Proceedings Tailings and Mine Waste 2011
Vancouver, BC, November 6 to 9, 2011

Thirty Years of Tailings History from Tailings & Mine Waste

Jack A. Caldwell

Robertson GeoConsultants, Vancouver, Canada

Dirk Van Zyl

University of British Columbia, Vancouver, Canada

Abstract

By virtue of its long-running success, and the many contributed technical papers, the proceedings of the Tailings & Mine Waste and predecessor conferences present a good opportunity to review and consider the progress that has been made in the design, operation, and closure of tailings facilities world-wide. This paper explores thirty and more years of tailings facility design, operation, and closure by way of a survey of some of the best and some of the seminal technical papers that have been published in the proceedings of the conferences on Uranium Mill Tailings and Tailings & Mine Waste. The story told in this paper is of the movement from simple upstream hydraulic fill, through larger and higher earth and rock embankments, to thickened and polymer-amended tailings. The story told is one of advancing from an emphasis on operation to a modern mind-set of design and operate for closure to integrate closed facilities into a final stable landscape.

Introduction

If you include the predecessor conferences on uranium mill tailings, the series of conferences on tailings and mine waste has been ongoing since 1978. In those thirty-three years, much has changed in the science, art, and engineering of tailings. The proceedings of the conferences contain what is probably the best record of the flourishing of the discipline one can think of as mine tailings management, a discipline that draws on geology, groundwater, hydraulics, hydrology, geotechnical engineering, economics, and the social and environmental sciences (and many other disciplines and skills too numerous to list). There has been a huge amount of work over the years in all these disciplines that have contributed to tailings management. Thus the papers in this conference series are many, diverse, and recount a history of continuous advance. The topic deserves and could fill a thick book or modern Wiki; thus the authors acknowledge all those fine papers not mentioned. In the few pages allowed here, the focus is on those of most interest to the authors. Hopefully others will take up the challenge to fill the obvious gaps in this paper.

Scope

Reading the many papers of the many symposia in this series, reinforces the following general principles that seem to have remained constant through the years. All involve control of the forces of nature. The interesting historical part is how we advanced in understanding, analyzing, and controlling these forces of nature to achieve better tailings management successes.

In the earlier symposia, the authors of the papers worked on the basis of observation and judgment. Today they have computer codes for almost all technical topics; and the work is done in back rooms by the junior engineers who feed printouts to the senior engineers who still rely on judgment, albeit now judgment strongly supported by quantification. Here follows a brief overview of these changes as they relate to the principles that always have and probably always will rule in the art, science, and engineering of tailings management. The papers discussed subsequently in this paper, well illustrate the points that follow.

Design for the Big Forces

Gravity and hence stability which dominates all other considerations. The first author of this paper designed the new Bafokeng Dam without doing any stability analyses. All that could be done was observe that no local impoundment stood higher than 30 m at which point the outer slopes slide along the low strength clays that were ubiquitous throughout the area. A small IBM 650 was used for stability analyses to support subsequent designs of the 1970s. Today, junior engineers carry out the most sophisticated slope stability analyses in a few minutes on far more powerful computers. For a long time we read papers on increasingly clever slope stability analyses. Today we see fewer such papers, for the job is routine.

Earthquakes which induce liquefaction and flow and failure of tailing facilities. In Pasadena in 1978 there was a conference on earthquakes. A number of South Africans participated as their quest was to try to find out how to analyze the seismic stability of a slimes dam in the Orange Free State province. Seismic shocks resulting form mine rock bursts had felled a five-story apartment building and there was concern about the "seismic" stability of the adjacent slimes dam. It was not possible to test the tailings as they did in the United States. So another way was found; basically construct perimeter buttresses. Today the junior engineers run FLAC to quantify seismic stability as a matter of unreported routine.

Erosion which washes away the tailings and will in the fullness of time reduce them to much different geomorphic expressions. In the 1970s in South Africa cement was used to stabilize slimes dams susceptible to wind and water erosion. In the 1980s vast rock rip-rap covers were placed on the Uranium Mill Tailings Remedial Action (UMTRA) Project to provide 1,000 years and more of erosion resistance. Now we have computer codes that replicate geomorphic processes and persuade us to create closed impoundments of "natural" contours. Hence the papers on long-term stability, erosion, and uranium mill tailings remediation.

Manage the Water. Good tailings management involves management of the water in the tailings stream, water deposited into the tailings facility, water flowing through the tailings, and water removed from the tailings facility. Hence the many papers in the conference proceedings on covers, drains, liners, groundwater impact, acid drainage, and geochemistry. And hence an accompanying paper in this conference on papers in this series of conferences on water into, through, and from impoundments.

Operate For Least Cost. Gravity is the cheapest form of energy. The tailings engineer seeks to use gravity to move the discharged tailings. The principle is to move the fluid tailings as far as you can by getting them to flow as far as possible to the ultimate desired location, before they loose water, and become solid. But keep in mind that gravity is also a great way to consolidate the tailings once deposited. A few meters of additional tailings, and the gravity-induced loads will squeeze water out, consolidate the tailings and cause them to increase in strength and solids content. Thus they are less susceptible to failure, flow, or deformation. Thus we have a plethora of papers on thickened tailings, paste tailings, and polymer amended tailings over the years.

The sun and the wind too are cheap forms of energy. Thin lift deposition is all the rage in the oil sands at this stage. The idea is to let the sun and wind dry out the tailings thereby increasing the density and shear strength. Climatic influences are important and despite our best modeling efforts there will be times when the sun and wind cannot be relied on.

Finally in cold climates there is freezing. Most soils and tailings will freeze if it is cold enough. Not many papers in the conference proceedings deal with freeze-thaw effects on tailings, although they are available in the broader literature..

Case Histories. As the years have passed there are more papers on case histories in the proceedings. The papers that teach us the most are those on failures. Sadly there are all too few such papers. Nevertheless, this paper proceeds to look at the history of tailings failures as described in papers in the proceedings. It is hoped that more such papers will be included in future conferences.

The Uranium Mill Tailings Conferences

The second volume of the proceedings from 1978 starts with a review of the papers presented at the conference. This summary of the 1978 conference notes: "It is evident from the dialogue at the symposium that considerable advances in the state-of-the-art are to be expected in the future."

Browsing through the papers from 1978, one observes the sparks of the beginnings of the many advances that indeed have been made in the intervening thirty-three years. Here are just a few of the comments in the review that point the way.

Scarano and Linehan (1978) note that the U.S. Nuclear Regulatory Commission (NRC) considers below-grade impoundment of tailings to be the prime option. However, in some instances an above-grade facility may be more advantageous, particularly if the below-grade impoundment would be in contact with groundwater. Below-grade tailings disposal is widely practiced in the Northern Saskatchewan uranium mines and this was clearly a far-sighted observation by the authors. Frankfort (1978) discussed a process that would result in dry or semi-dry tailings. Advantages would include major cost saving in processing, maintenance, and tailings management. Thickened, filter-pressed, and polymer-amended tailings are now common, although not as low cost as they envisaged back then.

Kays (1978) discussed general lining applications, their manufacture, and their placement. He computed that synthetic liners would be expected to remain intact for several thousand years. The estimates on longevity have reduced over the last 40 years and multiple hundreds of years are generally accepted.

Robertson, Bamberg, and Lange (1978) reviewed uranium mill tailings and their potential hazards. They state that whereas the NRC wants the environmental impact to be "as low as reasonably achievable," the cost should also be "as low as reasonably achievable." The paper is a fine set of ideas from the time. The idea of "as low as reasonably achievable" (ALARA) took hold for radiological risks. The years have shown that the hazards are controllable, but the costs may soar out of all reason.

Johnson (1979) reviewed the economic benefits of minimizing the risk of failure as related to the potential costs associated with failure. His insight about the fact that it is cheaper to prevent failure than deal with it, was good, but seemingly had little influence on the industry as a whole.

Shepherd and Nelson (1978) evaluated the long-term stability for three periods. The short-term of approximately 200 years, the medium long-term of approximately 2,000 years, and the long long-term of 100,000 years. Their idea of 200 years was incorporated into the UMTRA regulations. The 2,000 years was cut to 1,000 years. It was also realized that the Holocene has lasted only 10,000 years so 100,000 years is just too long. Even now the Canadians are talking of adopting 200 and 1,000 as the periods that covers in the cold north should last.

By 1982 the professional researchers and the staff of the UMTRA Project had taken over. Mark Matthews (1982) writes of the status of the UMTRA Project. Folk at the Pacific North West Laboratories (1982) write of the control of erosion by rock rip rap. Radon cover design is advanced (Baker et al, 1982) as is understanding of seepage (Champlin, 1982) and the possible need for liners (Relyea and Martin, 1982).

Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste Conferences

The 1984 conference includes many papers by those who worked on the UMTRA Project. Thiers, et al (1984) write of the design of the Cannonsburg closure works. Brinkman (1984) starts on what turned out to be a long road dealing with groundwater contamination at UMTRA sites. Bone and Schruben (1984) writes of cover stability on UMTRA piles. The doubters are still there—the doubt prevails today: can you stabilize for the long term. The doubters were quickly dismissed in this conclusion by Junge and Dezman (1984) in their paper "Use of maximum credible events is practical, can be realistically evaluated and can be economically achieved in the design of tailings disposal facilities." Yet even today the opposite can be heard of what was known and done thirty years ago.

Geotechnical and Geohydrological Aspects of Waste Management

The seven keynote papers from the 1986 symposium look back and look forward, and remind us of past efforts and the work that yet remained to be done. Matthews (1986) writes of design progress on the UMTRA Project; construction had not yet begun and would take another ten to fifteen years to complete.

Robertson (1986) is there with an "update" of the geotechnical and geohydrological aspects of mine waste. This is the first paper that touches on filter-pressed, dry-stack tailings. The author had suggested the idea for the Greens Creek mine in Alaska, but full implementation and today's more frequent use of the approach was then still a way off in the future.

The EPA is now a feature in mine waste as described in a paper by Jeyapalan and Knox (1986).

Through fifty-one papers in sessions ranging from regulations and public concerns, geotechnical design, geochemical transport, reclamation, and case histories, a full picture of a vital industry emerges. Groundwater and geochemistry were big; the UMTRA Project contributed six papers on the topics.

Wrench (1986) provided the only paper ever published on the Richards Bay phosphogypsum tailings impoundment in South Africa. The first author of this paper had designed this impoundment and spent many days on site during its construction. This was the first large-scale use of geosynthetic in constructing perimeter dikes over soft clays, the first to include sand drains in the base to expedite clay consolidation, and the first to adopt a side slope at what was then an amazingly flat inclination of five horizontal to one vertical.

Tailings and Mine Waste 1994

The four keynote lectures from 1994 capture the change in the years since 1978. Marjerison (1994) writes of Superfund or CERCLA-driven cleanup of old mine workings. Superfund was by now a reality and other papers in this conference predict dire consequences to the mining industry from Superfund. In reality the consequences have not been as dire as the nay-sayers predicted. In fact it may be postulated that threat of Superfund and other new regulations from that time drove some of the changes implemented today as part of responsible mining practices.

Shackelford (1994) concludes what we all know today:

- A low hydraulic conductivity measured on a laboratory compacted clay specimen is a necessary, but not sufficient, condition to ensure a low hydraulic conductivity for a field compacted liner.
- A low hydraulic conductivity for a field compacted clay liner is a necessary, but not sufficient, condition to ensure containment of contaminants.

Thus started the long march of composite liners, seep detection systems, and the complexities of modern tailings impoundment liners.

Link (1994) writes briefly of selection of pipes for tailings transport. If this was truly the state-of-practice in 1994 we have come a long way.

Finally Bird et al (1994) report on using MINTEQA2, PHREEQE, WATEQ4F, and BALANCE to do what is still hard to do: predict the post-closure water quality in a pit filling with water. The codes have advanced, changed, died, and new ones come into being, but the issues are still germane and essentially unsolved.

Frechette (1994) writes of the initial work on covering the Cannon Mine Tailings Impoundment in Wenatchee. It is to his immense credit that he had the courage, when faced with construction of a closure cover, to try placement of a geofabric over the top of the soft tailings and to construct a soil ramp atop this geofabric. He finally succeeded; today we owe him acknowledgement for being amongst the first to do this – or at least write about it. For today with FLAC and advanced geosynthetics, we know how difficult this is to do. Ulrich and Hughes (1994) was still introducing and selling the idea of CPT testing in tailings. Today this is routine. Williams and Gowan (1994) propose the idea to co-dispose of tailings and mine waste rock. Gowan is still an expert on the operational aspects of this and has written many subsequent papers on the topic.

Subsequent Tailings and Mine Waste Symposia

Overview

From 1994 including the breaks, there has been an ever increasing production of papers in this series of symposia. Thus in reviewing the papers from 1995 to the present, it is possible to consider specific topics, which relate to the themes set out earlier in this paper as having permanence in tailings and mine waste engineering.

Stability Analyses

The paper that best demonstrates how far we have come since 1978 is that by Charlie and Wardwell (1978) on earthquake effects. The paper is replete with the very fundamentals you now have to know before you begin in earthquake engineering in tailings. They conclude:

The potential magnitude of radioactive material release due to failure of any portion of the impoundment as a result of an earthquake will be influenced by the magnitude of the earthquake, the distance from the impoundment to the active fault, the soil conditions under the site, the nature of the tailings, and the disposal plan employed.

Some twenty years later the proceedings includes three papers on the topic of the seismic stability of tailings dams are found in the 1998 conference (Wimberly, 1998; Desai, et al, 1998 and Breitenbach, 1998).

The first is a fascinating examination of the accuracy and inaccuracies of the old codes then available for seismic stability evaluation, including SLOPE/W, REAME, and ICES SLOPE. The second uses a finite element code called DSC-DYN2D resulting from recent research at the time.

Allan Breitenbach, then of WESTEC simply writes about the “historic performance of fill structures under seismic conditions, the major types of geomembrane-lined fill structures being constructed in recent times, and the seismic risk associated with these lined facilities.” He concludes “the overall conclusion is that modern day design and construction for these lined facilities provides low seismic risk of instability." Although even today, more detailed numerical methods such as FLAC is used to more precisely quantify this conclusion.

In 1999 there appears the definitive approach to the seismic stability analysis of tailings (Kostaschuk, et al (1999). They write:

During an earthquake loose soil materials such as mine tailings may liquefy, resulting in severe damage or failure of the tailings dam. In this paper, a mechanics-based total stress analysis approach is presented which uses the finite difference geomechanics modelling program FLAC to model the triggering of soil liquefaction and the resulting large displacement.

The third author, Peter Byrne is still using FLAC to model deformation and drainage from oil sands tailings and to evaluate the seismic stability of a filter-pressed, dry-stack tailings facility where the earthquake could be as big as 8.5. He is still a strong proponent of FLAC.

By 2003, the approach described by Makdisi and Seed (1978) was being used to calculate the earthquake-induced deformation of a heap leach pad. The authors (Durkee, et al, 2003) of the paper do not identify the location of the mine is, but it is most probably in Arizona or California as two of the authors are from Arizona (Durkee and Kidd), and two from California (Augello and B. Joshi). They conclude that the design earthquake could induce deformation of 6 inches to 1 foot.

Thickened Tailings

Nowdays a standard method of tailings disposal, but not always so. In 2000 a paper was presented by the man who started it all Robinsky(2000) summarizes thickened tailings thus: "The system requires that tailings be thickened to a heavy, but pumpable slurry. Released from an elevated position, the thickened tailings form a self-supporting ridge or cone, designed to attain 2 to 6 percent side slopes. The principle aims of the TTD system are to eliminate the conventional settlement pond, reduce or eliminate perimeter dams, and allow the deposit to consolidate to permit progressive reclamation even as mining continues." It is noted that he introduced the idea in 1960, and in this paper, many years after the idea was first introduced, he reviews some seventy mines where the idea had been applied. Today there are hundreds and long conferences devoted to the subject.

It is interesting to compare Robinski (2000) with the following comments of Gipson (1998):

Currently paste disposal is being considered for several properties. The author is not aware of any existing project using this technology. It appears to have an application for relatively small projects, but may be expensive on larger projects. It would also be considered a developing technology.

Blight (2003) comments as follows on the topic:

Tailings disposal methods come and go, and thickened tailings disposal is currently fashionable again after a 20 year lapse of interest. It has always concerned the writer that claims made of "new and better" technologies are often unsubstantiated except anecdotally and qualitatively. Regrettably, the current promoters of thickened tailings disposal are also guilty of this, and some of the claims for the advantages of thickened tailings disposal verge on the ludicrous.

He concludes:

In certain circumstances a thickened tailings deposition system will prove preferable. In other cases an unthickened tailings system will be superior. In every case the relative merits should be compared fairly and quantitatively and not on the basis of sales slogans, fashion trends, or over-simplified calculations on the back of an envelop.

Erosion

Selection of the appropriate site for the tailings facility is key to success in controlling erosion: find a site that is geomorphically stable and erosion almost takes care of itself. There are few papers on the topic of site selection and Krause and Dwire (1999) is one of these. They use a variant of the many multi-attribute decision making procedures that have come and gone. This paper and others like it select criteria, a rating system, and then calculate numbers for alternative sites. The highest scoring wins. Today we know that site selection involves much more; in particular consideration of the wishes and preferences of those in whose territory the impoundment will continue forever.

Those who most advanced practice in the control of erosion of tailings impoundments are Steve Abt and Ted Johnson, both of whom both authors knew and from both of whom the senior author learnt much on the UMTRA Project in designing and constructing rock rip rap erosion resistant components. Sadly what they recommend and what is done is not consistent, even today---for it is expensive and there is a tendency to risk away reality with vegetation, roots, and spurious reasoning.

While not seminal, Abt, et al (1999) is as good as any to first record their ideas and recommendations. In this paper they note *"Stone is sized and placed on top of and partially down the slope of the impoundment cover. When a gully migrates up slope into the cover, the stone launches thereby armoring the leading edge of the gully."* And indeed it does. More like this needs to be done. A good example of how this is done is described in Sjostrom, et al (1998).

Beach Profile

A major determinant of the way in which a tailings impoundment is operated is the beach profile that develops on deposition. The beach profile determines the height of the header berms, how far flow will occur naturally—hence cell length, and the need to push the tailings further by mechanical or hydraulic means.

The first time this topic is discussed in the conference series is in 1998 in two papers, McPhail and Blight (1998) and Blight (1998).

The issue of beach profiles is still not fully settled. Just this year three different approaches were put forward during a course in Perth on beach profiles. Gordon McPhail was one of the presenters. He still adheres to his thesis, developed in his PhD dissertation that *"Changes in slurry and tailings characteristics brought about through changes in particle size distribution, particle density, and plant operations, have effects on tailings dam beach profiles that cannot be predicted with any degree of reliability without extensive field trials."*

McPhail (1998) notes that the beach profile may be approached as a problem in "*the application of energy and entropy maximization principles…..but unfortunately [this approach] still requires the input of empirical data.*"

Failure

Church Rock

Returning to the proceedings of the 1980 Uranium Mill Tailings Management conference for the story of a tailings impoundment that was mis-managed and which, in consequence, failed. The paper by Nelson and Kane (1980) describes the causes of failure (with some edits):

"*On July 16, 1979 the Church Rock Tailings Dam failed. The embankment was about 35-ft high and was constructed on a relatively deep deposit of clayey, silty sand. Certain soils were collapsible and laboratory testing indicated collapse in excess of ten percent upon wetting. The impoundment was not* *lined, and seepage into the foundation soils could readily occur. Along the southern half of the embankment, approximately three feet of settlement had been observed since the beginning of operation in 1977. As a result of the large settlement, differential movement of the embankment would be expected. Both longitudinal and transverse cracks had been observed in the embankment prior to the failure, and were attributed to the differential movement occurring in the embankment.“*

In order to protect against internal erosion of the embankment in the cracks, it had been recommended that a sand beach be maintained against the face of the embankment. The purpose of this sand beach was to act as a source of sand that could then be carried into any cracks that might develop. The idea was that passage of sand into cracks would prevent internal piping. The fact that sand was carried into the cracks was confirmed by observation after the failures of sand in the cracks on the walls of the breach.

Just prior to the failure, freeboard at the embankment had been decreased as a result of pond filling–the freeboard had been reduced to the point where tailings solution was in direct contact with the embankment and the sand beach had not been maintained. In that configuration, the sand beach, because it was below the tailings fluid, was ineffective and the cracks within the embankment probably filled with tailings solution. The owner’s consultants proposed as a probable cause of failure that internal erosion of the embankment occurred under the action of the fluid in the cracks. Slope instability was ruled out on the basis of a few simple 1979 style stability analyses.

Thus here is an instance of poor design, over-optimistic assumptions, and ineffective impoundment management resulting in failure. These days one cannot but wonder how they could stand by and see the embankment move, deform, crack, and not stop operations. No doubt some unnamed consultant told them the risk was small as long as the kept a sand beach above water. Which of course they did not do.

Merriespruit

The proceedings of the 1998 conference on Tailings and Mine Waste includes three papers on the failure of the Merrispruit Tailings Impoundment. At this remove of time it is still instructive to reread these old papers and ponder the lessons learnt. Here is a paragraph from the conclusion of one of the papers, Wagener, et al (1998):

Following the inquest/enquiry into the disaster, Judge Kotze found that "it is clear beyond all doubt that the tailings dam system, which was operated by people chosen by the mining company and the tailings dam company, did not function with any measure of safety. In passing it can be mentioned that the practice of the Department of Mines and Energy to appoint old mine captain, without training, as inspectors is definitely not satisfactory."

There follows this indictment of the system in the same paper, which supports the contention that many things have to go wrong for a system to fail:

The management structures within the industry were poor, as exemplified by the lack of proper contract documents and hence the lack of clarity on who was responsible for what. There was poor communication within the organizations, possibly aggravated by the lack of relevant technical knowledge by those charged with responsibilities beyond their expertise. This meant there was lack of adequate documentation or records on which any proper monitoring of problems or progress towards their solution could be based. Those placed in positions of authority had not received training in the fields of expertise required--largely the engineering performance of materials comprising tailings dams or the implications of environmental conditions. In fact, there seems to have been a dearth of the practical engineering skills required, instead of mining, electrical or mechanical experience.

Two accompanying papers (Brink, 1998 and McPhail, et al (1998) tell of the remediation of the dam after its failure and of planned long-term continued use of the facility. This is a magnificent set of papers---if only these days similar high-quality papers about large failures were published. But this is unlikely as the admissions of failures contained in these papers could only occur in the light of open court enquiry; no mine, no consulting company on their own would every permit publication in the absence of the findings of a judge and court. As noted in the paper by Wagener, et al (1998):

Consequently it was established beyond doubt that overtopping, as a result of inadequate freeboard, was the primary cause of the failure. While there was initially some indirect evidence pointing to this having been the case, it was only irrefutable proved after the satellite imagery had become available and subsequent confession by individuals who had been aware of the actual situation at the time. It is alarming to think that had such key evidence not been available, the true cause of the failure may still be shrouded in uncertainty.

Upstream Facilities

In 2000 a seminal paper by Davies and Martin(2000), then of AGRA Earth and Environmental Limited provided important learnings. The authors set out to defend upstream construction in the face of many preceding failures. They note:

Upstream tailings dams have become the "poorer" cousins to other tailings dam geometrics with many designers and regulatory jurisdictions. The reluctance to consider upstream dams appears to be at least partially due to upstream dams providing more than one half of the more dramatic mine tailings impoundment failures…..upstream dam failures can be attributed to poor design, construction and/or stewardship of the facility.

Hence they proceed to write about two new upstream tailings impoundments they had designed that avoided the flaws that lead to failure. Today there still are many upstream dams that are well designed, operated, and managed. Maybe this paper was part of the route that gave courage to others to proceed with what is, at basics, a cost-effective approach to tailings disposal.

In a second 2000 paper Martin and Davies (2000) write of "recent trends in the stewardship of tailings facilities both in Canada and worldwide." The authors note that this includes proactive initiatives by industry associations, and individual mining companies, and increased roles by consultants. They note publication by the Mining Association of Canada (MAC) of A Guide to the Management of Tailings Facilities, a volume that has been recently updated and broadly used in the industry..

Oil Sands Tailings

Conferences and publications on oil sands tailings abound these days. In terms of volume, oil sands tailings probably dwarf most other types of tailings. Research on better ways to dispose of oil sands tailings continues apace today. But back in 2000 there was only one paper on the topic by Pollock, et al (2000). They describe modeling with finite strain theory of Composite Tailings (CT) at a test facility at the Syncrude mine. Then CT was new, and held promise. No longer so, sadly, for the material has a tendency to segregate with "more sand near the discharge and more fines further from the discharge point."

Closure

The series of conferences contributed much to the development of better practice and an opportunity for the interaction of representatives from industry, regulatory agencies, consultants, suppliers and academia. Others are encouraged to review the proceedings from these conferences and thereby provide their own summaries of accomplishments.

References

Abt, S.R., Thornton, C.I., Lipscomb, C.M., Johnson, T.L. 1999. Launching stone methods for stabilizing reclaimed waste sites. *Tailings and Mine Waste: Proceedings of the Sixth International Conference, Fort Collins, Co. Colorado State University, January 24-27, 1999.* 207-216.

Baker, E.G., Freeman, H.D. and Hartley, N.J. Pacific Northwest Laboratories. 1982. Cost and effectiveness of radon barrier systems. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 383-396.

Bird, D.A., Lyons, W.B. and Miller, G.C. 1994. An assessment of hydrogeochemical computer codes applied to modelling post-mining pit water geochemistry. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 31-42.

Blight, G.E. 1998. Tailings beaches formed in air and water. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 27-34.

Blight, G.E. 2003. Quantified comparisons of disposal of thickened and unthickened tailings. *Tailings and Mine Waste: Proceedings of the Tenth International Conference, Vail, Co. Colorado State University, October 12-15, 2003*. 63-72 .

Bone, M.J. and Schruben, J. 1984. Long-term stability – Canonsburg, Pennsylvania UMTRA site. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Sixth Symposium, Fort Collins, Co. Colorado State University, February 1-3, 1984.* 453-462.

Breitenbach, A.J. 1998. Seismic behaviour on lined filled structures. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 201-206.

Brink, D. 1998. The long-term repair of the Merriespruit Tailings Dam. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 953-958.

Brinkman, J.E. 1984. Ground water – Canonsburg, Pennsylvania UMTRA site. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Sixth Symposium, Fort Collins, Co. Colorado State University, February 1-3, 1984.* 443-452.

Champlin, J.B.F. 1982. Use of scientific calculators and pocket computers for evaluation of seepage and contaminant transport. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 443-462.

Charlie, W.A. and Wardwell, R.E. 1978. Earthquake effects on uranium mill tailings impoundments. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 69-86.

Davies, M.P. and Martin, T.E. 2000. Upstream constructed tailings dams – A review of the basics. *Tailings and Mine Waste: Proceedings of the Seventh International Conference, Vail, Co. Colorado State University, January 23-26, 2000.* 3-16.

Desai, C.S., Shao, C., White, D. And Davis, S. 1998. Stability analysis for consolidation and dynamic response of mine tailing dam. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 193-200.

Durkee, D.B., Augello, A.J., Joshi, B. and Kidd, D.A. 2003. Seismic slope stability and deformation analyses for a heap leach facility. *Tailings and Mine Waste: Proceedings of the Tenth International Conference, Vail, Co. Colorado State University, October 12-15, 2003.* 131-136.

Frankfort H.J. 1978. A milling process providing flexibility to tailings disposal methods. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 21-30.

Frechette, R.J. 1994. Construction of access ramps and reclamation covers upon tailings impoundment surfaces. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 195-204.

Gipson, A.H. 1998. Tailing disposal – the last 10 years and future trends. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 127-138.

Jeyapalan, J.K. and Knox, R.J. 1986. US EPA regional training centers in hazardous wastes management – A new concept. *Geotechnical and Geohydrological Aspects of Waste Management: Proceedings of the Eighth Symposium, Fort Collins, Co. Colorado State University, February 5-7, 1986.* 81-92.

Johnson, T.D. 1978. Cost of failures. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 101-110.

Junge, W.R. and Dezman, L.E. 1984. An analysis of control standards for the long-term containment of uranium mill tailings. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Sixth Symposium, Fort Collins, Co. Colorado State University, February 1-3, 1984.* 485-494.

Kayes, W.B. 1978. Lining systems for seepage control in Uranium mill tailings holding ponds. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 59-66.

Kostaschuk, R.N., Byrne, P.M., Wilkinson, J.M.T. 1999. Predicting the deformation of tailings dams resulting from earthquake liquefaction. *Tailings and Mine Waste: Proceedings of the Sixth International Conference, Fort Collins, Co. Colorado State University, January 24-27, 1999.* 237-248.

Krause, A.J. and Dwire, D.L. 1999. Site selection approach for mine tailings. *Tailings and Mine Waste: Proceedings of the Sixth International Conference, Fort Collins, Co. Colorado State University, January 24-27, 1999.* 99-106.

Lindsey, C.G., Doesburg, J.M. and Vallario, R.W. Pacific Northwest Laboratories. 1982. A Review of long-term rock durability: implications for survivability of riprap used to protect uranium mill tailings. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 101-116.

Link, J.M. 1994. Tailings transport and deposition. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 23-30.Makdisi, F.I. and Seed, H.B. 1978. Simplified procedure for estimating dam and embankment earthquake induced deformations. *Journal of the Geotechnical Engineering Division, ASCE, Vol 104, No. GT7*. 849-867.

Makdisi, F.I. and Seed, H.B. 1978. Simplified procedure for estimating dam and embankment earthquake induced deformations. *Journal of Geotechnical Engineering,* ASCE, Vol. 104, GT7.

Marjerison, J.A. 1994. Construction activities in flood plain tailings. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 3-8.

Martin, T.E. and Davies, M.P. 2000. Trends in the stewardship of tailings dams. *Tailings and Mine Waste: Proceedings of the Seventh International Conference, Vail, Co. Colorado State University, January 23-26, 2000.* 393-408.

Matthews M.L. 1982. Status of the Uranium Mill Tailings Remedial Action Project (UMTRAP). *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 3-10.

Matthews, M.L. 1986. UMTRA Project: Implementation of design. *Geotechnical and Geohydrological Aspects of Waste Management: Proceedings of the Eighth Symposium, Fort Collins, Co. Colorado State University, February 5-7, 1986.* 15-22.

McPhail, G.I., and Blight, G.E. 1998. Predicting tailings beach profiles using energy and entropy. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 19-26.

McPhail, G.I., Stuart, R.J. and Venter, D. 1998. The disaster of Merriespruit and its consequences: Remediation – Making safe. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 959-966.

Nelson, J.D., Kane, J.D. 1980. Failure of the Church Rock tailings dam. *Uranium Mill Tailings Management: Proceedings of the Third Symposium, Fort Collins, Co. Colorado State University, November 24-25, 1980*. 505-512.

Parker, G.B. Pacific Northwest Laboratories. 1982. Handbook for the design, selection and construction of a rock cover for retired uranium mill tailings. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 127-134.

Pollock, G.W., McRoberts, E.C., Livingstone, G., McKenna, G.T. and Matthews, J.G. 2000. Consolidation behaviour and modelling of oil sands composite tailings in the Syncrude CT prototype. *Tailings and Mine Waste: Proceedings of the Seventh International Conference, Vail, Co. Colorado State University, January 23-26, 2000.* 121-130.

Relyea, J.F. and Martin, W.J. Pacific Northwest Laboratories. 1982. Evaluation of inactive uranium mill tailings sites for liner requirements: characterization and interaction of tailings, soil and liner materials. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 507-520.

Robertson, A.M., Bamberg, S.A and Lange, G. 1978. Current uranium mill wastes disposal concepts: a multinational viewpoint. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 67-100.

Robertson, A.M. 1986. Mine waste disposal: An update on geotechnical and geohydrological aspects. *Geotechnical and Geohydrological Aspects of Waste Management: Proceedings of the Eighth Symposium, Fort Collins, Co. Colorado State University, February 5-7, 1986.* 31-50.

Robinsky, E.I. 2000. Sustainable development in disposal of tailings. *Tailings and Mine Waste: Proceedings of the Seventh International Conference, Vail, Co. Colorado State University, January 23-26, 2000.* 39-48.

Scarano, R.A. and Linehan J.J. 1978. Current U.S. Nuclear Regulatory Commission Licensing Review Process: Uranium Mill Tailings Management. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 3-14.

Shackelford, C.D. 1994. Hydrogeotechnics of clay liners for waste disposal. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 9-22.

Shepherd, T.A. and Neslon, J.D. 1978. Long-term stability of Uranium Mill Tailings. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, Co. Colorado State University, November 20-21, 1978. Volume 1*. 155-172.

Sjostrom, J.W., Blubaugh, R.E. and Hassinger, B.W. 1998. Erosion protection for the Atlas Corporation uranium mill and tailings disposal area. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 409-420.

Thiers, G.R., Guros, F.B. and Smith, E.S. 1984. UMTRA Project: Canonsburg final design. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Sixth Symposium, Fort Collins, Co. Colorado State University, February 1-3, 1984.* 423-432.

Ulrich, B.F., and Hughes, J.M.O. 1994. SPT/CPT correlations for mine tailings. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 215-224.

Wagener, F.M., Craig, H.J., Blight, G., McPhail, G., Williams, A.A.B. and Strydom, J.H. 1998. The Merriespruit tailings dam failure – A review. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 925-952.

Walters, W.H. Pacific Northwest Laboratories. 1982. Riprap design considerations for long-term protection of uranium mill tailings. *Uranium Mill Tailings Management: Proceedings of the Fifth Symposium, Fort Collins, Co. Colorado State University, December 9-10, 1982*. 117-126.

Wimberly, P.M. 1998. Seismic stability analysis of a large slurry impounding embankment dam. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, Co. Colorado State University, January 26-28, 1998.* 181-192.

Williams, D.J. and Gowan, M.J. 1994. Operation of co-disposal of coal mine washery wastes. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, Co. Colorado State University, January 19-21, 1994.* 225-234.

Wrench, B.P. 1986. Surface water management and vegetation at a phosphogypsum tailings impoundment. *Geotechnical and Geohydrological Aspects of Waste Management: Proceedings of the Eighth Symposium, Fort Collins, Co. Colorado State University, February 5-7, 1986.* 173-184.