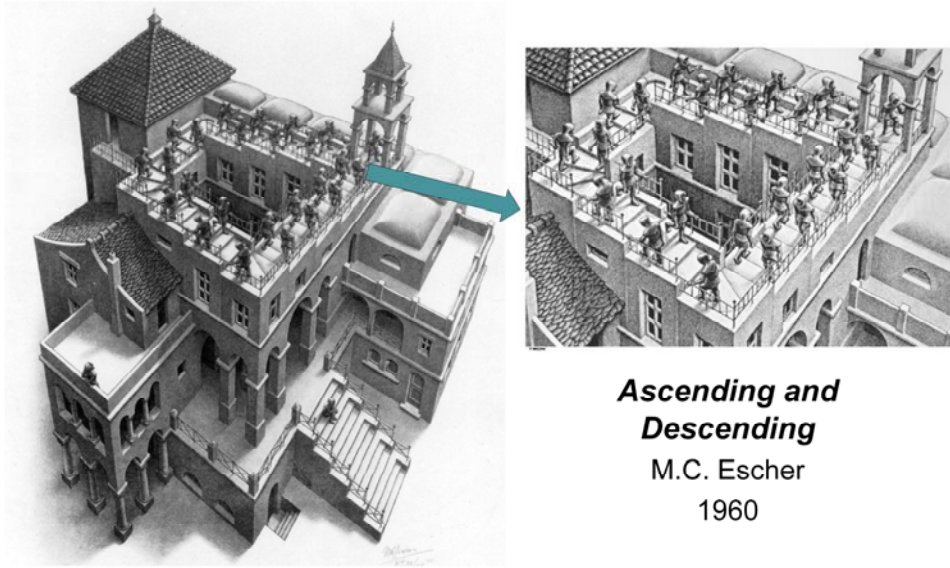
**19th ANNUAL BRITISH COLUMBIA-MEND
ML/ARD WORKSHOP**

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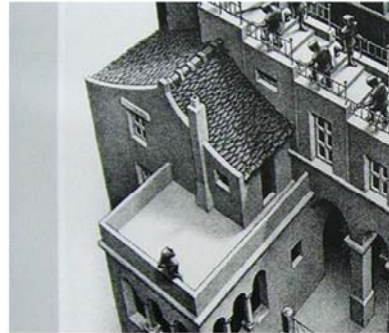
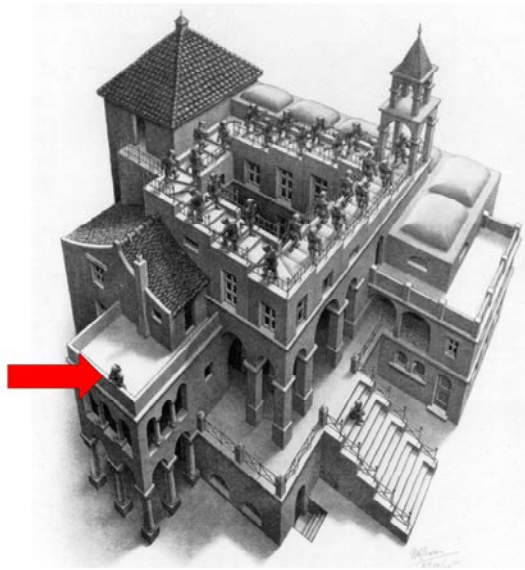


This morning I am going to subject you to a tailings dam engineer's perspectives and reflections upon the paradigm of permanent submergence of sulphidic mine wastes. I like to think of sulphidic tailings as a genie. Left unrestrained, the genie will make much mischief in the form of oxidation and metal leaching. To restrain that genie, we know well that permanent submergence is an effective means of prevention. To achieve permanent submergence, we need a bottle, and a permanent one at that. I will share with you this morning some thoughts on the challenge and commitment of keeping the genie in that bottle, and some thoughts on where we go from here.



We will examine the permanent submergence paradigm from three perspectives, for which Escher's *Ascending and Descending* provides a powerful allegorical representation.

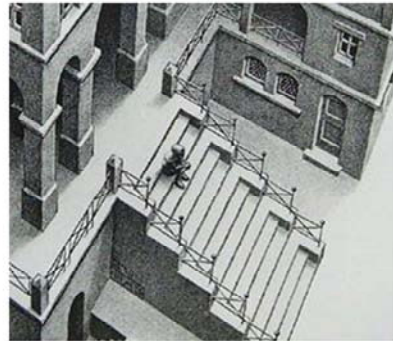
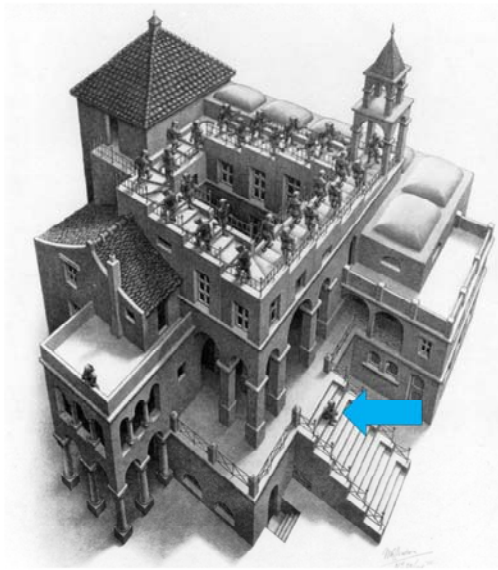
Our first perspective will be from within, walking with the monks continually ascending and descending the same set of stairs, thanks to Escher's genius for illusion. Within their paradigm, they continually advance and yet get nowhere.



***Ascending and
Descending***

M.C. Escher
1960

Our second perspective will be that of the outlier monk, on the outside looking in upon his colleagues casting a quizzical, skeptical, and perhaps disapproving eye upon their circuitous endeavors.



Ascending and Descending

M.C. Escher
1960

Our third and final perspective will be speculation on the future of mine waste management here in B.C., in the manner of the other outlier monk, the visionary, seated on the stairs, his back turned. Disillusioned with the paradigm of his colleagues, he ponders the arrival of the next.

Some typical scenery in the Golden Triangle



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The terrain in the Golden Triangle region, though picturesque, is very isolated, replete with geohazards, possesses a very wet climate, is seismically active, and is the most volcanically active region of the province. The challenges associated with bottle construction and long term genie confinement in such environs are both obvious and daunting.

Nonetheless, this region does appear to constitute the B.C. mining industry's next great frontier in terms of mine waste management

To place upcoming challenges in context, it is useful to review briefly how mine waste has been managed in B.C. in the recent past.

Island Copper Mine – submarine tailings disposal, 1971-1995.

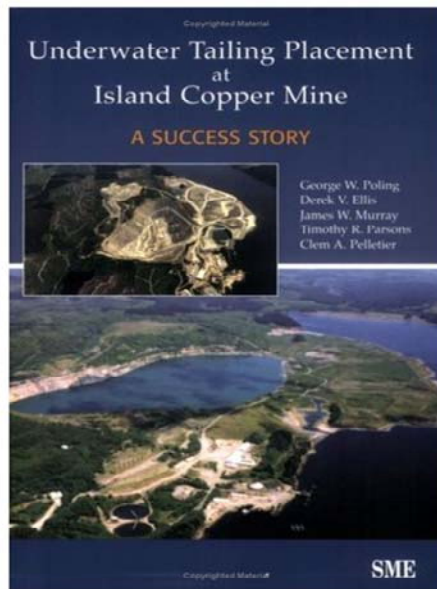


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The Island Copper mine, located near the north tip of Vancouver Island, operated from 1971 to 1995.

The potentially acid generating tailings were discharged using submarine tailings disposal into the Rupert Inlet fjord, a scheme then judged by DFO to represent a **lower** risk to fisheries resources than on-land storage of the tailings within constructed containment dams. Construction and long term maintenance of a man-made genie bottle was not the preferred ARD solution.

Island Copper Mine – submarine tailings disposal, 1971-1995.



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A more secure bottle for permanent confinement of the genie one could scarcely imagine. From a political and emotional perspective, the story was rather different.

Despite the controversies, at the end of the day, the science seems to have demonstrated no deleterious effects on fisheries, and rapid re-colonization and recovery of benthic ecosystems upon cessation of tailings discharge.

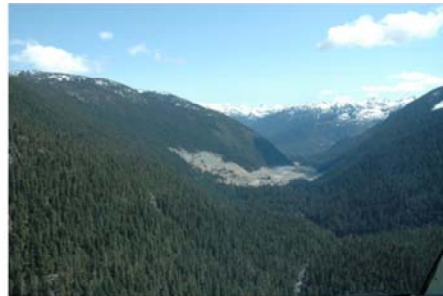
Nature is often far more resilient than we credit.

Nonetheless, such a scheme would seem unthinkable in B.C. today.

Myra Falls Pb-Zn Mine 1966 - present



- Subaqueous discharge of 5.5 Mtonnes of PAG tailings into Buttle Lake through 1984
- Site constrained by steep mountains, high precipitation environment
- Located within Strathcona Provincial Park
- Buttle Lake drains into Campbell River (water supply for town of Campbell River)



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The Myra falls mine is a primarily underground operation that began in 1966 and is still in operation today.

The mine is located within Strathcona Provincial Park in very steep, mountainous terrain, and receives about 2.5 m average annual precipitation.

From 1966 to 1985, tailings were deposited sub-aqueously, at a depth of about 30 m, into nearby Buttle Lake.

Myra Falls – a paradigm shift (1985)



- MEND (1989): *"it is reasonable to conclude that the submerged tailings are having no impact on Buttle Lake water quality at the present time. As burial by natural sediments continues, this conclusion will be reinforced"*.
- Pederson et al. (1999): *"the quantum of metal possibly being released to the deep waters in the lake from the submerged deposits appears to be so small as to be not measureable"*.

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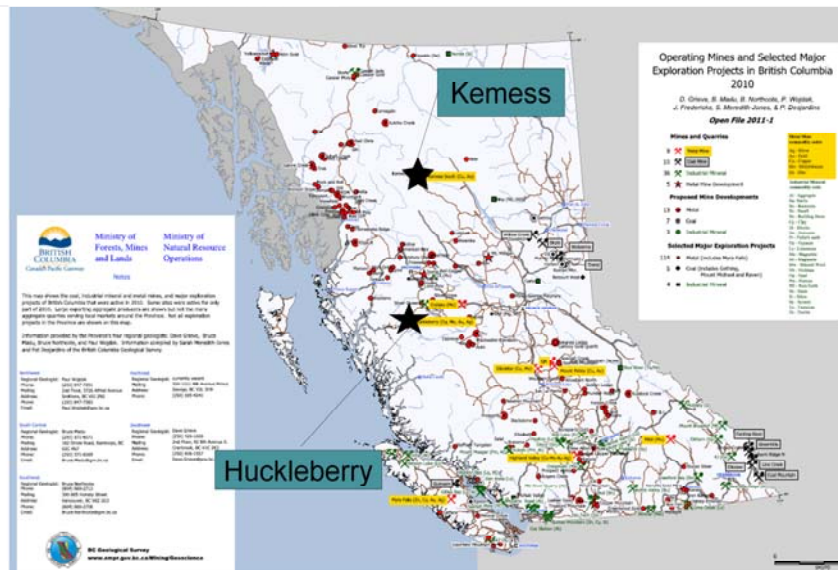
In 1985, in response to escalating concerns over rising zinc levels in Buttle Lake, an on-land tailings storage facility was commissioned.

It turned out however that the waste rock dumps from the small open pit portion of the operation were the cause of rising zinc levels, not the subaqueous tailings disposal.

Subsequent scientific studies, some cited here, confirmed that the tailings *"are having no impact on Buttle Lake water quality"*. Nonetheless, the end result is an impoundment of non-flooded sulphidic tailings, the seepage from which will require collection and treatment in perpetuity.

At this site Buttle Lake comprised the only feasible means of confining the genie. The modern zeitgeist in B.C. appears to dictate that lake disposal of tailings is a non-starter, however technically effective a solution it may be. Today's paradigm demands man-made genie bottles.

Huckleberry and Kemess



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We now consider two case records conceived, permitted, and operated in B.C. under this contemporary paradigm.

The Kemess and Huckleberry open pit mines both opened in the late 1990's.

The mine waste management plans for both were conceived when the B.C. ARD guidelines were still in flux and in draft form.

ML/ARD management plans: Prototypes for the draft B.C. ARD guidelines



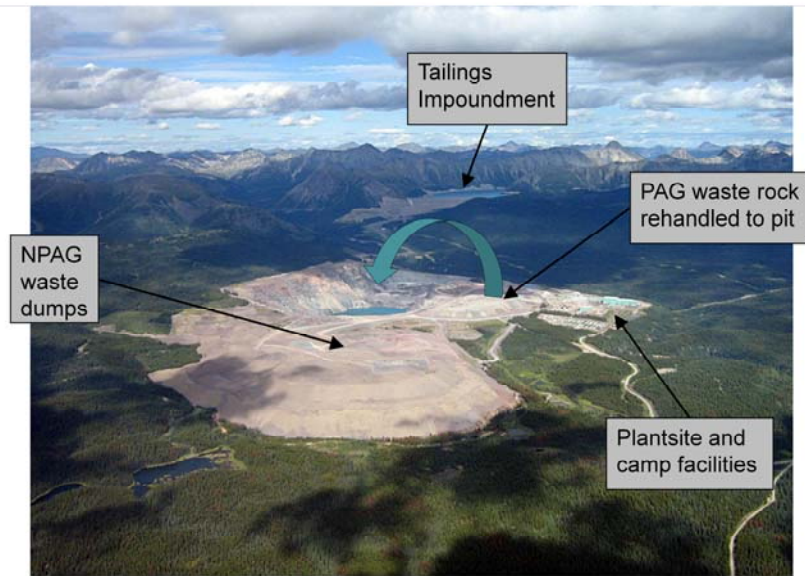
ML/ARD Management Plan Aspect	Huckleberry	Kemess
Permanent submergence of PAG waste rock and tailings	☑	☑
Submergence of PAG waste rock within two years of its exposure	☑	☑
Continuation of long term kinetic testing commenced prior to mine operations	☑	☑
Blast hole sampling to confirm NPAG/PAG prior to waste rock being hauled, and NPAG/PAG boundaries staked in the pit	☑	☑
Post-blast sampling and testing to confirm NPAG/PAG segregation to be correct	☑	☑
Rigorous field controls and checks to ensure NPAG/PAG waste rock hauled to correct destinations	☑	☑
Segregation of waste rock into 7 categories (considering neutral ML and ARD) for haulage to designated areas		☑
Lithology-specific PAG/NPAG NPR cutoff criteria	☑	☑
ML/ARD testing of materials used for downstream shells of the tailings dams to confirm NPAG materials only used	☑	☑
Regular ML/ARD management plan reporting to B.C. Ministry of Energy and Mines (MEM)	☑	☑

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Listed here are aspects of the ML/ARD management plans common to both mines.

I will not dwell on detail here, other than to note that the plans devised were rigorous, involved ongoing testing, learning, and adaptation, and yielded information that allowed both mines to implement substantial optimizations in terms of mine waste management.

It is important to acknowledge just how instrumental was the effective partnership with Ministry of Mines personnel in the development of those plans, and the optimizations of those plans as lessons were learned.



Here is an overview of the Kemess mine site, taken in 2011, a few months after the mill ceased operations. Reclamation is well advanced, and the PAG waste rock has been backhauled into the open pit for eventual flooding. Mined out open pits represent very convenient genie bottles.

The tailings facility is located in the background, some 8 km distant from the mine site, where the bottle that confines the genie is of a considerably different geometry.

Tailings impoundment looking downstream



Tailings Dam

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The tailings are contained by a 140-m high dam, on a geotechnically-sensitive foundation, forming an impoundment with a catchment area of 21.4 km².



Reclamation of the dam is well in progress. The closure spillway, with a length of 2.4 km and an elevation drop of 170 m, shown on the right side of the photo, is a major hydraulic structure upon which the safety of the dam will always depend.

The instrumentation system for monitoring of the dam and spillway is being automated, includes cameras, pre-set threshold levels and alarm triggers, and incorporates satellite transmission of data.

This genie bottle will require vigilant monitoring and maintenance in perpetuity.

Huckleberry Mine: 1993 and 2007
Designed for closure.



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We now turn to the Huckleberry Mine site, where the ML/ARD management plan to a significant extent drove the mine plan.



Mining commenced in 1997. Six years into the mine life, the first pit, the Main Zone, was mined out and was being backfilled with tailings and waste rock, as had been planned from the outset.

Mining had switched to the East Zone pit.



In 2007, mining of the third open pit, the Main Zone Extension, indicated by the arrow, was in progress, and backfilling of the East Zone Pit commenced.



By 2010, the main impoundment had been effectively dewatered. Mining of the Main Zone Extension pit continued, as did backfilling of the East Zone Pit.

The pit sequencing within the Huckleberry mine plan was driven by the mine waste management plan and closure objectives. This mine was not merely designed for closure, it was operated for closure from day one, but there is an intriguing and deeply ironic postscript to this story we shall come to in due course.

Huckleberry's genie bottles



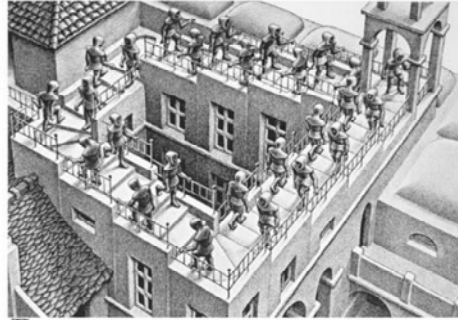
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Huckleberry has some enormous genie bottles – three constructed, and a fourth just getting started.

**The skeptic's view of today's paradigm:
3 questions**



1. Case record of experience of large, water-retaining dams that have endured "*in perpetuity*"?
2. Do we fully comprehend the level of stewardship required for the ever-increasing inventory of closed mine waste impoundments retaining flooded sulphidic mine wastes?



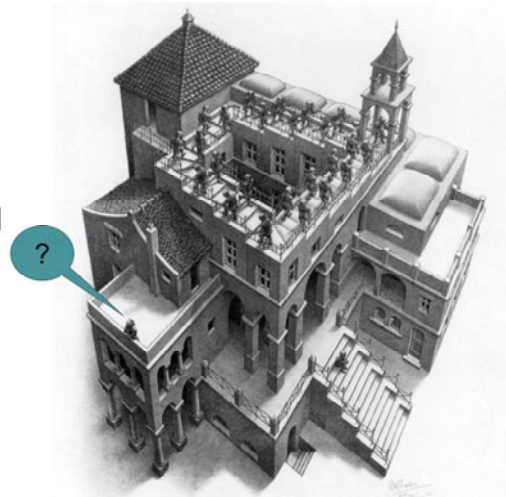
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We will now step outside of today's paradigm, and adopt the skeptical stance of the monk on the outside looking in.

**The skeptic's view of today's paradigm:
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1. Case record of experience of large, water-retaining dams that have endured "*in perpetuity*"?
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In so doing, we consider the two questions listed here as pertains to the legacy issues surrounding today's paradigm.

The permanent submergence paradigm vs. the 2nd law.....



In all natural systems change occurs in the direction necessary to establish and maintain equilibrium – a condition of the lowest possible energy.

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Our paradigm of permanent submergence behind constructed genie bottles sets us up against an adversary that is formidable, universal, and relentless – namely, the 2nd law of thermodynamics. The 2nd law holds that, if we stuff the cork in the bottle and leave it and the genie be, with no monitoring and maintenance, the “walk away” scenario, eventually the genie will get out.

Addressing Question 1:
These are not equivalent propositions.



This is the only one of the seven wonders of the ancient world still standing.....

≠



This is will require a much higher degree of stewardship than the Great Pyramid.

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We have only been constructing formally engineered tailings impoundments since the 1960's, and purposefully flooding impoundments to prevent ARD for considerably less time than that.

There is no demonstrated precedent for the legacy of permanent genie confinement we are constructing today. We've only just started the clock.

Question 2, do we truly understand the level of stewardship our growing inventory of flooded mine waste impoundments is going to require, is less straightforward.

Vick (CDA, 1999)
Dam safety implications of permanent submergence to prevent ARD



- Geotechnically, a dam maintaining permanent submergence of tailings/waste rock is never truly closed
- Above water beaches help but do not alter this salient fact
- As the inventory of “closed”, flooded impoundments increases, then so does the cumulative probability of a failure in a defined timeframe, unless.....
- ...the annual probability of failure decreases proportionately to offset the increasing inventory of such facilities
- How can we achieve this?

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In a keynote address for the 1999 CDA conference, Steve Vick, who literally “wrote the book” on tailings dams, provided a sobering discussion on the dam safety implications of the permanent submergence solution to sulphidic mine wastes.

In a nutshell, tailings dams impounding submerged tailings, or even saturated tailings, are **never truly closed in a geotechnical sense**.

As the inventory of such impoundments proliferates, the cumulative probability of a failure of such a facility, somewhere, must increase as time goes by. Moreover, as these facilities get ever larger, so does the aggregate consequence of such failures.

Is there any way to avoid this?

Our current options seem rather limited



1. ~~Achieving permanent solutions without dams, lakes and ocean (been there, done that.....)~~
 2. ~~Perpetual collection and treatment — rather unpopular with many..~~
 3. ~~Dry stacks? Very stable, but won't stop oxidation.~~
 4. Improving design, construction, and operations; and
 5. The highest level of post-closure dam safety stewardship
- How is the industry making out in regards to 4 and 5 thus far on a global basis?

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Well, here are some thoughts. Options 1 and 2, Nature's genie bottles, are now viewed as pariahs. Filtered tailings dry stacks will not prevent oxidation, but with appropriate controls, and covers, the issue is certainly much more manageable and devoid of any dam safety concerns.

Our current options seem rather limited



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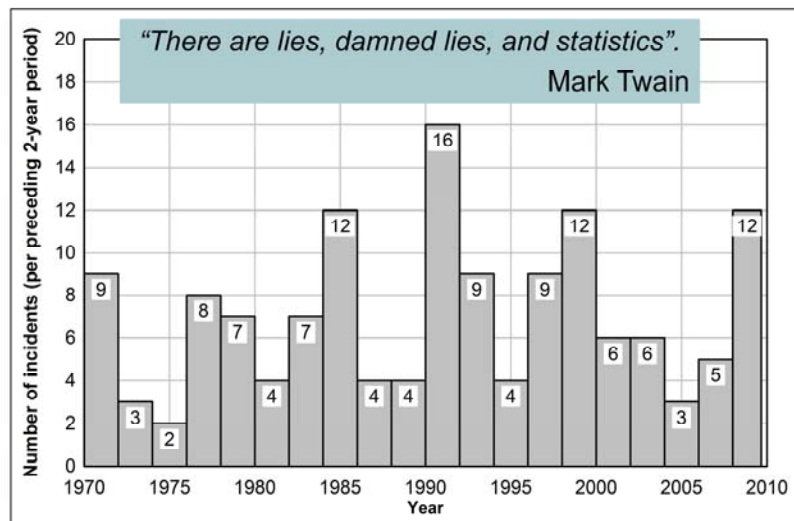
- How is the industry making out in regards to 4 and 5 thus far on a global basis?

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So it seems that ever-improving dam safety stewardship, items 4 and 5, is the one and only lever at our disposal **at the present time**.

Our skeptical monk might then inquire as to how we are making out in that regard.

**Number of incidents vs. time:
No discernible trend of improvement....**



From Davies and Martin (2010)

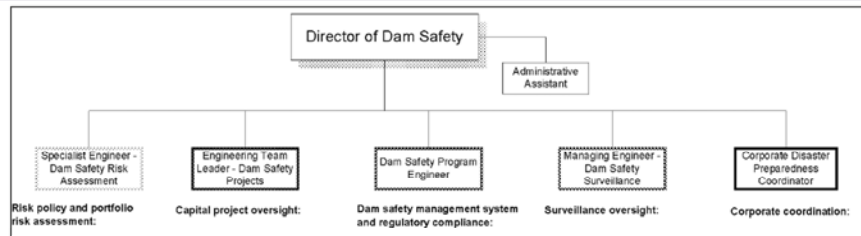
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Apparently, not as well as we need to. On a global basis, and bearing in mind Mark Twain's sage warning about statistics, the 40-year record indicates there to be no discernable trend of improvement.

Certainly the number of impoundments is steadily increasing so one might argue that the normalized frequency of incidents is declining, but that offers little solace.

The over-arching component of responsible stewardship is a high level of commitment to dam safety, and here in B.C. we have a ready frame of reference to consider....

An analogue to ponder B.C. Hydro's Dam Safety Program



- 42 dams in B.C.
- In 2002, 1,564 inspections of those dams
- 21 personnel in the Office of Dam Safety
- 5 dam safety area engineers throughout the province
- Annual reports by the Director of Dam Safety to B.C. Hydro's board of directors
- Advisory boards for 12 of its dams
- \$356 million in capital projects related to dam safety improvement projects 2002-2008

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B.C. Hydro owns about 42 dams within the province. Listed here are some noteworthy aspects illustrative of B.C. Hydro's level of dam safety stewardship, and the organizational structure it has adopted for its implementation.

B.C.'s mining industry must be prepared, collectively, to apply a commensurate "duty of care" to its expanding portfolio of operating and "closed" tailings facilities. That tailings facilities constitute liabilities rather than assets is not going to elicit any public sympathy or acceptance for a lesser duty of care.

We also owe a duty of care to future generations. To the extent we can, we are obligated to take account of their needs, values, and capabilities. But how realistic can we be looking, say, 100 years ahead?

How could miners 100 years ago have helped us today?



Hugh Matheson, 1st
president, Rio Tinto Group

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Well, we can't know the future, but we can know the past and present, so let's take another approach, and ask ourselves this.

How could miners 100 years ago have helped us today, and how well could they have anticipated and understood our needs?

Words and concepts unknown and unimaginable to our turn of the century miners.....



- | | | |
|---------------------------------------|------------------------------------|----------------------------------|
| ▪ Filtered tailings dry stacks | ▪ Nanotechnology | ▪ Gene therapy |
| ▪ ML/ARD management plans | ▪ Nuclear power | ▪ Liposuction |
| ▪ Geosynthetic liners | ▪ Airports | ▪ Arthroscopic |
| ▪ Cyanide destruct circuits | ▪ Jets | ▪ Hip replacement |
| ▪ Closure bonding | ▪ Helicopters | ▪ Radar |
| ▪ ABA tests | ▪ Tunnel boring machines | ▪ ICP analysis |
| ▪ Humidity cell tests | ▪ Antibiotics | ▪ Geotechnical engineers |
| ▪ Sustainability | ▪ Vaccination | ▪ Environmental engineers |
| ▪ Review boards | ▪ Computers | ▪ Video conferencing |
| ▪ Block models | ▪ Cruise control | ▪ Skype |
| ▪ 1 km deep open pits | ▪ Air-conditioning | ▪ Internet |
| ▪ 250 m high tailings dams | ▪ Email | ▪ Dark matter |
| ▪ Tailings and Mine Waste Conferences | ▪ Twitter, Facebook, Google | ▪ Antimatter |
| ▪ Soil mechanics | ▪ Biodegradable | ▪ Proton, Neutron, Electron |
| ▪ Oilsands | ▪ Income tax, carbon tax, GST, HST | ▪ Thermostats |
| ▪ Mature fine tailings | ▪ Satellites | ▪ Motion sensors |
| ▪ Floating covers over tailings | ▪ Television | ▪ Crayons |
| ▪ Geosynthetic liners | ▪ iMacs, iPods, iPads, iPhones | ▪ Windshield wipers |
| ▪ Engineered waste rock dumps | ▪ Camcorders, digital cameras | ▪ Penicillin |
| ▪ Water treatment plants | ▪ Plate tectonics | ▪ Photocopier |
| ▪ 360 tonne haul trucks | ▪ Human genome | ▪ Ball point pen |
| ▪ 67 yd ³ shovels | ▪ SMS, GPS, SUV, HIV, MRI, DVD, CD | ▪ Microprocessor |
| ▪ Metal Mining Effluent Regulations | ▪ MP3, VHS, NGO, RAM, ROM, EKG, | ▪ Viagra, Prozac, Multi-vitamins |
| ▪ Microwave ovens | ▪ PVR, ADD | ▪ Mountain biking |

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Here is a list of words and concepts unknown and unimaginable to our turn of the century miners, illustrating how drastically the world, and the mining industry, has changed in 100 years, and really, even over the last few decades.

Miners 100 years ago wouldn't have had a clue how to have helped us now, and even if they did they were ill-equipped to do so.

It is the pinnacle of hubris and irrationality to consider ourselves in a much different position relative to the world 100 years from now.

Nonetheless, we are certainly creating more a great many genie bottles to pass on to future generations.

So, let's try to look forward, but first, let's consider one example of why, as Yogi Berra famously intoned, "*prediction is hard, especially about the future*".

**Huckleberry – the best laid
schemes of mice and men.....**



- 2002: copper at \$0.75/lb, start backfilling Main Zone pit

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And so we return to Huckleberry. In 2002, when the backfilling of the mined-out Main Zone Pit commenced, the price of copper was \$0.75/lb. Backfilling of the pit made perfect sense, and in fact was the only way to keep the mine going.

It was inexpensive tailings disposal, sustainability in action, operating for closure, and constituted a stout bottle in which to permanently entomb the genie

Huckleberry – the best laid schemes of mice and men.....



- 2002: copper at \$0.75/lb, start backfilling Main Zone pit
- 2010: copper reaches \$4/lb, start pondering digging it all out
- What was “sustainable” in 2002 is no longer so a less than one decade later

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Ten years later, with the price of copper about four times higher, Huckleberry is removing the waste rock and tailings from the Main Zone pit, hauling those to a new impoundment facility, and will resume mining and enlarging the backfilled Main Zone Pit. The genie did not escape from the bottle in this case – it was instead forcibly evicted and relocated.

Less than a decade.....And yet we have notions of making plans for a century or two into the future? Do we really have the faintest idea what we are talking about?

I think not. Personally, there is only one person I would ever have been prepared to acknowledge as an authority on what is to come a century or two from now.....

....and sadly, *Carnac the Magnificent* is no longer with us.

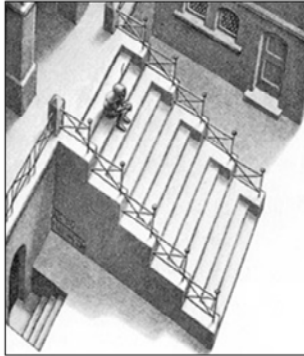


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And sadly, the all-knowing and all-seeing Carnac the Magnificent is no longer with us.

Despite my skepticism as to anthropogenic predictive capabilities, however, I will turn to our heretic monk and offer up the following speculation.....

The heretic's prediction.....

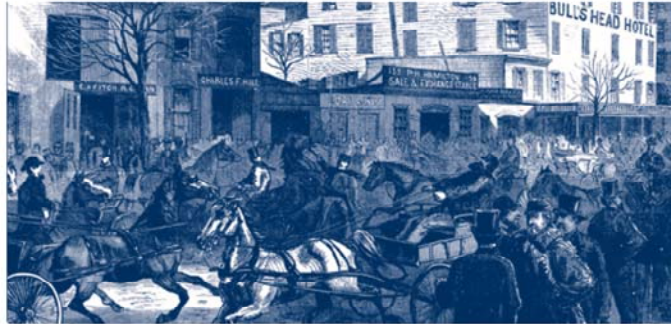


By about the mid 21st century, the notion of permanent submergence of sulphidic mine waste behind large containment dams will be viewed as antiquated technology and will be displaced by a new paradigm.

On what basis can I claim to be confident about this?



- I never said I **was** confident about it, least of all the timing.
- But this does seem to be the tendency with environmental concerns
- Consider another seemingly intractable waste management example as an analogy,
- the most serious urban environmental problem at the dawn of the 20th century....



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And on what basis can I claim confidence about this?

I never said I **was** confident, least of all over the timing.

But when one examines environmental problems in a historical context, a most interesting trend emerges.

Consider as an analogue a seemingly intractable problem proclaimed the pre-eminent urban environmental crisis at the dawn of the 20th century, namely...

....horse dung on city streets.

- 1900 - 100,000 horses in New York city produced 2.5 million pounds of horse manure per day.
- 1894 - Times of London estimated that by 1950 every street in the city would be buried nine feet deep in horse manure.
- 1890s – a New York “expert” concluded that by 1930 the horse droppings would rise to Manhattan’s third-story windows.
- Dead horses left to rot on city streets



....horse dung on city streets.

In 1898, the world’s first international urban planning conference in New York City was dominated by the seemingly intractable problem of horses and minefields of horse dung in city streets.

The congregated “experts” of the day somberly predicted that within several decades cities would, quite literally, be inundated in horse dung.

The 1898 conference intended to find solutions to this crisis broke up early in frustration and futility, the assembled experts having declared the problem unsolvable.

Yet within a decade arrived new technology hailed then as an environmental miracle....

The 20th century's environmental miracle? The horseless carriage.

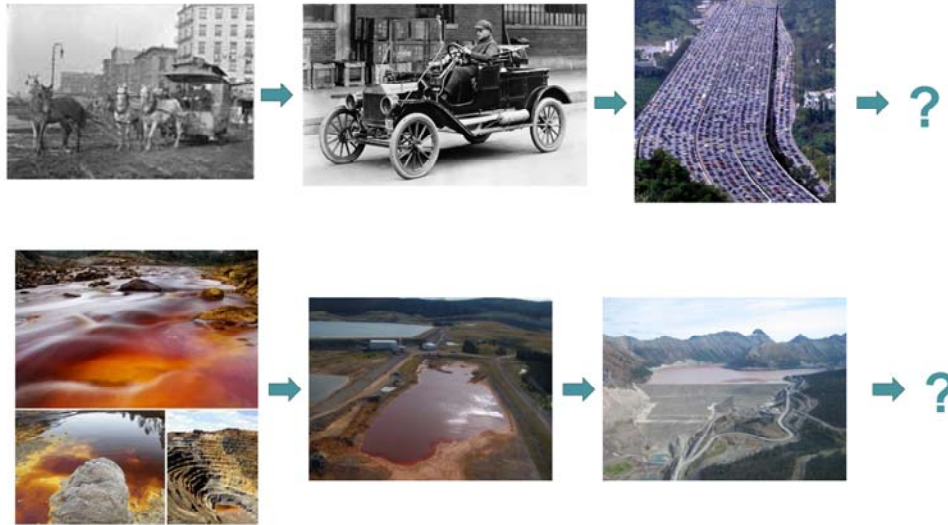


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Here is that environmental miracle, and no one saw this coming. What's more, the impetus behind this environmental miracle had absolutely nothing to do with the urban waste management crisis it eventually resolved.

But you don't hear many people referring to this as an environmental miracle nowadays, do you?

Each technological advance spawns a new set of concerns.....



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So the early 20th century's urban waste management crisis was solved by technology in the form of the horseless carriage, which in turn has spawned environmental concerns of a somewhat different nature, unforeseen and unimaginable in 1900.

The mining industry has seen a somewhat similar progression, culminating in the perpetual confinement of genies within man-made genie bottles, with the attendant dam safety issues and liabilities we grapple with today. We will be passing on many genie bottles to future generations.

Interesting that a solution to a given environmental concern seems to give rise to another in its stead.

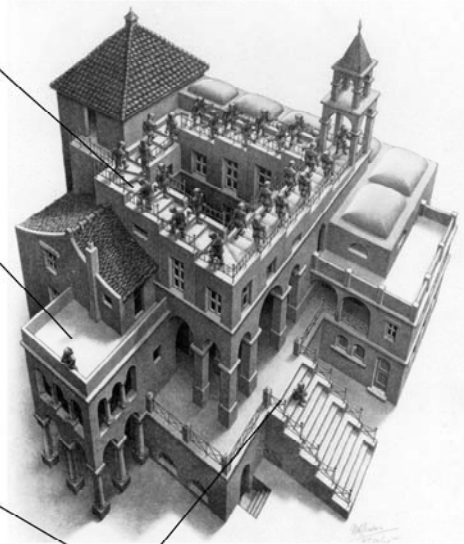
So how do we move forward?



Do our very best to muddle our way through given the paradigm of the day..

Question, challenge and improve that paradigm.

Strive to help establish an improved paradigm for tomorrow.



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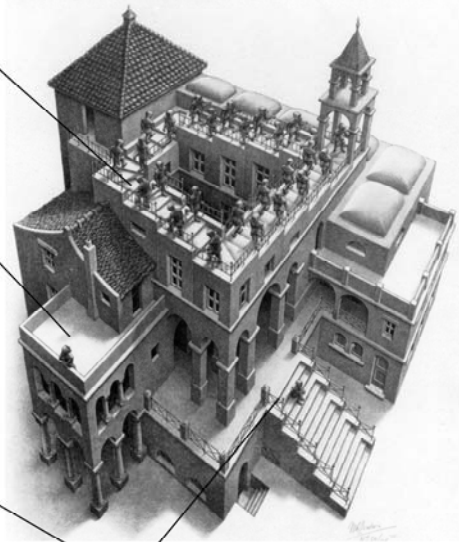
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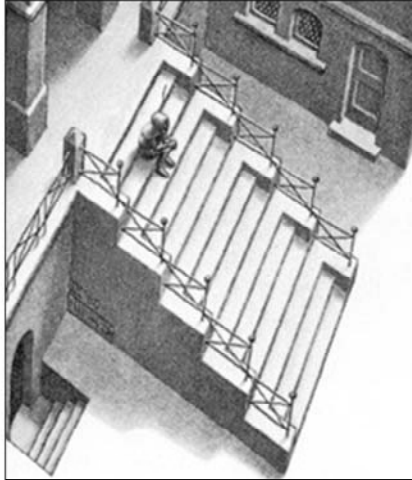
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So, in keeping with Escher's staircase paradox, we've wound up back where we started. Not coincidentally, all three of these points are what this this annual workshop is all about.

We all seek to contribute to the improvement of today's paradigm, and to the development of an improved paradigm for tomorrow.

That this workshop takes place every year demonstrates a greater degree of resolve and perseverance than exhibited by the assembled urban planners in 1898, who after a single confab collectively ran up the white flag and yielded in abject capitulation to the inevitability of the horse dung crisis.

The heretic's prediction.....



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Ultimately, I think we are moving towards a place where perpetual genie confinement within man-made genie bottles comes to be viewed as antiquated technology, and I speak as a genie bottle designer. One day I will be obsolete. But in the meantime, let's recognize the enormity of the challenge and commitment these structures represent. Bottle maintenance will be required as long as the 2nd law of thermodynamics applies, and it is no small task.

Thank you.

Thanks for listening.