Statement of Qualifications – Design of Final Landforms for Mine Waste Storage Facilities

Uniformity of design and construction does not necessarily achieve the mine closure objectives of minimum erosion and long-term sustainability.

The greatest physical risks to reclaimed landscapes are gully erosion and failure of surface water drainage courses.

These risk factors are much more prevalent at sites situated in cold regions.

Historically, rehabilitated mine landforms possess uniform slopes conforming to neat lines and grades. This lends itself to uniformity of design and construction, but does not necessarily achieve the mine closure objectives of minimum erosion and long-term sustainability. Uniform landforms represent immature topography, and are poised to evolve to lower energy states by shallow slope failures or accelerated erosion. In contrast, the development of a sustainable landscape for mine closure involves the development of landforms that replicate natural landscapes. The replication of mature and relatively stable natural systems reduces the rate and risk of accelerated erosion.

Following a tour of 57 abandoned and partially reclaimed operating mines, McKenna and Dawson (1997) created an inventory of mine closure practices, physical performance of reclaimed areas, and environmental impacts of reclaimed and abandoned mines. The inventory shows that the greatest physical risk to the landscapes is associated with gully erosion and re-established surface water drainage courses. Poor surface water management and landform instability are common factors leading to failure of mine waste cover systems around the world (MEND, 2004). These factors are much more prevalent at sites situated in cold regions where processes such as frost heave and snowmelt can substantially diminish the integrity and performance of a reclaimed mine landform (MEND, 2012).

This is a statement of O'Kane Consultants' (OKC's) qualifications in the area of landform design for mine waste storage facilities. Information provided below includes an overview of OKC, our philosophy and approach to landform design, relevant project experience, and personnel on our landform design team.

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OVERVIEW OF OKC:

OKC specializes in the design, construction, and performance monitoring of cover systems and final landforms for mine waste storage facilities.

OKC (www.okc-sk.com) is a geotechnical engineering and geoscience consulting firm with offices in the US, Canada, and Australia. The focus of OKC's work is on the application of unsaturated zone hydrology to closure of mine waste storage facilities and municipal landfills. OKC specializes in the design, construction, and performance monitoring of cover systems and final landforms for mine waste storage facilities. Currently, OKC has approximately 30 staff comprised of geotechnical, environmental and civil engineers, soil scientists, a hydrogeologist, a geochemist, CAD technologists, and administrative personnel. Most of the technical specialists involved in landform design for mine stockpiles are based in OKC's Saskatoon, Canada office.

In addition to over 75 conference and journal papers published by OKC staff, OKC has been the lead author on three key publications pertaining to mine waste cover systems. This includes the Mine Environment Neutral Drainage (MEND) manuals on design, construction, and performance monitoring of cover systems at a micro-scale (MEND, 2004) and macro-scale (MEND, 2007). The latter manual focuses on design and performance of rehabilitated mine landforms as well as their evolution over time. OKC also completed a project for the International Network for Acid Prevention (INAP) on improving the ability to predict the long-term functionality and performance of cover systems (INAP, 2003).

PERMAFROST FEATURES ON A LANDSCAPE

OKC has also been a part of recent publications related to the design of cover systems in cold regions. OKC was a technical reviewer of a Phase 1 study funded by MEND and INAC (MEND, 2009), which identified cold regions processes as potentially significant for the long-term performance of soil covers. OKC was a contributor to the Phase 2 study (MEND, 2010), which involved various tasks in support of advancing the state of cold regions cover research. Finally, OKC was retained by Aboriginal Affairs and Northern Development Canada (AANDC) in 2010 to form a Technical Advisory Group in support of developing a technical Guidance Document for the design of cover systems in cold regions. This document, which will be published in 2012, details the philosophy, feasible options and methodology for designing cover systems and final landforms for mine waste storage facilities in cold regions.

OUR PHILOSOPHY FOR FINAL LANDFORM DESIGN:

OKC's philosophy for design of final landforms for mine waste stockpiles can be summarized as follows:

- Design of a final landform should take place prior to construction of the initial landform;
- Geotechnical stability is paramount, but aesthetics and natural appearance should be considered in the design of mine landforms;
- Geomorphic principles must be considered in order to design landforms that will be stable over the long term; and
- Surface water management systems must be robust.

Landform design for mine rehabilitation requires a holistic view of mining operations, where each operational stage and each component of the mine is part of a plan that considers the end-use of the site as much as the immediate need. This plan, which needs to be flexible to accommodate changes in methods and/or technology, is about optimizing post-mining land capability, minimizing the costs in achieving optimal land use, and limiting long-term maintenance liabilities.

The incorporation of natural slope features into the final landform design for stockpiles not only improves aesthetics, but also emulates slopes that are in equilibrium with local conditions of rainfall, soil type, and vegetation cover.

The incorporation of natural slope features into the final landform design for stockpiles not only improves aesthetics, but also emulates slopes that are in equilibrium with local conditions of rainfall, soil type, and vegetation cover (Ayres *et al.*, 2006). The relatively small increase in costs for engineering and construction for creating natural landforms are more than offset by improved visual appeal, decreased slope maintenance costs, and improved long-term stability. In addition, constructing mine landforms that visually blend with the surrounding landscape has considerable public relations value for operators.

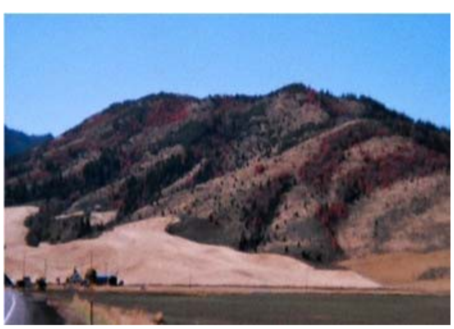
Reclamation failure can usually be traced to violation of geomorphic principles.

The consideration of geomorphic principles is fundamental when designing a stable landform. Reclamation failure can usually be traced to violation of geomorphic principles, most fundamentally having too great a disparity between force and resistance (Toy and Hadley, 1987). Basic geomorphic principles dictate slope angles, drainage density, and size of drainage basins, but many different landscape designs can satisfy these criteria. OKC uses creativity to develop an aesthetically pleasing landscape that not only satisfies the criteria for physical stability, but also contributes to the land capability and satisfies quantitative and qualitative criteria specified by key stakeholders.

Surface water management systems must be robust as any failure is visible to stakeholders.

Surface water management systems must be robust as any failure is visible to stakeholders. Even if the failure does not result in increased contaminant loading or other critical failures, small glimpses of erosion give the impression of poor design and management. In the north, 'icing' of surface water channels and ditches, particularly near the outlet area of the landform, is a very common failure mechanism of reclaimed mine landforms. Reclamation of large waste storage facilities should include the construction of small catchment areas and wetlands to reduce peak flows and increase sedimentation prior to reaching receiving streams. Finally, the design and implementation of a sound revegetation plan including rapid establishment of vegetation following construction can significantly limit erosion and sediment transport.

OUR APPROACH TO FINAL LANDFORM DESIGN:



OKC's approach for developing a sustainable final landform design for *future* mine waste or overburden stockpiles is as follows (from Ayres *et al.*, 2006):

1) Determine the final land use for the rehabilitated site through consultation with all stakeholders, and an assessment of potential geologic or structural control elements for the landform;

2) Observe and collect data on the natural landscape, such as hillslope forms and gradients, soil and vegetation types, drainage density, and watershed characteristics;

3) Determine the long-term eroded profile for the various slopes of the future final landform through erosion and landform evolution numerical modelling, to aid in the design/construction of the stockpile during mine operation;

4) Determine a suitable footprint design for construction of the stockpile based on the contours of natural landforms for post-mining visual blending and consideration for potential enlargement of the footprint following construction of the final landform;

5) Design a surface water management system to safely convey meteoric water off the final landform, and ensure runoff reaches final discharge points in volumes and at velocities that will not cause unacceptable erosion or sedimentation;

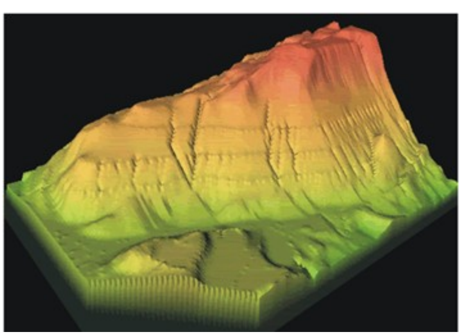
6) Develop a waste management plan/stockpile design that takes into consideration the storage of reactive and non-reactive waste materials (e.g. encapsulation of reactive materials with inert waste), and the findings from completing Steps 3 to 5 inclusive;

7) Develop a revegetation plan suitable for the swales and ridges in the final landform based on data collected in Step 2; and

8) Review the final landform design with key stakeholders for general acceptance prior to implementation with the aid of artistic renderings.

An existing stockpile can be reshaped to conform to maximum slope length and gradient requirements by utilizing a horseshoe-shaped landform without changing the footprint of an existing stockpile.

The above design approach can be applied to *existing* waste or overburden stockpiles with slight modifications. For instance, an existing stockpile can be reshaped to conform to maximum slope length and gradient requirements by utilizing a horseshoe-shaped landform, which creates a small, well-defined catchment without changing the footprint of an existing stockpile.



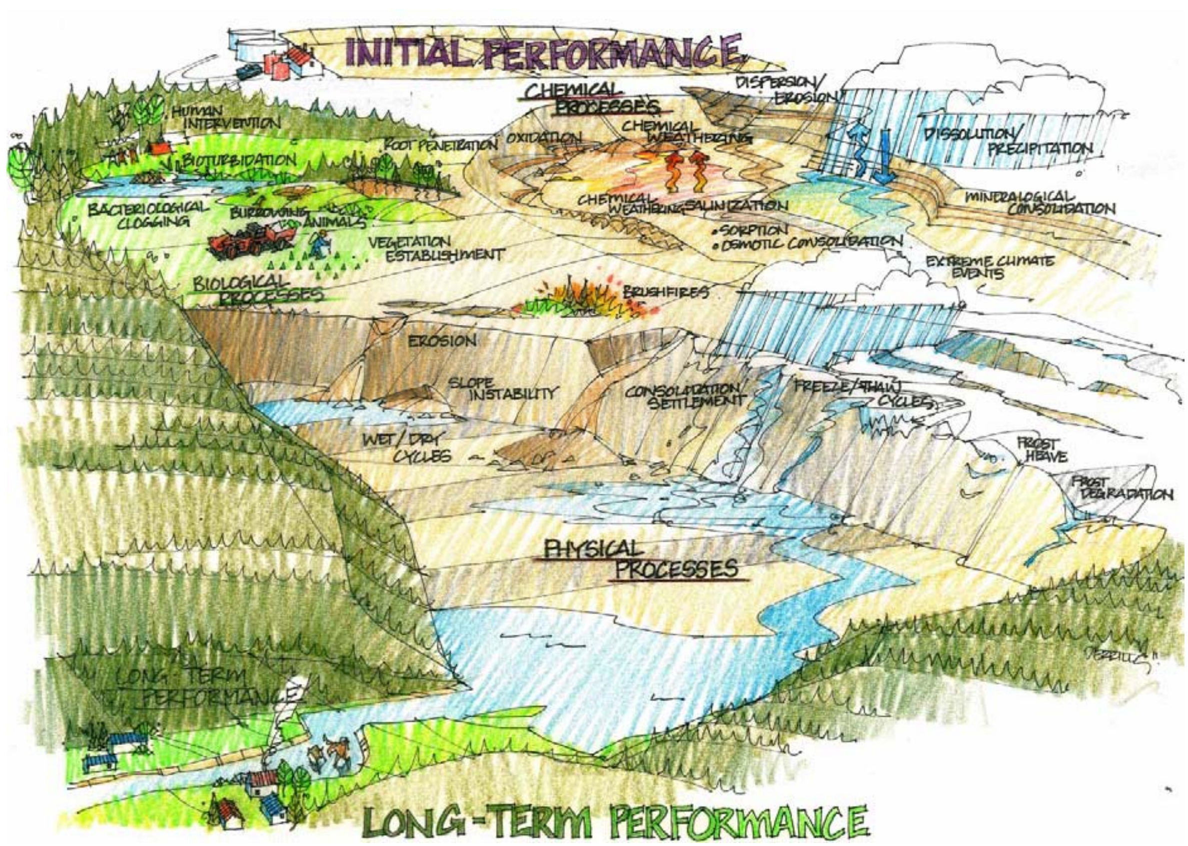
Source: Greg Hancock

Numerical analyses of erosion/landform evolution allow an assessment of current and future landscape designs without the problems associated with field studies. Where appropriate, OKC uses the models Water Erosion Prediction Project (WEPP; Laflen *et al.*, 1991) and SIBERIA (Willgoose *et al.*, 1991) to aid in the design of final landforms. WEPP can be used to determine short-term erosion rates for input to the SIBERIA model. SIBERIA (a 3-D topographic evolution model) predicts the long-term evolution of channels and hillslopes in a catchment on the basis of runoff and erosion. Ideally, the SIBERIA model should be calibrated; however, in lieu of measured, site-specific erosion rates, SIBERIA is a powerful tool for assessing relative differences in geomorphic stability for various landform design alternatives.

Numerical analyses of erosion/landform evolution allow an assessment of current and future landscape designs without the problems associated with field studies.

OKC uses the USDA Technical Release 55 (TR-55) model and tractive force method for appropriately sizing and lining surface water drainage channels planned for a mine stockpile final landform. OKC determines the maximum allowable flow in a channel based on Manning's equation for various channel geometries and linings, and evaluates the hydraulic condition (i.e. stability) of the channel flow based on the Froude number.

An understanding of the long-term evolution of a landform requires understanding the physical, chemical, and biological processes that lead to change over hundreds, even thousands of years. Specific processes may be studied; however, the complexity and time required to fully understand all aspects in the development of a landform cannot be simulated in a laboratory-scale experiment. Landform evolution should be monitored following construction, such as revegetation and erosion developments, defining the water balance, and evolution of cover soils. A watershed is the ideal unit size of a landform to evaluate the behaviour and evolution of a landscape (MEND, 2007). OKC has considerable experience in the design, installation, and maintenance of watershed-scale performance monitoring.

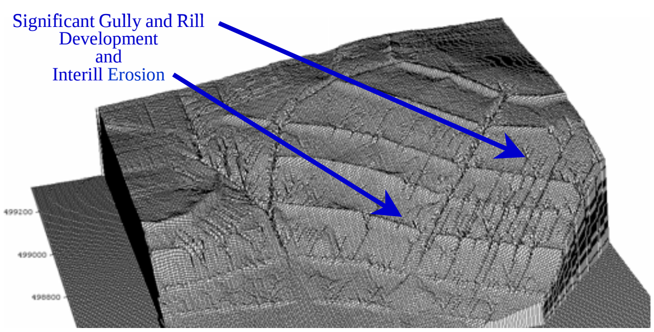


RELEVANT PROJECT EXPERIENCE:

Case Study #1: *Whistle Mine Backfilled Pit Remediation Project*
Client: Vale (formerly CVRD and Inco) *Completed:* 2005

OKC completed erosion and landform evolution numerical modelling to design a runoff management system and final landform for the backfilled open pit at Whistle Mine near Sudbury, ON, Canada (Ayres *et al.*, 2007). The site has a mean annual precipitation and potential evaporation of 900 mm and 520 mm, respectively. Approximately 30% of the annual precipitation occurs as snow. Due to acid-generating potential and surrounding wetlands, all waste rock stored on surface was relocated to the open pit and subsequently covered. The cover system consists of nominally 0.45 m of compacted clay overlain by a minimum of 1.2 m of sand and gravel, with 0.08 m of topsoil admixed to the cover surface to increase nutrients for revegetation efforts. The surface of the backfilled pit, which covers ~10 ha, has an average slope of 17% over a maximum length of 125 m as a result of natural relief in the area.

The WEPP model was used to estimate erosion rates from the cover surface, while the SIBERIA model was used to predict the evolution of two final landform design alternatives. The first landform alternative examined consists of a highly engineered system to manage runoff generated from spring snowmelt and rainfall events. The landform has contour banks to capture runoff water and divert it laterally to one of two collection channels oriented parallel to the slope. The SIBERIA model output (see below), after running a 100-year climate database, shows breaching of the contour banks, development of gullies and rills, and, in general, failure of the landform over a 100-year period.



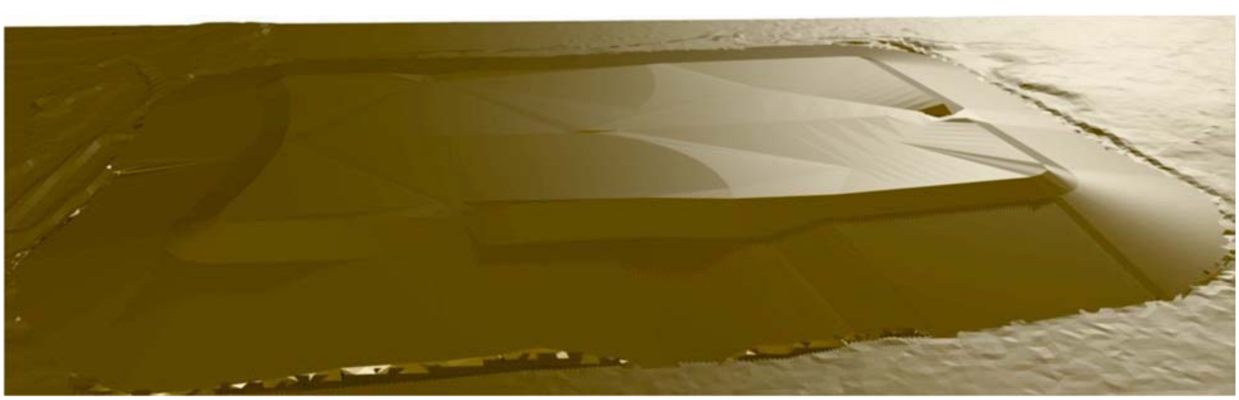
The second alternative and ultimate landform design implemented for the backfilled pit cover system consists of a number of catchments oriented parallel to the slope with a 'swale and ridge' pattern (see below). This micro-topography is beneficial for revegetation efforts because snow accumulates in the troughs, thereby increasing soil moisture levels, and wind velocities are reduced across the ground surface, thus reducing potential loss of topsoil and grass seeds. Progressively higher levels of erosion protection were used in the hillslope channels as the contributing area and associated design flow velocities increased towards the south. The Whistle Mine pit cover system has experienced minimal soil loss and remains a stable landform since completion of construction in 2005.

Case Study #2: *Rabbit Lake B-Zone Waste Rock Pile Reclamation Project*
Client: Cameco Corp. *Completed:* 2011

OKC was retained to develop a detailed reclamation design for the B-Zone waste rock pile (BZWRP) at Rabbit Lake Mine in northern Saskatchewan, Canada. The mean annual precipitation and potential evaporation for the site is approximately 540 mm and 400 mm, respectively. About 33% of the annual precipitation occurs as snow. The initial BZWRP landform was between 18 and 30 m high with 37° side-slopes, covered a surface area of 22 ha, and had a volume of about 5 million m^3. The water quality of seepage emanating from the pile was characterized by elevated levels of several metals and radionuclides, notably As, Ni, Mn, ^{226}Ra and U, and a pH typically between 3.3 and 5.5.

A soil cover system was needed for reclamation of the BZWRP in order to improve the quality of waters running off the pile, reduce the net infiltration of meteoric waters, and provide a medium for sustainable growth of native vegetation species. Following physical and geochemical characterization of the waste and potential cover materials, OKC completed soil-plant-atmosphere and seepage numerical analyses to determine the optimum cover system design for closure. The final design for the BZWRP comprised a 0.2 m (nominal) thick layer of compacted waste rock overlain by 1.0 m (nominal) of silty-sand till.

Several final landform design alternatives were considered for closure of the BZWRP. The preferred final design included three catchments on the plateau with each having its own armoured drainage channel. One of the design criteria was to incorporate features of local glaciated landforms where possible for aesthetic purposes. The selected final landform design included a concave east and west slope, where the upper third of the slope is 3H:1V and the lower two-thirds is 5H:1V. The intent was to mimic a natural slope profile, which tends to be steeper in upslope regions and flatter towards the base of the slope (i.e. a concave profile). Erosion analyses completed also show that the concave slope profile is less erodible than linear slope profiles considered for final grading of the BZWRP. Re-grading of the BZWRP and cover system construction was completed in 2011.

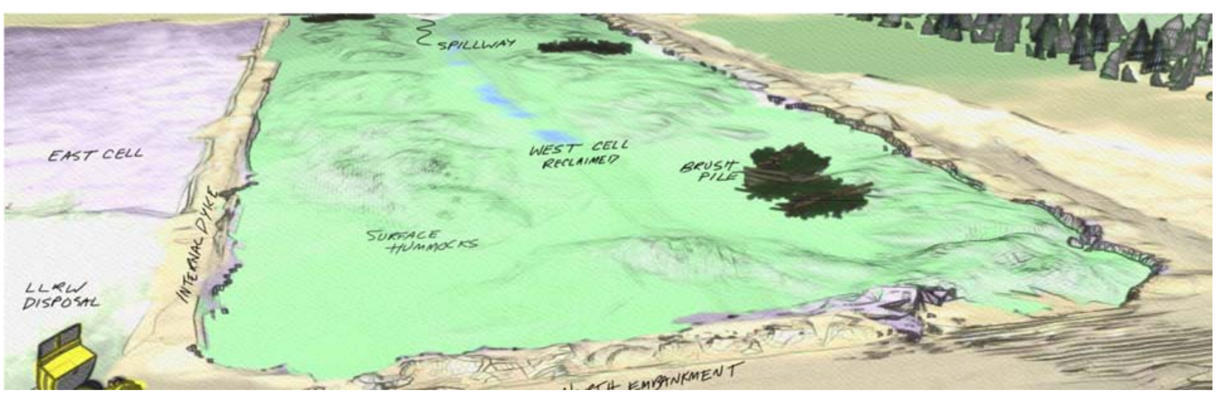


Case Study #3: *Key Lake Aboveground Tailings Management Facility Reclamation Project*
Client: Cameco Corp. *Completed:* 2012

OKC was retained to assist Cameco with updating plans for management and closure of the Aboveground Tailings Management Facility (AGTMF) at Key Lake Mine in northern Saskatchewan, Canada. Climatic conditions at this site are similar to those at the Rabbit Lake site. The AGTMF, with a footprint of 64 ha, contains approximately 3.5 Mt of tailings. The embankments are approximately 20 m high with outer slopes of about 3H:1V. Although tailings deposition ceased in 1996, Cameco wants to use the Key Lake AGTMF as a contaminated waste (CW) storage facility for future wastes generated at their operations. With proper management of CW disposal, some areas of the AGTMF can be filled to capacity to facilitate progressive reclamation, which has several social, performance, and operational benefits.

The current AGTMF landform features planar, linear side slopes rising 20 m above the surrounding landscape. Unfortunately, for reasons of long-term geotechnical stability and physical containment of tailings, it was not possible to substantially change the current shape of the perimeter embankments. Nonetheless, the following design concepts were identified to improve the aesthetics of the final landform:

- *Landscape improvements to the embankment crests* – Breaking the horizontal sight-lines of the existing embankment crests through adding irregular mounds (varying in height and length).
- *Addition of mounds on the final reclaimed surface* – Additional mounds to further improve aesthetics of the final surface and potentially add diversity to the revegetation community.
- *Incorporation of surface drainage features analogous to natural systems* – Avoidance of linear drainage paths; integrating a variably sloping surface and presence of mounds to produce meandering drainage paths properly designed and armoured.
- *Revegetation of the final reclaimed surface through planting of different species.*
- *Revegetation of the AGTMF embankments to break up sight lines of the planar embankment slopes*.



OKC's LANDFORM DESIGN TEAM:

- ***Mike O'Kane, M.Sc., P.Eng.*** – is a Senior Technical Advisor for all of our landform design projects. He has 17 years of experience in the design of cover systems and final landforms for mine waste storage facilities. Mike has been involved with landform design projects at sites all across Canada and Australia. Most recently, Mike was the lead for the Technical Advisory Group that was retained by AANDC to develop a technical guidance document for design of cover systems in cold regions.
- ***Dave Christensen, M.Sc., P.Eng.*** – is a Senior Geotechnical Engineer with over 10 years of mine closure experience. He is the lead of OKC's numerical modelling group, with expertise in the application of the WEPP and SIBERIA erosion models to develop sustainable final landform designs.
- ***Justin Straker, M.Sc., P.Ag.*** – is a forest ecologist / soil scientist and principal with the Integral Ecology Group. He has 17 years of experience in applied terrestrial ecology with expertise in the design and implementation of revegetation plans for mine reclamation projects.
- ***Ivan Turgeon, A.Sc.T.*** – is a Senior CAD Technologist with nearly 10 years of mine closure experience. Ivan uses AutoCAD Civil 3D v2012 software for design grading and cut/fill balancing, and Autodesk's Maya platform for visualization of landform design alternatives.
- ***Derrill Shuttleworth*** – is a contract illustrator / graphic artist that has over 15 years experience preparing renderings and artwork for mining projects. When necessary, Derrill is brought in to prepare artistic renderings of final landform designs for improved visual presentation to clients, regulators, and other stakeholders.

REFERENCES:

Ayres, B., Dobchuk, B., Christensen, D., O'Kane, M. and Fawcett, M. 2006. Incorporation of natural slope features into the design of final landforms for waste rock stockpiles. *In* Proceedings of the 7th International Conference on Acid Rock Drainage, St. Louis, MO, USA, March 26-30, pp. 59-75.

Ayres, B., Lanteigne, L., Smith, Q., and O'Kane, M. 2007. Closure planning and implementation at CVRD Inco's Whistle Mine, Ontario, Canada. *In* Proc. 2nd International Seminar on Mine Closure, Santiago, Chile, Oct. 16-19.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S., and Kohl K.D. 1991. WEPP soil erodibility experiments for rangeland and cropland soils. Journal of Soil and Water Conservation, Vol. 46, pp. 39-44.

McKenna, G.T. and Dawson, R. 1997. Closure planning practice and landscape performance at 57 Canadian and US mines. Draft, July 18, 1997.

INAP (International Network for Acid Prevention). 2003. Evaluation of the long-term performance of dry cover systems, final report. Prepared by O'Kane Consultants Inc., Report No. 684-02, March.

MEND (Mine Environment Neutral Drainage). 2004. Design, construction and performance monitoring of cover systems for waste rock and tailings. Canadian MEND Program, Project 2.21.4, July.

MEND (Mine Environment Neutral Drainage). 2007. Macro-scale cover design and performance monitoring manual. Canadian Mine Environment Neutral Drainage Program, Project 2.21.5, September.

MEND (Mine Environment Neutral Drainage). 2009. Mine Waste Covers in Cold Regions. Canadian Mine Environment Neutral Drainage Program, Project 1.61.5a, March.

MEND (Mine Environment Neutral Drainage). 2010. Cold Regions Cover Research – Phase 2. Canadian Mine Environment Neutral Drainage Program, Project 1.61.5b, November.

MEND (Mine Environment Neutral Drainage). 2012. Cold Regions Cover System Design Technical Guidance Document. Canadian Mine Environment Neutral Drainage Program. *[In progress]*.

Toy, T.J. and Hadley, R.F. 1987. Geomorphology and Reclamation of Disturbed Lands. Academic Press Inc., Florida.

Willgoose, G.R., Bras, R.L., and Rodriguez-Iturbe, I. 1991. A physically based coupled network growth and hillslope evolution model: 1 Theory. Water Resources Research, Vol. 27, pp. 1671-1684.