

Thirty Years of Tailings Seepage History from Tailings & Mine Waste

Bernard Brixel and Jack A. Caldwell

Robertson GeoConsultants, Vancouver, Canada

Abstract

This paper explores thirty and more years of the development of methods and approaches to the evaluation, analysis, and quantification of seepage into, through, and from tailings impoundment to subsurface soil and rock and the subsequent impact thereof on the environment. This is done by way of a survey of technical papers that have been published in the proceedings of the conferences on Tailings & Mine Waste. The story told in this paper is of the movement from simple professional understanding of the geology through the development of flow nets, computer codes, 3D modeling of seepage and geochemical interaction, an understanding of acid drainage and the many ways to deal with it, and hence the current ability of mines to understand, predict, and control potential impact of tailings seepage to the environment.

Introduction

In this paper we focus on a personal selection of papers that have appeared through the years in the proceedings of the symposia of which this is the latest. The papers of which we write are those which, in our opinion, epitomize the state-of-practice as it evolved and developed. We say sorry to those whose papers are worthy but are not mentioned here. Let our omissions be a prod to others to rectify our biases and the failure on our part to achieve a comprehensive telling of what is a vast and fascinating history well-deserving of more pages than we have here.

The Conferences

In an accompanying paper in this symposium the history of the series of symposia, of which this is the most recent, is documented (Van Zyl and Caldwell, 2011.) Briefly this series started in 1978 as a forum for papers on uranium mill tailings, expanded some five years later to include hazardous waste, then refocused on the geotechnical and geohydrologic aspects of tailings. Finally today's name was adopted and it has stuck: Tailings and Mine Waste.

Infiltration into the Bare Surface of the Tailings

We note the paper Wels and Robertson (2003) mainly because we work with the authors and know that the study they write of back then still continues. To our knowledge the approach they write of has not been bettered. It incorporates these three phenomena:

- Entrainment losses during initial settlement of the tailings
- Evaporation losses from flooded areas of the tailings beach
- Rewetting or seepage losses during discharge of fresh tailings onto older, desiccated tailings beaches.

We are still applying these principles to the water balance of oil sands tailings.

Infiltration through Covers

Stormont, et al (1996) represents, to our knowledge, the first account in the conference proceedings on the subject of infiltration through mine waste cover systems and their potential to limit acid mine drainage from wastes dumps and tailings. In this paper, the performances of three types of covers are compared: capillary barriers, simple soil covers, and covers overlying compacted soil. By focusing on water-balance calculations, unsaturated flow modeling and by looking at the effects of the cover thickness on oxygen diffusion, the authors clearly demonstrated their understanding of two of the key aspects commanding the choice of a cover, that is its ability to limit water percolation and minimize the ingress of atmospheric oxygen into the underlying columns of waste or tailings. In this case, the authors observed that capillary barriers exhibited greater water contents than the other soil covers tested, a result of lower percolation rates, and a larger storage capacity of the former. Consequently, they concluded that capillary barriers could be advantageous in cases where the cover profile is only partially saturated.

The use of numerical models like SoilCover, SEEP/W and HELP as investigative and decision making tools for the selection of an optimal cover became increasingly important in the late 1990's, as illustrated by papers such Kowalewski, et al, (1998) and Kowalewski (1999). Both studies used numerical simulations designed to assess percolation through reclamation soil covers. In the first paper, the model SEEP/W was used to simulate a tailing impoundment and estimate the surface and bottom fluxes (precipitation and seepage out of the impoundment) while the model SoilCover was used to simulate a series of different covers; both model results were then considered along with constructability and construction cost estimations so as to implement the overall most favorable reclamation soil cover. In the second paper, the model SoilCover was selected and used to reevaluate the results from a previous analysis performed with the model HELP. The author showed that the latter had overestimated by two or three times the amount of percolation through the soil profile most likely due to its oversimplification and less sophisticated inputs requirements. Note that these simulations were executed on a 133-Mhz Pentium processor equipped with 16 Mb of RAM, which reportedly constrained the average simulation running time to 24 hours.

Innovative work on store-and-release covers was undertaken by Wels, et al (2002). This study, designed as a combination of field tests and modeling experiments, aimed at evaluating the overall performance of a proposed storage cover, consisting of locally-derived silty gravels, under conditions representative of final closure. Not only does this constitute one of the first reports of such undertaking in The Tailings and Mine Waste Proceedings, it also represents a significant step forward in terms of incorporating simulated, future climatic conditions into the evaluation of storage cover's long-term effectiveness. The major findings made by the authors were: (1) a vegetated soil-cover is more effective at reducing net percolation than thin and/or larger soil unvegetated covers; (2) the incoming meteoritic water not intercepted is stored underneath the soil cover as moisture present in the tailings and (3) much of this moisture is removed by evapotranspiration during dry periods.

Nowadays, papers like Dobchuk, et al (2009) remind us that the use of numerical models to simulate moisture dynamics in unsaturated soils and subsequently evaluate soil cover performance is now common practice. In this paper, the authors focus on the model themselves. They compare the model HYDRUS-1D with VADOSE/W, showing that both model results are in general agreement with each other.

As models get more complex and sophisticated with time, the need for larger and more representative datasets is required, which often must be obtained from long, properly set-up field work. In Amorin, et al (2008) the authors report good results from an in-depth field experiment. In this study, the authors

juxtaposed two different cover systems, simply labeled cover 1 and cover 2, equipped them both with lysimeters, with the simple objective to evaluate the relative performances of these two cover configurations. They observed that the cover which included a clayey layer, remained almost permanently saturated and better prevented the "movement" of water and oxygen, and therefore concluded that it constituted in this case a more effective option. This study serves as a good example that the temptation to simply rely on modeling must not overshadow the fact that almost always much is learned from a good field work study.

By 2009 there was not much more to be said. One may almost conclude that the paper by Bobchuck, et al (2009) says it all. This is what they say:

Design methodology for soil covers for mine waste has evolved to the point that the use of numerical simulations to evaluate performance is commonplace. There are a number of numerical models capable of simulating moisture dynamics in surficial soils in response to climate and vegetation.

They proceed to calibrate two such codes using real-time data.

Seepage through Tailings

Larson and Stephens (1985) write of what is now commonplace, namely unsaturated hydraulic conductivity of soils. Just recently we had the laboratory of Stephens' company in Tucson do some similar testing for us for a filter-pressed, dry-stack tailings facility.

Drains

A classic paper, Van Zyl and Robertson (1980), summarizes the then state-of-the-art. The details they write of pretty much derive from standard South African slimes dam practice, although they dutifully list most of the seminal papers on the topic written from 1959 onwards. Not much has changed since that paper in the art and practice of drains in slimes dams, although we are now more inclined to focus on liners and perimeter embankments to control seepage and ensure perimeter stability.

In 1984 the impact of a drain on top of a liner beneath a pit filled with tailings was examined by Witten, et al (1984). It appears they wrote their own code. They were bold in that they examined transient drainage, that is the fall with time of the saturated zone in the tailings mass filling the pit. The idea of filling pits with uranium mill tailings has been applied extensively in Saskatchewan, where we have seen far more extensive drains surrounding the entire pit perimeter.

Not used much since to our knowledge, Pakalnis, et al (1985) tells of increase to the flow rate from horizontal drains and hence expedited drawdown of the water table in the tailings. Admittedly this was a badly designed impoundment where extraordinary remedial works were justified.

Liners

At the start of this conference series, McWhorter and Nelson (1978), Johnson (1978) and Kays (1978) provided three papers on seepage: an auspicious beginning by men who later proved to be the experts. The first paper uses equations, no computers or numerical methods to do the following:

Seepage from a tailings impoundment located over partially saturated foundation materials is analyzed, the seepage phenomenon is divided into four distinct stages and seepage rates and the duration of each stage are calculated based on the theory of unsaturated and saturated porous media.

They proceed to examine the four stages, including downward wetting from tailings deposition, upward movement of the water table, steady-state saturated seepage during operations, and the post-closure transient dropping of the water table to long-term equilibrium. This is bold insight and still what we should, but seldom do these days.

In the second paper, the author struggles with what is now routine: pathway prediction of the migration of pollutants from impoundments to receptors. In the third paper, the author, Vice President of Global Linings in Long Beach, California, surveys the history of linings, sets out the categories of lining current in the late 1970s, and writes of failures. None of the lining systems he writes of are in use today; none have survived the passage of practice or time.

By 1980 the art had advanced to the point that Davis (1980) could write a paper on the numerical modeling of seepage beneath tailings impoundments, the primary purpose of which was to “determine the feasibility of using a computer model to estimate the seepage rates from impoundments.” Again we have a detailed listing of the equations, but very little in how these equations are programmed by the authors into a finite difference code, and solved. Today, we would purchase a code, ignore the equations, and send the task to the junior engineer---and certainly not write a paper about it.

From about 1973 to 1976, the senior author lectured in the use of finite difference and finite elements in the solution of seepage problems. The theory is simple: divide the flow field into a series of elements; what goes into an element comes out (less any change in storage); hence solve the many equations using a fast computer. In those years, we did not have fast computers; but we understood the theory. Most consultants did not. Hence even in 1998, Reid (1998) provides some background to these evaluations.

Miller and Hornaday (1998) describe Geosynthetic Clay Liners (GCLs). Nowadays routine, but then new and innovative, and the subject of a paper by a company no longer in business.

A magnificent paper by Small (1980) of Universal Linings could still serve as a primer for anyone faced with the need to specify the installation details of a liner. A classic that reminds us of the repetitive nature of too many papers that followed.

Nasiatka, et al (1981) focus on the interaction of acidic tailings seepage and the impact thereof on the integrity of clay liners. Clearly in the preceding year some intelligent regulator had asked the question: “Will clays stay stable or increase in permeability if acidic seepage hits them?” This paper, surely represent what has become a major industry, namely the impact of chemicals on liners, clay and geosynthetic. The authors demurely note: “The results indicate that three of the clay materials exhibit relatively stable coefficients of permeability for the permanent solution. One of the clay materials had variable permeability coefficients for the solutions.” Can you imagine a high profile paper with those conclusions today? If you can, maybe we should avoid that conference.

Lupo (2008) sets out the considerations that affect liner selections stemming from the interaction of seepage constituents and liner materials. By now we have the range of materials for careful liner selection and we understand the impact of chemicals on the various liner materials.

Perhaps the most dramatic illustration of the changes over the years in liner design is set out in the paper by Morrison, et al (2008). They write of a nearly six-component liner system proposed for the Pinon Ridge Project in the Uravan Mineral Belt of Colorado. They note the forcing role played by regulations and regulators in moving towards so complex a lining system. Another major change from the days of 1980: the project is still “advancing” as noted in this quote from a June 21, 2011 report:

The Piñon Ridge Mill was granted a radioactive materials license — what amounts to a permit — but is still collecting final approvals from the state. An environmental group from Telluride,

Sheep Mountain Alliance, is challenging the approval in court. Energy Fuels, meanwhile, has already made a bond payment and is looking for financing. Steele estimates that once the company collects financing it will take 10 months to build the mill, the first built in 25 years and only the second in operation in the country.

Seepage to the Environment

Recall the hand-held, programmable calculator? It was novel enough in 1982 for Champlin (1982) to write a paper on the use of such devices for evaluating seepage and contaminant transport. You can still feel the issues of the times in these quotes: “Consideration of such problems in detail becomes onerous and is commonly relegated to a computer in some distant office. Evaluation of such problems has led to use of both scientific programmable calculators and pocket computers because of their advanced capability, relative speed, very low power requirements, and convenience of size.”

Lam and Barbour (1985) describe the use of the finite element method for mass transport by seepage. Who today would write a paper that includes a detailed description of finite element methods, including the basic equations? Yet in those days they were ahead of the pack and leading the way.

McIntosh and Van Zyl (1985) describe probabilistic approaches to unsaturated flow analysis through the use of a “very small, 8 bit, 64k computer to examine the variation in calculated seepage front advance of a wetting front from an impoundment. As expected the variations in the hydraulic conductivity of the soils dominates variation in seepage rates. Still this paper is a bold attempt to advance analysis of unsaturated seepage and probabilistic methods.

Wuolo and Nemanic (1985) provides an interesting paper in which they advocate the use of analytic element models (AEM) at the expense of finite-element methods models mainly because the former types do not require the use of a grid mesh and are therefore more suited to studies where the scale of the model needs to be expandable. However, what this study is remarkable for is that it is one of the first to specifically point out and address the potential for models to simulate and evaluate the outcome of proposed groundwater remediation and seepage control alternatives. In fact, the authors assessed the effects of existing interception systems combined with a hypothetical one based on the results of a calibrated steady-state groundwater flow model. They found that either (i) a well-field consisting of 12, ~3000 feet-wide equally spaced extraction wells pumping at 1 gal/minute or (ii) a drain/trench system represented effective mitigation options. In the end, the well-field system was selected due to excavation problems encountered during the implementation of the drain/trench system.

While it is true that discretizing a grid mesh (and setting up a numerical model in general) was a computationally over-expensive undertaking in the mid-1990's, doing so nowadays has become a relatively banal task and finite-method modeling codes such as MODFLOW and FEFLOW are now used routinely. For example, an approach to estimate the extent of acid rock drainage/seepage into surface water bodies from mine waste units was proposed by Uwiera and Reeves (2000). The authors used the particle tracking package MODPATH and sub-regional water budget ZONEBUDGET- two MODFLOW packages now widely-used- to accurately determine the mass load discharged into a nearby shallow lake.

More recently, progress in numerical modeling have allowed us to simulate variably saturated groundwater flow, as exemplified in Gard, et al (2010). Using MODFLOW-SURFACT, the authors developed a variably-saturated flow and transport model to delineate the present and future geometry of a Uranium and sulphate-bearing seepage plume with the objective of establishing alternative concentration limits (ACL) and accelerating the facility closure.

Groundwater Contamination

There is a fun paper by Norman (1994) on the need to deal with groundwater contaminated by historic deposition of mine tailings and petroleum contamination during the construction of new casinos in Central City and Black Hawk, Colorado. In this case, determining the extent of the environmental contamination was not the major challenge faced by the authors. Instead, having to deal with an unusually complicated interplay of project management constraints, including amongst others: negotiating remediation/recycling procedures with official bodies, working on a historic landmark site requiring the maintenance of almost all existing buildings, and dealing with a short time schedule available to guarantee the on-time inauguration of the casino, turned out to be the major difficulties to overcome. Clearly, this paper is a very good example of how project management, and not so much the actual engineering support, is sometimes the challenging aspect of a project!

System Water Balance

These days you use GoldSim or one of the competing models to simulate the water balance of the tailings impoundment. Burgess (1980) writes of a self-written code to do the job. This is a remarkably forward-looking paper for its time, and well-worth going back to in order to check on the validity and approaches we commonly use today.

Nelson et al (2008), in essence apply the same logic to water balance as Burgess did in 1980. Except now we are concerned for Acid Rock Drainage, and a Superfund site, neither of which figured in 1980.

In 2008 with the return of the series of symposia, there is a special session called *Water management and geochemistry*. Keep in mind that by this time, there are umpteen major focussed conferences on geochemistry, acid mine drainage, mine closure, paste tailings, and more and more detailed aspects of mining and environmental science and engineering. By 2008, the focus is on computer models, planning, and making decisions in the face of uncertainty.

Trautwein (2008) captures the situation, modeling is fast and easy in a short paper:

Less than 20 years ago, it was not unusual for a computer to take hours to perform a water balance analysis and many more to prepare the output. Now with some of the available water balance solutions being described and modern computer systems, a short-term analysis takes seconds and a long-term analysis (with a long climatological record) takes a couple of minutes. It is now practical to use water balance models for daily forecasting.

The current power and use of models in decision making is best illustrated by the words of Eary, et al (2008):

The hydrogeochemical model discussed in this paper is a simple representation of water and chemical balances for a pit lake in which many hydrochemical processes are lumped together. This simple structure is consistent with the purpose of the model, which is to provide a tool for rapidly investigating the relative merits, effort required, and costs of different alternatives for improving water quality in the pit lake after mine closure.

Whitman, et al (2009) present the results of years of work to establish that current seepage from the site is far better than background. The tragedy is that the golf courses and large estates downstream do not like contaminated water from an old mine to enter their property, regardless of what water quality was a thousand or even a hundred years ago. Hence the solution at this mine: dilution of excess waters in

the runoff from high rainfall events. Maybe it is time all the industry and all the regulators recognized this as a practical solution to the reality of water balance management.

Closure

We have not sought in this paper to write the history of the development of the many technologies that we have touched on here. It will take the hard work of others to write papers on the history of the development of the many technologies that make up the topics of seepage and tailings. We hope only that this paper serves to stimulate those who can, to write these histories. For we believe that we lose much by not being aware of previous efforts, by not being familiar with the old literature, and by trying to reinvent the solutions to problems we face.

References

- Amorim, N.R., Azevedo, R.F., Ferreira, O.R. Ribeiro, A.G.C., Azevedo, I.D. 2008. Field performance of cover systems. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 199-206.
- Burgess, P.J. 1980. The design and simulation of a no-release water management system in a tropical monsoon climate. *Uranium Mill Tailings Management: Proceedings of the Third Symposium, Fort Collins, CO. Colorado State University, November 24-25, 1980.* 179-198.
- Champlin, Jerry 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.
- Davis, L.A. 1980. A computer model for seepage and groundwater response beneath tailings impoundments. *Uranium Mill Tailings Management: Proceedings of the Third Symposium, Fort Collins, CO. Colorado State University, November 24-25, 1980.* 197-218.
- Dobchuck, B.S., O'Kane, M.A., Shumiak, R.E., Newman, G.P., Barbour, S.L. 2009. Modelling techniques for evaluating net percolation through soil covers for solid and hazardous waste – a comparative case study. *Tailings and Mine Waste: Proceedings of the Thirteenth International Conference, Banff, Alberta. University of Alberta, November 1-4, 2009.* 639-650.
- Eary, L.E., Jakubowski, R., Eshleman, J. and Watson, A. 2008. Applying numerical hydrogeochemical models as decision support tools for mine closure planning. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 221-232.
- Gard, M., Warner, J., Cope, L. and Raabe, K. 2010. Groundwater modelling at the Panna Maria uranium facility in support of an ACL application. *Tailings and Mine Waste: Proceedings of the Fourteenth International Conference, Vail, CO. Colorado State University, October 17-20, 2010.* 143-156.
- Johnson, J.E. 1978. Pathways of radionuclides released from tailings piles. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, CO Colorado State University, November 20-21, 1978. Volume 2.* 51-58.
- Kays, 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 2.* 59-66.
- Kowalewski, P.E. 1999. Comparative reclamation soil cover modelling in an arid environment. *Tailings and Mine Waste: Proceedings of the Sixth International Conference, Fort Collins, CO. Colorado State University, January 24-27, 1999.* 427-436.
- Kowalewski, P.E., Dorey, R., Wilson, G.W. and Duckett, R. 1998. Tailings impoundment reclamation soil cover design at the Ridgeway Mine. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, CO. Colorado State University, January 26-28, 1998.* 369-378.

- Lam, L. and Barbour, S.L. 1985. Saturated-unsaturated mass transport modelling by finite element method. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Seventh Symposium, Fort Collins, CO. Colorado State University, February 6-8, 198.* 431-440.
- Larson, M.B., Stephens, D.B. 1985. A comparison of methods to characterize unsaturated hydraulic properties of mill tailings. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Seventh Symposium, Fort Collins, CO. Colorado State University, February 6-8, 198.* 335-346.
- Lupo, J.F. 2008. Liner system design for tailings impoundments and heap leach pads. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 177-188.
- McWhorter, D.B., Nelson, J.D. 1978. Drainage of earthen lined tailings impoundments. *Uranium Mill Tailings Management: Proceedings of a Symposium, Fort Collins, CO. Colorado State University, November 20-21, 1978. Volume 2.* 31-50.
- Morrison, K., Elliott, J., Johnson, J., and Monok, B. 2008. Uranium tailings facility design and permitting in the modern regulatory environment. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 305-314.
- McIntosh, B.J. and van Zyl, D. 1985. Probabilistic approach to unsaturated seepage analysis. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Seventh Symposium, Fort Collins, CO. Colorado State University, February 6-8, 198.* 441-450.
- Miller, B. and Hornaday, C. 1998. Geosynthetic clay liners for the mining industry. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, CO. Colorado State University, January 26-28, 1998.* 361-368.
- Nasiatka, D. M., Shepherd, T.A. and Nelson, J.D. 1981. Clay permeability in low pH environments. *Symposium on Uranium Mill Tailings Management, Fort Collins, CO. Colorado State University, October 26-27, 1981.* 627-645
- Nelson, M., Fundingsland, S., Hazen, G., Hight, P., Ketellapper, V. 2008. Stochastic prediction of mine site water balance, Gilt Edge Mine Superfund Site, Lawrence County, South Dakota. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 253-264.
- Norman, T.S. 1994. Soil and groundwater cleanup takes the gamble out of casino. *Tailings and Mine Waste: Proceedings of the First International Conference, Fort Collins, CO. Colorado State University, January 19-21, 1994.* 79-88.
- Pakalnis, R., Chedsey, G. Robertson, A.M., Follin, S. 1985. Vacuum horizontal drainage for depressurization of uranium tailings. *Management of Uranium Mill Tailings, Low-level waste and Hazardous Waste: Proceedings of the Seventh Symposium, Fort Collins, CO. Colorado State University, February 6-8, 198.* 549-558.
- Peterson, S.R. and Krupka, K.M. 1981. Contact of clay liner materials with acidic tailings solution Part 2. *Uranium Mill Tailings Management: Proceedings of the Fourth Symposium, Fort Collins, CO. Colorado State University, October 26-27, 1981.* 609-626.
- Reid, E.I. 1998. Some key equations of ground water modelling simply explained. *Tailings and Mine Waste: Proceedings of the Fifth International Conference, Fort Collins, CO. Colorado State University, January 26-28, 1998.* 481-490.
- Small, D.M. 1980. Establishing installation and material selection parameters for liner placement systems. *Uranium Mill Tailings Management: Proceedings of the Third Symposium, Fort Collins, CO Colorado State University, November 24-25, 1980.* 251-298.

- Stormont, J.C., Morris, C.E., Finley, R.E. 1996. Capillary barriers for covering mine wastes. *Tailings and Mine Waste: Proceedings of the Third International Conference, Fort Collins, CO. Colorado State University, January 16-19, 1996.*
- Trautwein, A. 2008. Using water balance tools for site design, operation and expansion management. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 265-268.
- Uwiera, M.M.E. and Reeves, M.J. 2000. Application of 3D groundwater models to the assessment of ARD source loadings in surface water bodies. *Tailings and Mine Waste: Proceedings of the Seventh International Conference, Vail, CO Colorado State University, January 23-26, 2000.* 213-222.
- Uziemblo, N.H., Erikson, R.L. and Gee, G.W. 1981. Contact of clay liner materials with acidic tailings solution Part 1. *Uranium Mill Tailings Management: Proceedings of the Fourth Symposium, Fort Collins, CO. Colorado State University, October 26-27, 1981.* 597-608.
- Van Zyl, D. and Robertson, A.M. 1980. Subsurface drainage of tailings impoundments: some design, construction and management considerations. *Uranium Mill Tailings Management: Proceedings of the Third Symposium, Fort Collins, CO. Colorado State University, November 24-25, 1980.* 153-178.
- Van Zyl, D. and Caldwell, J. (2011). Brief history of the conference series, *Tailings and Mine Waste: Proceedings of the Fifteenth International Conference, Vancouver, BC. University of British Columbia, November 6-9, 2011.*
- Wels, C. and Robertson, A.M. 2003. Conceptual model for estimating water recovery in tailings impoundments. *Tailings and Mine Waste: Proceedings of the Tenth International Conference, Vail, CO. Colorado State University, October 12-15, 2003.* 87-94.
- Wels, C., Fortin, S., Loudon, S. 2002. Assessment of store-and-release cover for Questa tailings facility, New Mexico *Tailings and Mine Waste: Proceedings of the Ninth International Conference, Vail, CO. Colorado State University, January 27-30, 2002.* 459-468.
- Whitman, A., Hutchinson, I., Juliani, J., Bortz, S. 2008. Water balance management approach to mine closure at the Royal Mountain King mine, Copperopolis, CA. *Tailings and Mine Waste: Proceedings of the Twelfth International Conference, Vail, CO. Colorado State University, October 18-23, 2008.* 613-626.
- Witten, A.J., Pin, F.G., and Sharp, R.D. 1984. The effect of drains on the seepage of contaminants from subgrade tailings disposal areas. *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.* 167-178.
- Wuolo, R.W. and Nemanic, P.E. 1995. Integrated design of tailings basin seepage control systems using analytic element ground-water models. *Tailings and Mine Waste: Proceedings of the Second International Conference, Fort Collins, CO. Colorado State University, January 17-20, 1995.* 121-132.