srk news

Mine Closure: Can closure create opportunities?

Defining an effective post-mining land use

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Griffon heap leach closure, Nevada: Future wildlife watering hole

Defining post-mining land uses is an essential part of mine closure. Properly selected, the post-mining land use will guide the operator's closure vision and objectives, and inform the selection of closure methods and technologies.

The 2019 International Council on Mining and Metals guidelines tell us that the closure vision should be aspirational. But when selecting a post-mining land use, we should also ensure that it is both productive and sustainable.

Sustainable post-mining land use must also be practical and – if possible – bolster socioeconomic transition and create opportunities for current and future stakeholders. However, a productive post-mining land use does not necessarily mean that the site will return direct economic benefit – not every closed mine site can be a recreational resort, an alternative energy facility, a research center, or prime agricultural land. Sometimes, the best solution is to stabilise a site physically and chemically, and restore it to a sustainable environment capable of supporting local biota and restoring, enhancing, or creating wildlife habitat.

...continued

Defining an effective post-mining land use *(continued)*

A preliminary selection should occur early in the mine life cycle. It should be reviewed periodically to consider what is feasible, and incorporate a number of factors including location, pre-mining and surrounding land uses, local environment, proximity to population, land tenure, regulatory requirements and corporate requirements, and, most importantly, stakeholder input because some of these factors may change during the mine life.

The site environmental, social and legal context will ultimately determine feasible post-mining land uses, and a number of questions should be addressed during the closure planning. What site infrastructure could contribute to socioeconomic transition? What site conditions could limit potential land uses for some areas of the site? What technical and economic constraints could affect land use? What are the perceived and real long-term risks to the environment and public health and safety? What would local stakeholders like to see?

Although critical to the process, stakeholder engagement has its limitations when it comes to mine closure. The first challenge is that, early in the mine life cycle, it is difficult to get many stakeholders, especially local communities, to envision future land uses that may not be realised for years if not decades. Second, even when the engagement process does identify selections that reflect the aspirations and expectations of local communities, some may not be practical, economically viable, or sustainable. For example, a large, flat area like the top of a tailings impoundment might seem like an ideal place for agricultural use, but the chemistry of the tailings could risk livestock and human health. And, the permanence of closure means that the needs of future stakeholders should also be represented in selecting the post-mining land use. Therefore, assessing post-closure land use risks should consider the types of unplanned land uses that could occur because some potential future uses may not be compatible with the closure actions taken and could place the environment at risk. For example, if artisanal miners migrate to the area, the performance of engineered closure measures, such as mine waste covers, could be compromised.

In conclusion, it is imperative to begin an early discussion with local and regional stakeholders including the government and communities, regarding closure and post-closure land uses, maintaining these discussions throughout the lifecycle of the mine, adapting closure plans as needs of the local and regional stakeholders change while identifying changing post-closure land use risks.

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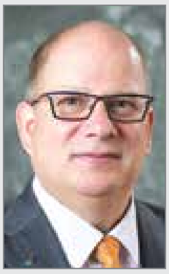
JEFF PARSHLEY



Jeff has over 35 years of project experience in North America and internationally. He holds a degree in Geology from Dartmouth College, Hanover, New Hampshire. Jeff's expertise includes mine closure and remediation, mine environmental studies, mine permitting, and environmental geochemistry. In particular, he has specialised in closure cost estimating work including the development of the public domain Standardized Reclamation Cost Estimator (SRCE) model used by mining companies around the world to prepare closure cost estimates.

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In mid-2017, SRK was appointed to prepare a closure plan to pre-feasibility study (PFS) level for a mine in Southeast Asia. The mine area had more than 40 pits, some backfilled, and 13 waste rock dumps. To support closure planning, it was important to identify the pits and dumps that represented significant contamination sources, and to develop effective mitigation measures to manage the ongoing release of contaminants as part of the closure design.

Available information for the site included drill hole data, geological block models, current topographic surfaces, future pit and dump designs, outcomes from geochemical characterisation studies, and water quality monitoring of data surface water and groundwater. Conceptual

Source assessment to support closure designs for a site in Southeast Asia

Lake forming in one of the pits - exposed wall rocks include sulfidic materials

models were developed for distributing reactive materials and contaminant sources within key pits and dumps. The most significant sources identified for producing post-closure solute were expected to be related to oxidising sulfide minerals present in unsaturated materials in above-ground waste dumps, pits backfill located above the long-term water table, and pit walls that remain exposed after closure, i.e. those not covered by backfill, or remaining above the long-term pit lake levels.

Field-scale solute production rates (inferred from laboratory column test results) were combined with water flows to calculate water chemistry at the source and downstream after mixing with other water sources. Additional project work included a site water balance, including representation of surface and groundwater flows at the site. The water quality results were used to examine the range of possible mine-impacted water chemistries for (i) base case flows and solute loadings – to reflect the condition of the site before implementing active closure measures, and (ii) post-closure design conditions – to examine the effect of closure measures, such as placing low infiltration covers on dumps. Using the site-wide water and solute load balance, it was possible to identify the optimal closure measures for mitigating water quality impacts on to downstream receptors (drinking water resources).

The geochemical assessment formed a key part of a multi-disciplinary approach to support the development of overall closure designs for this large, complex site in tropical, high precipitation conditions.

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CLAIRE LINKLATER

Claire has 25 years of experience in interpreting geochemical data, building conceptual models of processes that control in-situ geochemical behaviour and applying geochemical modelling codes. Claire's experience includes sulfidic materials management; acid/alkaline rock drainage (ARD) assessment and prediction; water quality and pollutant mobility from waste rock dumps, tailings storage facilities, underground workings and pit walls; and assessing the effectiveness of potential mine closure strategies.

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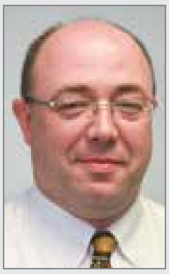
ROB BOWELL



Dr Rob Bowell is SRK's Corporate Consultant in Geochemistry & Geometallurgy with internationally recognised expertise in the geometallurgy of complex ores. He spent over 28 years specialising in applying geochemistry and mineralogy to diverse mining and engineering projects, including characterising oxide ores amenable to ISR, solution mining and heap leaching, refractory gold ores, autoclave mill residues, complex base metal and uranium ores and rare earth element mineralogy. Rob has worked on ISR projects for copper, uranium, lithium recovery from brines, mine waters and ISR fluids and potash solution mining on nearly every continent.

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EMILY HARRIS

Emily, CEnv, MIEMA, has over 10 years of environmental and social management experience in the mining industry across a range of commodities and jurisdictions covering Europe, West Africa, Central Asia, Middle East, North and South America. She is skilled in identifying and recommending practical solutions for key risks in the context of performance against local environmental permitting requirements, good international industry practice and international financial lender requirements. Emily has managed numerous environmental and social impact assessments for large mining developments and contributes to project engineering studies and closure planning processes.

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Finding value in closure

Borska Reka, Serbia

Tsumeb smelter waste, Namibia

The closure and abandonment of mining areas is rarely caused by complete consumption or extraction of a resource but rather is typically associated with diminishing financial returns based on metal values, or social, political, and environmental restrictions that lead to an uneconomic scenario for a resource unit. With regard to legacy mine sites, the removal and concentration of metals is a logical step in improving environmental water quality and in producing saleable products that can assist in offsetting water treatment costs.

Each mine site requires a site-specific evaluation to determine the potential for recovering metals and to identify suitable technologies. In assessing a mining area, there are several potential sources of economic value, including:

- Previously unidentified resources in the mining area;
- Mining of known in-situ ore and stockpiled unprocessed ore;
- Recovery of value from previously processed waste and previously cited mine waste;
- Recovery of value from undeveloped resource, such as the processing of mine water to recover metals and valuable salts;
- Recovery of new value from mining facilities such as mine sludge processed to recover ferric oxyhydroxides as a source of iron, pigments and trace metals; and
- Development of mine water resource for agricultural, industrial or even potable water.

In the case of the first two potential sources, unconventional or innovative methods of exploration may be required to identify these resources. Additionally, the development of water as a resource - either for metal or salt recovery or as a source of useable water - requires hydrogeochemical investigations. The successful development of these resources and value recovery often requires more efficient metallurgical

circuits or new chemical and physical extraction procedures to recover value.

SRK has been involved in developing new technologies, the transfer of existing technologies to new applications, and in assessing abandoned or closing mines and mine waste at existing operations with the challenge of recovering value. These projects are typically multi-disciplined and often are developed to fit in the scope and operations of existing mining or closure activities. Successfully developing them has a number of benefits: removing or isolating potential pollutants from waste, recovering value that otherwise would be lost, generating revenue, and/or off-setting closure and reclamation costs. Each operation is unique and requires a unique approach and SRK has experience in doing exactly this.

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Collaborative closure planning

It's no secret that effective mine closure planning requires a multi-disciplinary approach, but integrating inputs and teams can be a challenging task. For the Pueblo Viejo project in the Dominican Republic, SRK led an extensive team of engineers and environmental specialists who collaborated on ideas and activities to design an effective closure solution at this challenging site.

Pueblo Viejo operated from the mid-1970s until 1999, when economic and technical reasons forced the operation to stop without formal closure. Following its acquisition of the project in 2009, Pueblo Viejo Dominicana Corporation (PVDC), a subsidiary of Barrick Gold, was keen to develop closure plans for both government liability areas and the new development area. These plans were needed to comply with numerous pre-existing environmental obligations, Barrick Corporate standards and international financial lender requirements.

The first step in the closure planning process was to build the right team for the job and clearly define responsibilities. Water management and geochemistry were two particularly challenging aspects of the closure scenarios due to the high rainfall and high-sulphide content of the deposit, and existing waste rock. SRK brought together groups with expertise and extensive site knowledge in these areas to contribute to a closure design that was responsive, and appropriate, to the site-specific conditions.

SRK held interactive workshops to draw together ideas from the client, project engineers and environment team on closure objectives, key closure actions and assumptions. It was critical to align these across the team so that the closure design met expectations and requirements from each stakeholder group. The breadth of experience from workshop attendees was also used to identify unknowns that could present risks to successful implementation of the closure design and define where future studies would be required.

Extensive team communication continued throughout the project to deliver a closure plan that provided defensible solutions to key environmental challenges and, importantly, was considered realistic and practical to implement by the site operations team.

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Observing water quality challenges at the site *(Photo credit: William Schafer)*

Design-build mine remediation projects

Anyone who has been involved with project management or construction can attest to the inherent challenges that can be experienced on mine remediation projects. They are often remote, unpredictable, and the work can be greatly impacted by the weather and environmental conditions. Such challenges directly affect a project's schedule, budget, final product, and even the safety of the workers. A project delivery approach that many members of SRK execute effectively is called design-build. The design-build approach encourages a high degree of collaboration and continuity between the engineering and construction teams.

An SRK project example is the design-build remediation of the Emerald Glacier mill and tailings facility (completed in 2013) for the British Columbia Ministry of Forest Lands and Natural Resource Operations. Challenges faced during this project included: a shortened design schedule, developing a cost-effective budget and design, ensuring the safety of its workers, and working in a remote location with limited access. The design-build structure brought together designers, contractors, and consultants as a team. The design-build team was able to shorten the time required to produce a final design and mitigate problems prior to construction.

The design-build project structure allows the contractor to provide input in order to optimise construction sequencing, timelines, and suggest alterations to suit the contractor's equipment. Designs that often look good on paper do not always reflect the ability of common construction equipment or the specific conditions of the site. Design-build also minimises the project timeline by allowing efficient "real-time" design modifications when construction challenges were encountered.

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STUART MCPHEE

Stuart is a Civil Engineering graduate from the University of Saskatchewan with more than 9 years of experience in natural resource, engineering consulting, and construction. His experience includes working with government agencies, industry, First Nations, and private sectors. Stuart has provided project consulting in civil and geotechnical engineering, forestry, environmental, mining and energy, reclamation, and land development at multiple sites in British Columbia, Alberta, Saskatchewan, Manitoba, Nunavut, and the Yukon.

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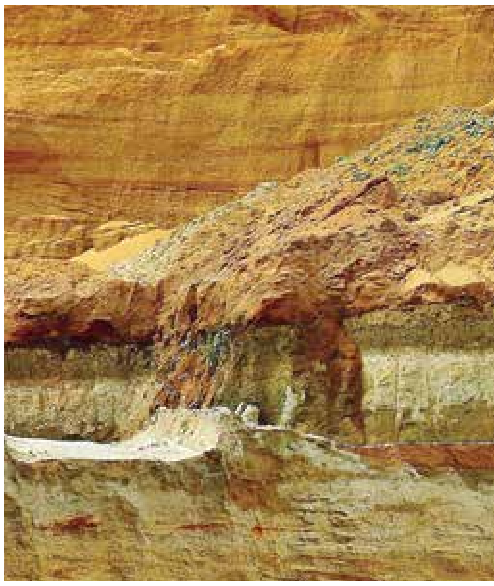
Emerald Glacier, looking north along tailings area



Sand and aggregate are two of the most commonly used natural resources in modern society to maintain the existing infrastructure and provide for future construction. After air and water, sand is the natural resource most used by human beings (Beiser). About 70 percent of the world's sand is quartz formed by weathering and erosion. Sand has a myriad of uses in everyday products, such as glass, detergent, toothpaste, solar panels, and silicon chips; however, the bulk of the world's sand is used for concrete in buildings and roads, and rail ballast as well. Highway agencies and municipalities are experiencing difficulties in locating suitable aggregate for new construction and long-term life-cycle performance objectives.

Recently, the world's supply of readily available sand and aggregate has been diminishing due to demand. The production of cement

Sand and aggregate: diminishing natural resources and potential sources

is reported by 150 countries and reached 47 and 59 billion tonnes in 2010 (UNEP). For each tonne of cement, the building industry needs about six to seven times more tonnes of sand and gravel (USGS, 2013b). The production of aggregate has become more difficult over time due to depletion of suitable sources, transportation distances, and conflicting land uses (Not-in-My-Backyard/urbanisation).

Mine waste rock and mill tailings have the potential to lessen the sand and aggregate shortage, provided the source material meets the physical and geochemical criteria (soundness, hardness, strength, porosity, and specific gravity) and can be transported economically. The production of sand and aggregate from mine waste rock and tailings has the potential to offset a portion of the mine's reclamation costs by using existing equipment, trained work force, environmental permits and authorisations, and infrastructure such as power, water, and access.

Alternatively, portions of the mining facility can be sold or leased to a sand and aggregate producer.

A mine operator can assess the potential for converting waste rock to a saleable product by determining the physical and geochemical properties of rock types that will be encountered and consider selectively handling the material for concomitant or future uses. The physical and geochemical properties can be determined during resource drilling concurrently with other geochemical characterisation programs required for mine permitting.

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Beiser, V., 2015. T*he Deadly Global War for Sand*, www.wired.com, accessed October 19, 2017.

United Nations Environmental Programme (UNEP). 2014. Sand, Rarer than One Thinks, March 2014.

U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013b. (USGS, 2013b)

Langer W.H., 2011, Aggregate resource availability in the conterminous United States, including suggestions for addressing shortages, quality, and environmental concerns: U.S. Geological Survey Open-File Report 2011–1119.

VAL SAWYER

Val has over 30 years of experience in mine environmental permitting and compliance and metallurgical engineering. She has prepared numerous plans of operations for different agencies throughout the western United States. Her environmental experience includes the management and preparation of National Environmental Policy Act (NEPA) documents, permitting of precious metals mines, and environmental compliance. Val has managed multi-discipline studies for the collection of environmental baseline information for the support of environmental impact statements.

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Jerritt Canyon tailings storage facility

The Jerritt Canyon Mine Tailings Storage Facility 1 (TSF1) located in northeast Nevada was commissioned in 1980 and operated through 2013 for the disposal and containment of spent tailings slurry from the Jerritt Canyon milling operations. TSF1 was designed in seven phases as a ring dike impoundment constructed over partially compacted native soils without a synthetically-lined containment system. Tailings were typically deposited from its outer perimeter creating a pronounced conical depression in the center of the impoundment. Throughout most of its operations, this depression was used to store approximately 500 million to more than 800 million gallons of surplus supernatant water.

As a result, seepage was detected in the alluvium seven years after TSF1 was commissioned. A recharge mound and migration of tailings supernatant solution with elevated total dissolved solids and chloride concentrations were detected beneath the impoundment. Since 1987, dozens of pumpback, freshwater infiltration, and monitoring wells were installed surrounding TSF1 in an attempt to manage and mitigate the seepage plume.

In 2011, in an effort to completely evacuate supernatant inventories from TSF1 and prepare for closure, Jerritt Canyon began transferring the remaining TSF1 supernatant to the newly-constructed water storage reservoir. This is a double-lined pond designed to contain approximately 380 million gallons of surplus solution. By mid 2014, the TSF1 supernatant pool was completely removed by pumping to the water storage reservoir. As a direct result of these actions, seepage collection and removal decreased from 900 to approximately 600 gpm, reducing the recharge mound and lowering of the groundwater table beneath TSF1. This caused numerous pumpback wells to dry up.

SRK originally submitted a Final Plan for Permanent Closure (FPPC) for TSF1 to the Nevada Division of Environmental Protection (NDEP) in 2010. During its preliminary development, SRK evaluated store-and-release covers that primarily rely on evapotranspiration from plants to limit infiltration. Synthetic-lined covers were considered inadequate, since most Jerritt Canyon precipitation occurs as winter snow and snowmelt and infiltration occurs while plants remain dormant in spring. Therefore, a synthetically-lined geomembrane cover design, approved by NDEP in 2011, was selected to 1) preclude any meteoric infiltration into the underlying tailings, and 2) eliminate the driving hydraulic head causing continued migration of contaminates into underlying vadose zone and groundwater.

The FPPC closure cover consists (from bottom to top) of an interim working platform layer, 40-mil HDPE geomembrane, and a 3-foot-thick alluvial-type growth media cover. It slopes towards the southern end of the impoundment where stormwater runoff drains the facility in a controlled manner through an outflow spillway into an existing stormwater diversion channel.

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DAVE WANNER

Dave, PE, has over 20 years of experience in the industry, 10 of which have been in consulting and construction. He has been instrumental in the design and permitting of mine and process facilities throughout Nevada, including tailings storage facilities, process ponds, heap leach pads, solution conveyance, and stormwater control structures. Beyond new facilities, Dan has facilitated reclaiming and closing mine and process facilities, providing engineering support for mine closure and reclamation projects as project superintendent and manager. Dave has also compiled reclamation bond determinations and asset retirement obligation calculations for mining companies.

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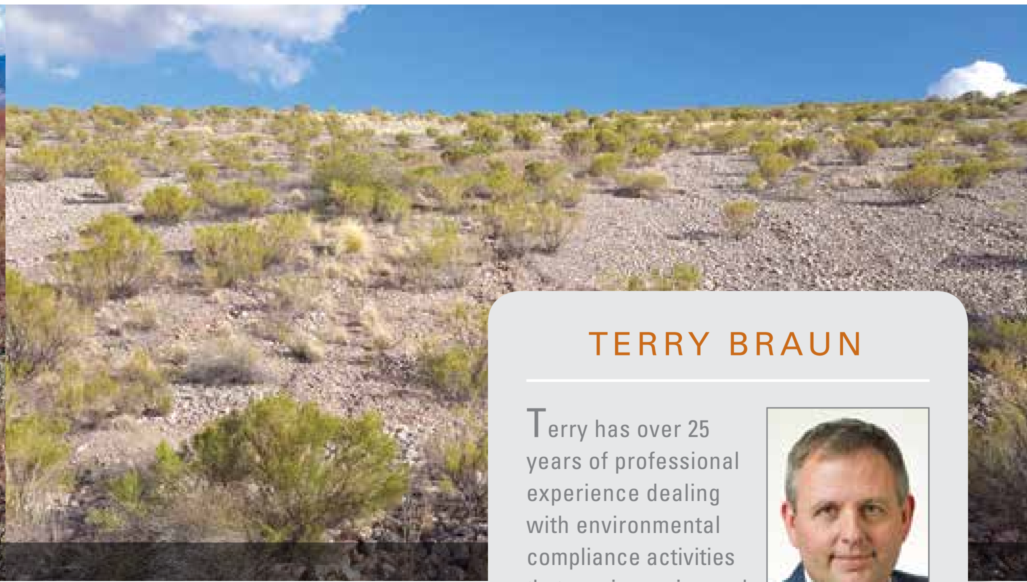
Reclaimed tailings

For owners of active mines, mine closure links past performance to future permission. Their success in expanding existing mines, new brownfield developments or greenfield projects will depend on the owner's track record for mine closure. Without that record, a project's closure plans will be compared to similar projects.

Most investors in the mining industry understand if an operator fails to successfully close a mine, the expected investment returns will be impaired. Shareholders now demand more environmentally-responsible performance during operations and closure.

Project financiers tend to enter and exit a project long before mine closure. However, international lenders now follow global guidelines, such as the Equator Principles, that address the mining life cycle of planning, building, operating and closing. Financial institutions will demand best practice for mine closure as part of the funding requirements.

Investor, lender and owner perspectives on mine closure



The global mining industry strives to improve best practices in mine closure organisations, like the International Council on Mining and Metals, fund research and prepare guidelines for mine closure planning and goals for new sustainable mining projects. The industry's commitment for continuous improvement is real.

Today, owners and developers for new mines embrace the challenge of implementing best practices, including synthetic-lined process facilities, dry-stack or low-water consumption tailings practices, and progressive reclamation techniques. The mining projects of the future must consider the project's life-cycle. This means mine closure practices and economics become an upfront conversation with regulators, the public and investors.

For legacy sites or active mines with a multiple-decade history, applying international best practices is more complicated. Legacy sites live with long-since-discontinued operating practices. Their owners include governments, non-mining companies or individuals that inherited or acquired them secondhand. Further complicated by funding limitations and/or legal uncertainties, permanent and effective closure of legacy sites remains a unique challenge and opportunity.

Active mines may have multiple-decade operating histories, having opened before and during the modern era of mining and environmental regulation like the massive copper porphyry deposits in Africa, Chile, Peru and the southwest U.S. These long-lived properties include un-lined leach dumps and exposed sulfide-rich mine rock piles. Long-term producers often address these issues concurrent with active mining operations. Owners and operators work with regulators, investors and other stakeholders to align mining operations with regulatory requirements and industry best practice.

In fact, large institutional investors and financial institutions understand the difference in closure risks for long-term producers and future operations. And, mining companies recognise that building a track record of successful mine closure for depleted assets builds credibility with these institutions, as does reducing the environmental liabilities posed by legacy sites. Both trends are rising.

No matter the commodity, mining method or geographic location, project developers must recognise the rising expectations of investors and financial interests for responsible mine closure.

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TERRY BRAUN

Terry has over 25 years of professional experience dealing with environmental compliance activities that require engineered solutions at mining operations. His projects often require negotiations with regulatory agencies and other stakeholders to achieve client objectives. Terry's multi-disciplinary project teams address unique technical issues associated with mining, including permitting, design, construction and long-term monitoring of large-scale mine closure projects.

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Rehabilitation at closure of a Ag-Pb-Zn mine in Argentina

Old wind swept tailings at a long-standing Ag-Pb-Zn mine in Argentina

This case history is about an old mine in the province of Jujuy, Argentina, which has been producing silver, lead and zinc for 80 years. The mine site is in the arid Puna environment at 3,800 meters above sea level, in a beautiful landscape where tourism, sports and other cultural activities are practiced.

During operation, tailings were generated and deposited in seven tailings storage facilities (TSFs) which cover an area of about 5 km^2. TSF management has been poor; some of the storage ponds have been placed partially on top of older ones, and little care has been taken in protecting the surface of the tailings despite the strong winds that are common in the region. Not surprisingly, wind-blown tailings have spread over an area of 2.5 km^2. Topographic depression zones have been filled with sandy tailings. Dunes can be observed all around producing a legacy of environmental, and health and safety issues.

The current mine management team put forward a strategic plan to improve this situation. Under this plan the most recent TSF was lined; the three largest ponds were covered using a low-permeability liner overlain by organic soil for re-vegetation; and several consulting groups were retained to produce a program to upgrade the whole operation to international environmental standards.

SRK was commissioned to undertake a pre-feasibility study for the remediation of the area around the TSFs. The challenge was not only to eradicate or minimise health and safety risks, but to optimise the expenditure for environmental conservation and protection. SRK's recommendations included a revegetation program, the relocation of the windswept tailings,

IGNACIO EZAMA

Ignacio has solid knowledge in geomechanics and vast experience in developing geotechnical solutions in site-based and desktop applications. He has been involved in developing numerous major geotechnical structures (from scoping through to detailed design and construction), with practical experience in site selection, field investigation and geotechnical characterisation, design of embankments and other geotechnical structures, and hydraulic and seismic-related risk assessments. Ignacio has worked on projects involving a broad scope of tailings management covering a variety of commodities and climates, globally.

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CAMILO DE LOS HOYOS

Camilo, Senior Consultant Geochemistry/ Hydrogeology has 14 years of experience in water resource assessment, environmental geochemistry and lithium-potassium brine exploration in salars and igneous/metamorphic petrology. He has participated in water resource projects in Argentina and Venezuela. He has key experience in assessing acid rock drainage (ARD) and metal leaching (ARDML), as well as ARD treatment and mine waste remediation programs. Camilo's speciality in lithium-potassium brines includes comprehensive resource exploration programs, geological exploration and assessment of materials for brine processing and technical due diligence.

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and a prioritisation plan which allows for the progressive remediation of the site aligned with the allocated budget and management expectations. It is expected that the remediation program will significantly reduce the exposure of the mine to scrutiny by the environmental authorities and the risk of future non-compliance with regulators.

This is another example highlighting the importance of a closure-focused approach at all stages of a mine design and operation, and of the value of adopting progressive closure measures to reduce costs and impact to the environment.

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Modelling landform evolution

Landform evolution models (LEMs) are used to estimate potential surface water runoff and predict resulting erosion and deposition processes on a landform scale. When applied to mining landforms, predicting landform erosion can be useful to inform closure design and to predict post-closure performance. The use of LEMs to simulate the post-closure evolution of water-shedding mining landforms, such as waste rock dumps, is well-documented. However, tailings storage facilities (TSFs) are unique landforms in that they often have contributing upstream catchments, long and flat (tailings beach) slopes consisting of spatially variable material types, and can be closed systems (i.e. do not release water). These factors all need to be accounted for when using an LEM to simulate a TSF.

SRK took on landform evolution modelling to simulate the evolution of a valley-fill TSF over a 1,000-year post-closure period. The client's project was located in an arid region of Australia. The key objectives of the LEM included assessing whether water erosion of land surfaces could have the following effects:

- Compromise the water storage capacity of the closed TSF;
- Result in entrainment of tailings in water discharged to the environment; and
- Result in embankment failure or significant erosion or undercutting of the TSF spillway.

Landform evolution modelling was undertaken using the CAESAR-Lisflood (CL) model to simulate surface water runoff and to predict the resulting erosion and deposition from single storm events and from cumulative, long-term simulations.

The CL model combines a topographic evolution model (CAESAR) with a high-quality hydraulic model (Lisflood). Recent developments in CL modelling have significantly improved the run speed and computational efficiency of the model. This particular project took advantage of these advances, incorporating the use of digital elevation models with different spatial resolutions, sensitivity analyses of key model parameters, long-term simulations using 1,000 years of sub-daily rainfall data, and the assessment of alternative design options. The model considered a number of different scenarios including: tailings capping alternatives, a detailed embankment-only model, different project stages, and various climatic scenarios.

The results indicated that the water storage capacity of the TSF is expected to be progressively reduced due to the sediments that are eroded and deposited within the pond area; however, not to the extent that could result in water (and potentially entrained tailings) being discharged to the environment. The LEM was also used to identify areas where management options could be used to improve or mitigate long-term landform instability, and to develop recommendations for future works to calibrate and verify the model.

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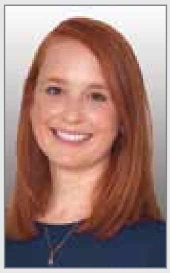
HEATHER THOMSON



Heather is a Chartered Professional Engineer who specialises in the design, construction, operation and closure of tailings storage facilities (TSFs). With almost a decade of experience, Heather understands that water is the key to a safe and stable TSF. She is experienced in modelling surface water and assessing soil-water interactions such as slope stability, dam breaches and erosion, allowing her to find solutions to challenging problems. Her recent projects include designing an integrated TSF and hydropower facility in Papua New Guinea, and a 1,000-year post-closure landform evolution model for a TSF in South Australia.

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Thickened tailings deposition for closure

NICHOLAS THOMPSON

Nick has over 8 years of experience specialising in tailings, waste rock management and heap leach facility engineering. He has experience across a diverse range of projects covering various commodities in both tropical and arid climates around the world. Nick is involved in a range of desktop designs and site-based roles, including geotechnical investigations, site selection, detailed design, construction, auditing and closure. He works on a broad scope of tailings management including thickened, dry stack, cyclone and co-disposal methods.

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JUAN (PEPE) MORENO

Pepe has over 25 years of diversified geotechnical/ geoenvironmental engineering experience throughout South America, Southern Africa and Australasia. He is a recognised expert in the design of tailings management systems, heap leach pads, waste rock disposal and earth retaining structures. Pepe's geotechnical background includes shallow and deep foundations, soil dynamic response and drainage. He typically provides expert review for tailings and waste management for due diligence and peer review projects for banks and potential investors.

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Typical operation of central thickened tailings discharge

With an ever-present need to control costs, the management and closure planning of tailings storage facilities (TSFs), already perceived by many as a heavy cost burden, are key areas targeted for savings.

Closing a TSF can be deemed successful if it is geotechnically stable, geochemically benign with a suitable cover in place, and the area fit for the agreed post-mining land use. The concept of 'deposition for closure' using thickened tailings and central discharge is becoming increasingly attractive due to budget pressures and more stringent closure requirements. Thickening and dewatering technology in general is continually being developed and improved, and there are key learnings from mine sites across the globe that adopted this strategy – advantages as well as challenges.

When closing a conventional slurry TSF, a major challenge is the long-term management of the central surface pond. The tailings typically take a long time to consolidate, and creating a suitable final closure landform shape can often require substantial earthworks and quantities of borrow fill material. Implementing modifications to introduce thickened tailings and a central deposition strategy at an existing TSF towards the end of operations can help create a final convex, water-shedding surface, which can be complemented with a suitable cover layer at the end of the life of the facility. This early change allows passive management of excess water as part of closure preparations by directing the controlled flow of runoff away from the TSF by way of a spilling point into natural drainage downstream.

The use of thickened tailings can result in a shorter delay between the end of operations and the start of cover placement, which means less time and cost expended in overall closure of the mine. In addition, the strategic placement of thickened tailings can increase the storage capacity in the TSF, which could potentially reduce further footprint impact.

Before implementing a change to thickened tailings deposition, the TSF requires a thorough evaluation to ensure that the facility can safely and economically transition to a central discharge system. The slurry's geotechnical, geochemical and rheological characteristics must be investigated, and geotechnical stability of the embankment slopes should be analysed to ensure they are not compromised by water ponding against them. Additionally, the impact of thickened tailings on the beach slope must be assessed, along with the liquefaction potential. The potential for differential settlement to occur between the existing conventional tailings and the new denser thickened tailings should be considered in the deposition plan.

A deposition for closure strategy applied to an existing project raises site-specific issues and challenges. These include considering the cost required for the necessary infrastructure – including thickeners, disposal pipelines and a causeway to the central deposition area. Adjusting the disposal methods to include central thickened tailings discharge may be more operationally intense, requiring specific training and guidance for operational staff.

While there are numerous potential advantages, including overall reductions in both cost and time expended in implementing a facility's closure, it is critical to have a thorough understanding of the potential trade-offs before implementing the new strategy.

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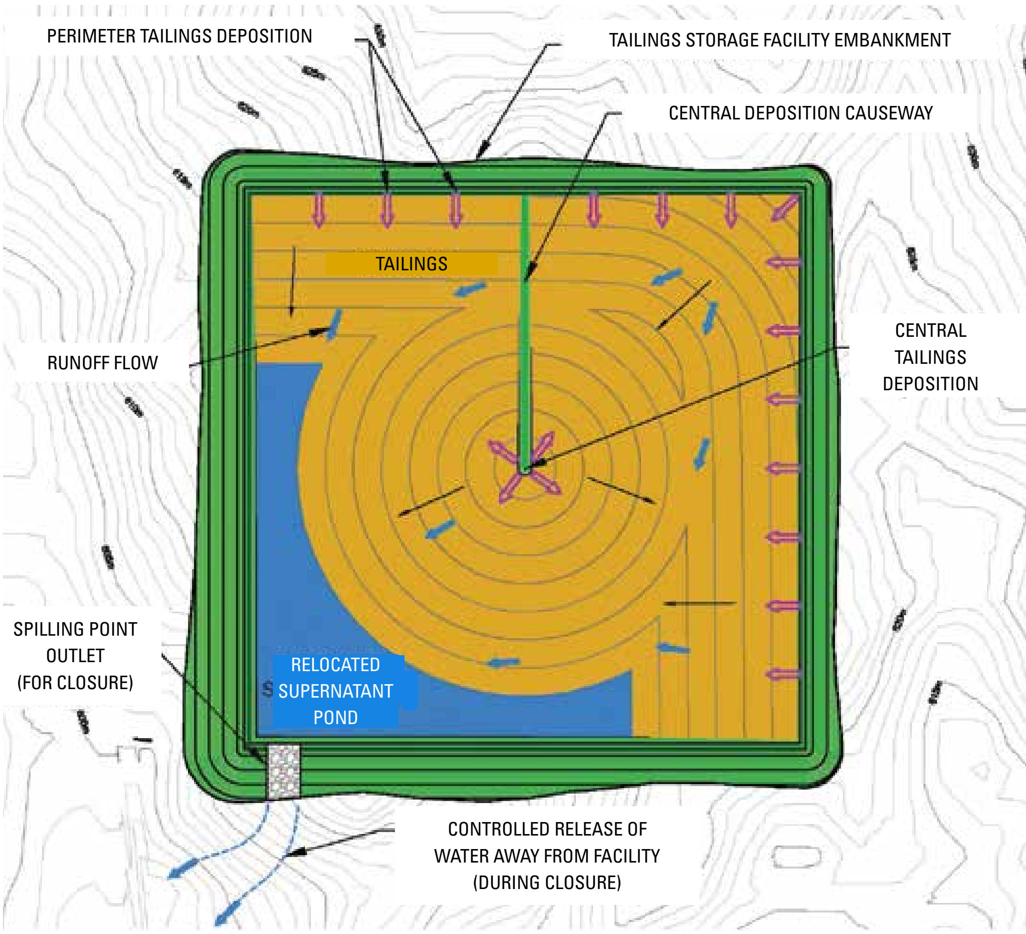
Schematic TSF with revised deposition strategy by which central and perimeter tailings discharge creates a water-shedding surface directing runoff towards a controlled spilling outlet



A variety of heap closure solutions at one mine site

SRK has assisted a client with closing four gold heap leach pads at the same mine through various phases of operation and ownership since 1998. The continued expansion of the pit and waste rock disposal areas (WRDAs) has necessitated closing or relocating the heap leach facilities. The different approaches to closure for each leach pad underscore the complexity of waste and water management requirements for successful mining: "there are no one-size-fits-all solutions in mine closure".

SRK prepared comprehensive closure plans for the mine site between 1999 and 2004. The original closure studies for the heap leach pads focused on rinsing and offloading spent oxide ore for use as cover material over WRDAs. However, the low permeability of the ore, coupled with onerous rinse water management requirements, pointed to closure in place as the most feasible alternative.

Updated closure plans were prepared and implemented as part of expanded mining in the open pit. Each heap was to be overdumped by WRDA expansions around the pit perimeter. Draindown was captured in gravel drains constructed around the perimeter of each leach pad, using existing geomembrane-lined perimeter channels. Heap sideslopes were graded over the drains to protect them during overdumping.

Heap leach liner installation

Collection drains were routed to a centrally-located sump and then to transfer tanks. All pipelines and tanks were buried to protect from freezing. As draindown flows were initially too high to manage by evaporation, collected draindown flows were pumped from one transfer tank to another and ultimately to the process circuit. Nearby process ponds were re-purposed as emergency overflow ponds.

After implementing these closure measures, the following modifications to the closure plans have been implemented:

Pad 1 – To accommodate the pit expansion, the mine relocated 2.8 million tons of spent ore from Pad 1 to a containment cell on top of a nearby WRDA. The ore was graded to drain infiltrating meteoric water away from the spent ore and a geomembrane liner was constructed over the spent ore. The containment cell is currently being overdumped with 50 to 150 feet of waste rock.

Pad 2 – The need to stabilise a pit wall called for relocating Pad 2 to prevent it from failing into the pit and releasing process solution to the environment. Pad 2 spent ore was placed in a vertical expansion over the Pad 4 liner.

Pad 3 – This is the only heap closed as originally planned by overdumping with waste rock. The constructed perimeter drain is operational, and an evaporation cell was constructed in 2018 to manage long-term draindown.

Pad 4 – To facilitate mining in the existing pit, about 13 million tons of tailings had to be removed. The tailings were mixed with waste rock and placed in a disposal cell formed by a waste rock containment berm constructed directly over the existing Pad 4 geomembrane liner. The Pad 4 liner captures the tailings draindown and routes it to the perimeter draindown collection system. Pad 4 and the disposal cell were incorporated into an expanded WRDA. Plans are currently being developed to manage draindown in a lined evaporation cell.

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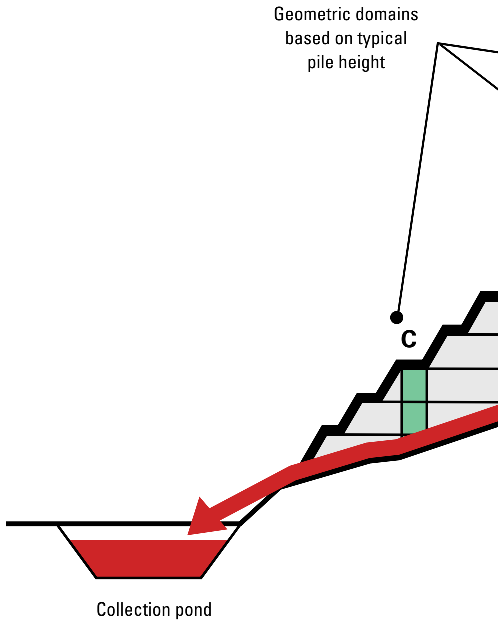
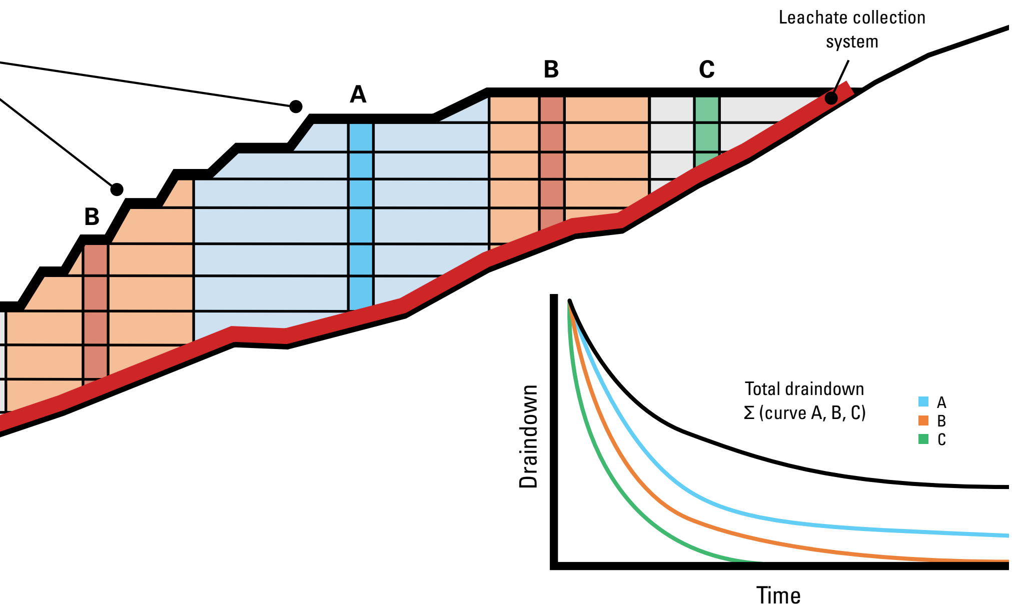


Vast inventories of leach solutions unsuitable for direct discharge to the environment are among the legacies of heap leach operations at closure. The final rinsing and subsequent draindown is a complex technical problem often involving significant cost to the operators. To compound the problem, leachate inventory at closure often exceeds the holding capacity of existing ponds.

The active management phase at closure typically consists of recirculating leach solution to a portion of the heap leach and/or water treatment and discharge, followed by longer-term passive management (without pumping) leveraging evapo-transpiration to continue reducing inventory. Managing the leach solutions represents a significant financial liability. The duration of active management should therefore be carefully planned both technically and financially. SRK has developed a method by which draindown rates and cumulative volumes can be predicted at a daily time scale, enabling the

Heap leach final draindown model



rapid development and comparison of options and scenarios, leading to improved planning.

SRK has modelled unsaturated flow through the pile, coupled with analytical modelling of leachate inventory, to predict the time required to achieve passive water management. First, the heap leach pile is discretised into geometric domains, grouping areas based on similar height and/or similar hydraulic properties. Next, the unit draindown rate is determined for each domain through a rigorous finite element numerical model based on the physical and hydraulic properties of the leach material. Finally, the unit draindown curves are applied to the representative footprint of each geometric domain and assembled into an analytical model to compute the expected volume of draindown from each domain.

An example of this modelling approach is provided at a project located in a high-altitude arid and cold environment, where the regulatory agencies imposed a zero-discharge condition on the heap leach facility at closure. Elimination of the excess inventory was achieved through evaporation by recirculating the leach solution to select areas of the pile, coupled with evaporation from the storage ponds. Draindown volumes were computed in a daily time step and compared to the remaining inventory.

This approach solved one major challenge of draindown complexity, where portions of the pile are in distinctly different stages of draindown according to when they were last irrigated. Recirculation to some areas and not others also had a significant effect on the time required to reduce flow rates to an acceptable level.

Once the inventory was sufficiently reduced and the draindown rates diminished below the evaporation rate from the storage ponds, the pumps were turned off. SRK's model was used to determine the likely duration of active management and at what point the system could move to long-term passive management. Several alternatives were assessed, providing crucial data for the cost-benefit analysis of the available options.

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IOZSEF MISKOLCZI

Iozsef, MASc, PEng is a Mining Engineer with 12 years of experience in the mining industry with a focus on numerical modelling of unsaturated flow in mine waste and soil cover systems. His project work spans all climates from wet tropical to arctic, including alpine periglacial environments. Iozsef completed numerous soil-atmosphere flux boundary models for tailings, waste rock, and heap leach covers, using state-of-the-art modelling software. He also completed heap leach facility closure draindown modelling, including analytical models to predict post-closure active water management requirements and time of transition to passive water management.

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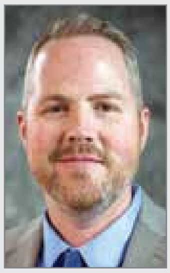

Breese is a Principal Engineer and Practice Leader in SRK's Nevada GeoEnvironmental group, with a BSc in Geology and an MSc in Geological Engineering. He has more than 24 years of experience in engineering design and environmental permitting services for the mining and solid waste industries, including facilities for mine water management, tailings disposal, heap leaching, waste rock disposal, and solid waste disposal. Breese has also completed site characterisation, conceptual and detailed design, construction supervision and management, and operational assessments at numerous industrial, mining, and landfill properties throughout the western United States and South and Central America.

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Land use versus land capability

Legislative requirements in many jurisdictions require that the mine closure plan include a detailed plan of the post closure land uses. In essence, this plan is required to indicate how each rehabilitated footprint can potentially be used in the post closure environment. SRK has observed that in most jurisdictions in which we practice, legislation not only requires this detailed land use plan, but also requires that the post closure land use is sustainable, with community use as the basis of the sustainability requirement.

This requires the closure proponent to assess past practices, current community and other stakeholder requirements and then, within the constraints and opportunities presented by the socio- economic and environmental systems in the region, identify possible future land uses. The achievement of these uses then becomes the target against which remediation and rehabilitation activities are conducted and the ultimate closure objectives achieved.

However, SRK's experience in closure planning in Africa and other developing nations has illustrated that this approach may not be the most appropriate. The primary reason is that the mines have little or no control over post closure use once the operation has returned a rehabilitated footprint to the owner, with control of the land vested in the owner or possibly community structure. Therefore, if the owner wants to utilise a rehabilitated footprint for a purpose outside the post closure land use plan, the mines have no influence over changing that. If the land cannot support the owner's purpose, mining companies could suffer reputational damage.

Furthermore, we have observed that land use of a specific rehabilitated footprint is dynamic: post closure use can undergo a number of changes as community requirements evolve. In addition, many of the mines for which we consult show the land ownership or land use is complex, with multiple stakeholders owning small blocks within the footprint. If post closure land use wants are not aligned, trying to prepare a post closure land use plan based on the multiple owner requirements results in a mosaic of land uses that are not necessarily complementary and very difficult for the mine to implement.

SRK's approach to mitigating mines' risks from little to no control over post closure use, and evolving land uses is to recommend an approach of restoring land capability rather than land use. We now develop relinquishment criteria specific to restoring land capability. By planning to implement specific land capabilities on footprints, we can allow the post closure users to choose how to use the land, within the constraints imposed by the environment. This involves determining likely potential post closure land uses and determining how to provide footprints that support these evolving land uses.

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JAMES LAKE

James is a Principal Scientist with 20 years of experience. Trained as a Geochemist, he developed broad experience in general environmental management working on a colliery in South Africa and on various consulting projects. Over the last 10 years, James specialised in preparing closure liability assessments in many jurisdictions for numerous minerals. He also contributes to Environmental and Social Impact Assessments, often within the Equator Principles II framework.

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Water erosion

Post-closure site management at mine sites typically includes measuring surface reclamation success, monitoring surface water and groundwater quality, and maintaining active or passive water management systems. The effects of water erosion on engineered cover materials for regraded slopes and surfaces often pose a long-term and costly maintenance challenge for the owner. If the owner had known about the negative (i.e., underestimated) financial impact of this long-term maintenance before finalising the closure design, the trade-off between initial capital and long-term maintenance costs might have changed the original design.

While reclamation and revegetation practices are firmly established and widely adopted throughout the mining industry, the ability to improve predictions of long-term erosional

Predicting erosion impacts to closed mine waste facilities

stability of closed mine waste facilities is an emerging and interesting field. Born in the agricultural sciences and adapted to land management practices, erosion modelling methods range from simplified empirical relationships to multi-variable finite element models. Empirical methods offer meaningful comparisons of average annual erosion estimates between different cover designs and slope angles; however, empirical models lack the accuracy needed to estimate long-term maintenance costs and extreme (high or low) precipitation events. The emergence of Landscape Evolution Models offers the promise of increasing robust predictions of erosion impacts and associated costs over timescales of decades or longer.

As always, models are only as good as the data available and the judgment of the practitioner. More sophisticated models incorporate new variables that characterise the rainfall model and the physical properties of the soil. The industry is moving toward new analytical methods in terms of precipitation models, field testing and interpreting the erosion impacts to the undisturbed surrounding landscape. SRK continues to develop useful analytical tools to simulate precipitation dynamics over designated design periods. SRK also collaborates with researchers and specialists focused on new ways to measure key parameters for the predictive models.

SRK teamed with a specialist soil erosion firm to co-develop an erosion assessment work plan for a closed mine site in the southwestern U.S. The plan included field-scale testing of erosion resistant soil/rock covers constructed from locally-available materials. The team applied innovative on-site rainfall simulation techniques to estimate the rainfall-runoff and sediment-yield parameters for each cover system. The results of the testing program informed a screening analysis of the different erosion covers.

The team then developed a range of 3D surfaces of different slope profiles for an existing tailings embankment. The range of 3D surfaces included simple linear profiles, compound slopes and natural analogs. The team combined the short-list of erosion covers with the different 3D surfaces and analysed the long-term erosional performance of the integrated cover system. This process provided the client with a robust technical basis for decision-making.

The SRK global library of mine closure projects offers valuable experience in assessing erosion impacts for our clients involved in planning mine closures.

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(Bio on page 9)

Is your pit lake a post-closure liability?

Orange is not the new green

MARK WILLOW

Mark is a Certified Environmental Manager in Nevada, and a Registered Member of SME, with 25 years of environmental project experience. As an SRK Practice Leader he oversees work scope implementation and provides senior technical review for various environmental studies. Mark draws upon his diverse background as a human health and ecological risk assessor to monitor potential environmental impacts of mining operations, especially post-closure pit lakes. He provides environmental due diligence for mining projects throughout the world, and is a Qualified Person under National Instrument 43-101 Standards.

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MATTHEW LAW

Matthew, is a Senior Environmental Management Consultant and Economist with more than 11 years of experience. He specialises in Environmental Impact Assessment (throughout Southern Africa), Economic Impact Assessment and strategic environmental management planning. Matthew has detailed knowledge of, and practical experience with legislation governing applications relating to environmental authorisations, mining rights applications and waste management and water use licensing.

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Except in some extremely arid environments or at higher elevations, open pit mining tends to result in the development of semi-permanent or permanent water bodies post closure, when dewatering has ceased and pre-mining water tables have recovered. Historically, little attention has been given to the development and quality of post-closure pit lakes, many of which are dotted around the landscape in mining districts.

More recently, however, regulatory interest has been focused not only on some of these existing pit lakes, but on the predicted occurrence of post-closure open pit mine lakes that are in the environmental impact phase of project permitting.

Through baseline groundwater monitoring coupled with numerical flow modelling, the hydrogeologist attempts to predict the extent of the pit lake, while the geochemist attempts to predict the chemistry of the water through the post-closure decades. But what does it all really mean? Will that pit lake end up being a long-term liability to the mining company, and how does one assess those risks?

Aside from examining the potential impacts that a pit lake may have on local groundwater resources (flow-through or not flow-through), one generally needs to assess whether the pit water will have a toxicological effect on human health, as well as terrestrial and/or volant wildlife. This is more frequently accomplished using an Ecological Risk Assessment.

The U.S. Environmental Protection Agency recognises several methods for estimating risk in their Guidelines for Ecological Risk Assessment, including: toxicity test results, assessments of existing impacts at a site, or risk calculations comparing exposures estimated for the site with toxicity values from literature. The last approach, more commonly known as the Hazard Quotient Method, calculates toxicity reference values (TRVs) using the body weights, water ingestion rates, and published toxicological data for specific ecological species. A conservative assessment will utilise No-Observed-Adverse-Effect-Level (NOAEL) studies from the toxicological literature, which represent the level of exposure which does not cause observable harm or effects. In some cases, however, a risk manager may defer to Lowest-

Observed-Adverse-Effect-Level (LOAEL) data when studies are limited or inconclusive, or when the NOAEL is deemed overly conservative. LOAELs represent the lowest dose in a toxicity study resulting in adverse health effects, and, when used, can provide a more reasonable TRV calculation.

By dividing measured or predicted water quality constituent concentrations (known as exposure point concentrations) by this TRV, Hazard Quotient ratios are calculated. When a ratio is less than 1.0, there is reasonable certainty that the chemical constituent is not likely to harm the ecological receptor; when the ratio equals 1.0, the chemical constituent alone is not likely to cause ecological harm, but could have an additive effect if other constituents are also somewhat elevated; and when the ratio is greater than 1.0, the potential for adverse effects cannot be ruled out. In the end, it is the risk managers who interpret the validity, veracity, and appropriateness of these calculations when assessing the potential liability associated with the post-closure pit lake.

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Rehabilitation metrics and value of knowing what can be achieved

Along with other countries, holders of mining and prospecting rights in South Africa must provide financial guarantees for rehabilitation. Rehabilitation is achieved when closure commitments are met, confirmed by a Closure Certificate issued by the Department of Mineral Resources.

Although South Africa's legislation compares favourably to other countries, there are few examples of successful mine closure. More than 6,000 mines have been abandoned without adequate rehabilitation. Too often, both mine owners and regulators overlook the importance of realistic closure targets, with owners making impracticable commitments, which cannot be implemented or are ignored.

In the past, failure to comply posed a limited risk. However, mine closure will soon be regulated under the National Environmental Management Act (NEMA). It will require plans for ongoing rehabilitation, closure and managing environmental impacts. Financial provision will need to be independently audited and subjected to stakeholder engagement. New regulations will impose strict penalties, including possible imprisonment, and stakeholders are becoming increasingly vocal about inadequate closure. It is therefore essential for mining operations to understand what level of rehabilitation can be achieved and the residual environmental impacts anticipated, what measures are needed annually and at closure and what they cost, and what metrics are needed to assess rehabilitation to facilitate reporting and management.

SRK recently agreed to ascertain rehabilitation performance at a large open-cast mine on South Africa's west coast, and what rehabilitation can be achieved using current methods. The owners also required a robust system to monitor and measure progress without specialist supervision. Previous owners of the mine had committed to return the site to baseline grazing potential, which owners and regulator believed was achievable, despite intensive rehabilitation that failed to deliver.

SRK sub-contracted a restoration ecologist to sample proximate sites as a pre-mining baseline. A customised grazing index was developed, and the grazing value of these sites was calculated using the index. The results provided the first quantitative measure of baseline grazing value, a metric to assess rehabilitation performance – a significant step in closure planning. Subsequently, the grazing value of areas under rehabilitation was calculated using this index. The assessment revealed that although significant vegetation cover had been achieved, progress in returning the site to agricultural potential was slow, indicating that at the historical trajectory of rehabilitation, residual liabilities would be high, and that additional or alternative interventions were required during the remaining life of the mine. The use of the grazing metric will help the owner plan enhanced rehabilitation techniques, accurately assess and report on rehabilitation, consider adaptive management of rehabilitated areas, and update plans to accurately reflect costs. This will significantly reduce the owner's risks at closure, in the face of more stringent closure regulations and penalties, and increased oversight in the sector.

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Concurrent rehabilitation in an arid environment

Presenting closure plans to communities

The typical mine closure plan is a lengthy report designed to meet all the requirements of owners and regulators, not to mention SRK's numerous technical specialists. Is it any wonder that the average person has trouble forming a clear picture of the plan's final results?

For over ten years, SRK's Vancouver staff have been working with clients to more fully engage community groups, and other stakeholders in mine closure planning. Bridging the gap between the detail required by good technical practice and the clarity needed for effective dialogue is one of the key challenges. We won't claim to have it all figured out yet, but we have developed one tool that seems to be helpful.

CONTRIBUTORS

Lucas Hockley is a recent graduate with a long-term interest in computer graphics; very long term if you include growing up in the video game generation. He has been applying his skills on SRK projects for three years now, and has completed 3DS-Max models for two of Canada's largest mine closure projects, as well as one of the largest tailings management projects in the world. But it takes a team to raise a 3D model and the team in this case includes the sharp pencil of Aaron Fultz, SRK Vancouver's technical communications specialist, the sharp eyes of Terri Hopkinson from the marketing department, the sharp ACAD and MineSight skills of Dan Tarasoff, and the sharp tongue of those picky project managers who insist that the trees should be just a bit greener -- and a little to the left please.

The renderings below are produced using a program called 3DS-Max, formerly known as 3D-Studio. The 3D-Studio series is one of the premier animation platforms in use today for movies (Avatar, anybody?), video games, and other virtual modelling. SRK Vancouver staff has developed a workflow that allows the engineering drawings typically found in closure plans to be transformed into 3D-Studio models, and then rendered to produce individual pictures and even short videos of closed and reclaimed mine areas.

The workflow is the key. Really anyone could do this, given enough time. But doing it with an efficient workflow makes it possible to see what the site will look like under many closure options, and that helps to truly engage community groups in the closure planning process.

The graphics shown here were used in a multi-day closure planning meeting with over 90 community participants. They helped to show people exactly what each option would leave behind for their children and grandchildren. Interestingly, even the veteran engineers and scientists in the room took great interest in these graphics. Maybe the innate 3D visualisation skills that we mining and geology types like to boast about are not quite as effective as we think? Or maybe it's just that a picture really is worth a thousand … engineering drawings!

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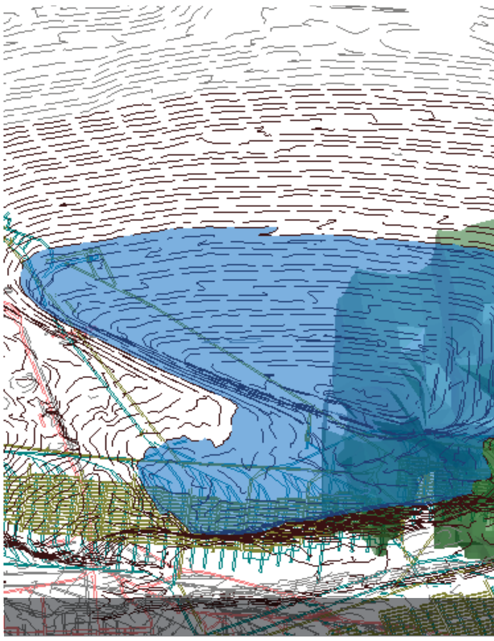
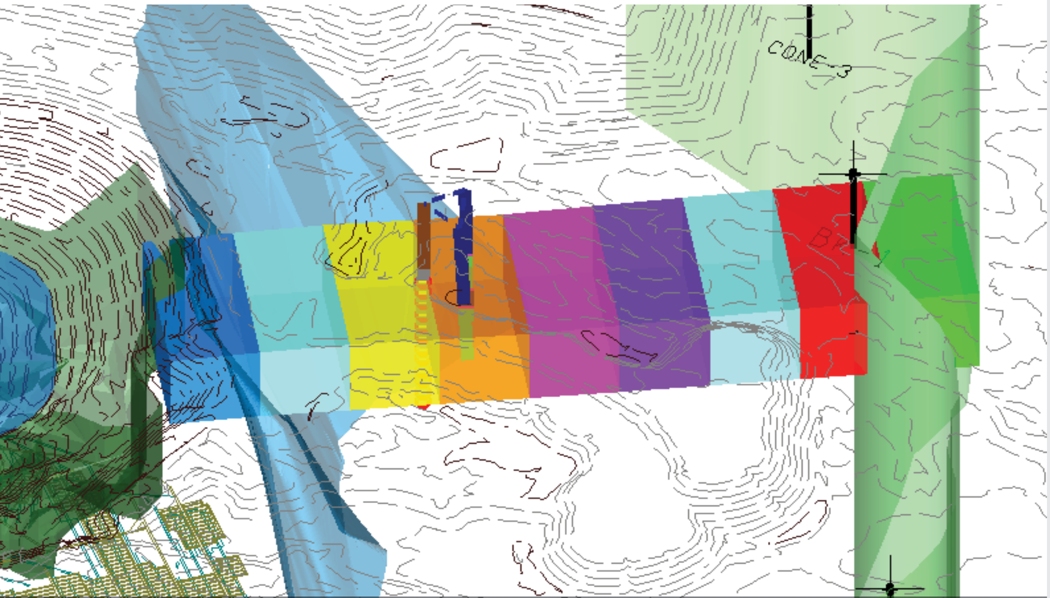
Two examples of post-closure minesite models



Geochemical modelling may not immediately come to mind when scoping a work plan to develop a mine closure strategy. However, geochemical modelling is often essential in forecasting the long-term impacts of mining facilities, results from which can be applied to selecting closure strategies consistent with regulatory requirements. Closure planning for decommissioned tailings, waste rock, pit lakes, and underground mines can all benefit from predictive geochemical modelling calculations, combined with laboratory or field scale testing.

While laboratory and field tests provide crucial data on the leaching characteristics of mining wastes and pit wallrocks, integrating time varying hydrologic fluxes and other scalable parameters work best with an integrated predictive calculation approach. For example, field plots and barrel tests of waste rock are very useful in providing field scale leachate

Geochemical modelling to support mine closure planning



Conceptualisation of reaction transport model flowpath from pit lake to compliance wells

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David, PG, RM-SME, is a Principal Geochemist with 32 years of professional experience in surface and underground mining hydrogeochemistry, exploration geology-geochemistry, feasibility-due diligence studies, and regulatory compliance. His expertise includes design, execution, and interpreting mine waste geochemical characteristics, water quality sampling and monitoring, assessing mine drainage impacts, regulatory compliance, permitting, and bonding. David uses various software in geochemical modelling, predicting pit lake water quality, modelling reaction transport of groundwater solutes, tailings and leach pad drain-down chemistry, assessing waste rock leachates, and tracking contaminant sources.

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data, but typically offer only an abbreviated time fraction for generating weathering data for long-term environmental impact assessments. The same is true for laboratory testing.

Reliance on quantitative predictions of post-closure pit lake water quality has gained prominence in recent years, not only in the developed world but globally, as operators and regulators appreciate their importance for environmental impact forecasts. They are often required for closure plan approval, to forecast likely changes in future water quality.

This exercise cannot reasonably be expected to produce a valid forecast without using a detailed geochemical model that includes water balance (ground inflow and outflow, precipitation, evaporation, surface water runoff/runon), spatial and temporal geochemical characterisation of solids, secondary mineral precipitation and redissolution, and such limnological processes as mixing and stratification.

SRK recently completed a comprehensive program of geochemical modelling concerning closure alternatives for the pit lake, tailings, and waste rock in a feasibility study for an open pit gold mine in South America. To predict waste rock leachate quality, SRK combined short-term leach test data and accelerated kinetic test data with a detailed waste rock extraction schedule from the mine plan. The spatial variation of the acid generating characteristics of the waste rock combined with the high tropical rainfall posed challenges for managing predicted acidic waste rock runoff. The first material excavated was non-acid generating saprolite overburden, followed by the ore host, an acid generating intrusive rock. The leachate characteristics of this untimely sequence of waste rock was predicted in a geochemical model that provided the impact assessment needed to formulate the closure plan to minimise the handling of acidic runoff.

SRK incorporated detailed geochemical and mineralogical characterisation of pit wall rocks into a pit lake geochemical model that combined a water balance from groundwater flow and Goldsim models to predict post closure pit lake water quality. This forecast provided the information necessary for closure planners to select an appropriate pit closure strategy. Among other options, the pit lake water prediction indicated that available fresh water was adequate to neutralise acid production, so that natural infilling was identified as the optimal approach.

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Major funding available in China's mine closure market

An example of urgent issues - a waste dump adjacent to farm land in Southern China

SRK China focuses on mine closure business development in China, and visited potential business partners and clients, together with SRK South Africa and SRK North America. Two types of funding for mine closure in China have been identified:

- Type 1: funding from the central government with taxpayers' money; and
- Type 2: funding from project finance through Public Private Partnerships (PPP), mainly from banks, debts markets, or other financial markets.

Type 1 funding: According to the Contaminated Soil Remediation Action Plan (also known as China's Soil Ten) prepared by the State Council in May 2016, one of the key targets is to curb worsening soil pollution and is considered a milestone by the environmental industry in China. The equivalent of USD 50 billion in taxpayers' money has been budgeted in soil remediation annually. In the first few years, the majority of the funding will be allocated to the regions adversely contaminated by heavy metals from the mining industry or other industries, including pollutants leaching from waste rock dumps and tailings storage facilities. The money must be used to solve urgent pollution issues with reliable and cost-effective technologies. For most projects funded by this type of funding, SRK, as the consultant, needs to identify local construction firms and build a team to tackle these pollution issues through a design-bid-build process. Based on visits SRK made to various clients in recent months, it is understood that SRK's international mine closure experience is highly valued in China.

Type 2 funding: Normally the contract period lasts about 30 years. Since the funds are more focused on investment, the location of the mine site, the future land use and the growth of the post-closure land value are considered critical. Each PPP project carries various risks, such as plans for changes in zoning or replacing key local government

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officers. The reputation and skills of the environmental consultants are essential for the mine closure and post-closure development. SRK will join forces with financial institutions, local governments, and construction companies, contributing our capability in mine closure design and land development services. However, sometimes a consultant may be required to share the financial risk associated with PPP by establishing a joint venture, a vital concept to be carefully evaluated.

One good piece of news surfaced recently for all international consulting firms. A company licence is no longer required to prepare an EIA or a feasibility study report, which was a major marketing hurdle in China. SRK China will continue to market its worldwide mine closure experience in China and differentiate itself from others based on technical excellence and cost effectiveness.

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Mine closure regulations in Chile

Assessing mine closure in Chile is a process that began partially in 1994 with the Law 19.300, Law of Environmental Bases, which requires an environmental assessment of the closure phase of all projects, establishing conceptual measures focused on prevention, mitigation and/or compensation of the environmental impacts produced in the closure phase.

The Mining Safety Regulation included a mandatory closure plan in 2004 presenting measures related to the physical stability and safety of the facilities. Three years later, a specific regulation was published for tailings deposits introducing obligations for its closure measures.

Law 20.551 came into force in 2012 regulating mine closure and mining facilities, which increased the requirements for mine closure, establishing that all mining sites should have an approved closure plan prior to the commencement of operations. This closure plan should contain each mine´s features with a risk evaluation and environmental commitments of the closure phase as central themes.

Some of the objectives of this law are to ensure the physical and chemical stability of the remaining facilities, establish a financial bond to the state and create a post closure fund for monitoring closed mines.

Methodological guides for closure plans have been developed by SERNAGEOMIN, the relevant authority. These are focused on the development and presentation of closure plans including the minimum contents required and technical criteria.

This new regulation has mobilised the mining industry towards including closure aspects in the mining plan with the following relevant topics: legal actions, design criteria and operational and financial considerations. However, one aspect that has not been considered in the current regulation is related to social implications associated with mine closure where a number of stakeholders are involved, such as direct and indirect employees as well as the communities impacted by the mining project. Currently, this is an issue that each mine may or may not approach according to its internal policies defined by their strategic guidelines.

In 2012, SRK Chile established geochemistry and mine closure services providing technical and strategic support throughout the whole life cycle of the mining projects to address the new regulatory environment. Currently, highly-experienced and knowledgeable professionals enable the company to be positioned as a point of reference nationwide in this field, engaging the most important mining companies of the country within SRK´s portfolio.

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MARCELA CUROTTO

Marcela is a Civil Chemical Engineer with 20 years of experience in environmental issues for the large-scale mining industry in Chile and abroad. She has served as project manager and specialist engineer in closure plans, estimating closure costs, conducting environmental audits, due diligence, environmental and geochemical studies. Marcela has carried out consulting projects, proposing environmental solutions as well as identifying geochemistry characteristics of dump materials, tailings, water quality and waste management for closure cost estimation.

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Mine closure practice in Turkey

Mine closure and reclamation issues are among the more recent regulatory developments in the Turkish mining industry. Historically, these issues were not regulated adequately. Some rudimentary clauses existed in the mining and forestry codes without much practical implementation. In the late 1990's when the Environmental Impact Assessment (EIA) regulation arrived, some attention was given to closing and reclaiming mining lands, but the subject's treatment was superficial. Handling of the mine closure issues improved in the EIA studies, but the approaches were not standardised and without any specific regulations, they gave rise to inadequate practices.

The first regulation on the subject, "Reclamation of the Lands Disturbed by Mining Activities" was released on 14 December 2007 and revised in 2010, but it did not meet the needs of mine closure and reclamation and was far less effective than its contemporary regulations in other jurisdictions. There were no technical studies (e.g. acid rock drainage/metal leaching assessment etc.) to back up the plans, nor any cost estimates or financial guarantee mechanisms spelled out. With this regulation, the mining companies were required to submit a conceptual closure plan with EIA permitting studies for new or expanding projects.

However, land use and ownership types presented complications. Currently, this regulation only applies to treasury and private lands, not to forestry and agricultural lands. Forestry lands require a separate reclamation plan and agricultural lands require a separate soil protection plan. This issue becomes somewhat problematic for mining projects on different land-use types, especially those with large mining structures partially on different land uses. It makes it difficult to adopt a unified closure and reclamation approach.

In 2015 a new regulation, "Mine Waste Management Regulation," was adopted from the European Union Directives. The regulation aims at managing mine wastes only (waste rock, tailings, depleted heap pads etc.) from operation to post-closure to prevent any damage to people and the environment. The regulation requires preparing a waste management plan to classify waste facilities, based on properly assessing waste geochemical characteristics, and risks. The original EU directive calls for arranging financial mechanisms to fund closure and reclamation activities, as well as remedying potential environmental problems. However, the financial aspects of this directive have not yet made it into the Turkish regulations. The Mine Waste Management Regulation came into force in July 2017 after two years of delay. This new regulation will require improvement in the coming years; it does not address closing and reclaiming the entire mining operations. Consequently, Turkey still lacks a unified approach to mine closure and reclamation issues.

Considering the deficiencies in the Turkish mine closure regulations, SRK provides a unified international approach to mine closure in Turkey to eliminate various risks to the mining industry. Individual closure plans meeting the specific needs of the Turkish regulators are prepared, complemented with a more comprehensive Mine Closure and Reclamation Plan covering both the Turkish and international requirements and best practices.

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Consolidated and capped residue dump

South Africa has a long history of mining extending beyond 100 years. Over time, many mines had not implemented closure plans once resources were depleted. This has resulted in between 5,000 – 6,000 ownerless and derelict mines across the country, which are now the responsibility of the South African government. These mines include almost every mineral commodity that has ever been exploited in South Africa.

As many of these operations often represent a significant health, safety and environmental risk, authorities have instituted a program to address the risks at these operations by implementing rehabilitation activities to effect closure. Given the health risks, such as asbestosis, mesothelioma, lung cancer and pleural plaques of communities exposed to asbestos fibres, the authority has initially focused its attention on rehabilitating asbestos mines.

Rehabilitating a legacy

In the last quarter of 2013, SRK was appointed to provide engineering and design services for the rehabilitation and ultimately the closure of several abandoned and derelict mines throughout South Africa. In undertaking the activities, SRK deployed a multidisciplinary team to assist with identifying site specific risks for which remedial measures are required.

Mitigation of risks was then utilised as the basis of the conceptual design and ultimately the final design for the remedial measures. A phased approach was adopted where various possible conceptual closure designs were considered and then assessed against practicality, cost, and ability to mitigate risk and achieve the desired closure objective. Closure measures included limiting mobilisation of loose fibres present over the surfaces where mining and processing activities took place, as well as limiting mobilisation of fibres in the rock matrix in which asbestos was contained, which are now stored in various residue disposal facilities.

The closure activities also included sealing the means of ingress and egress from the workings. The majority of these ownerless and derelict mines are located in steep terrain, where protection from erosion and other water related damage had to be incorporated into the closure design. The integration of the disciplines, which included geotechnical and civil engineers, hydrologists, geologists and scientists, is undertaken within the context of our internationally recognised experience in all aspects of mining and waste management.

In total, SRK has overseen design-to-construction monitoring phases of 13 derelict operations since 2013. Since mine closures are becoming more of a reality worldwide due to operations depleting mineral resources, SRK believes that the integrated approach focusing on risk mitigation created for this project, is adaptable for rehabilitation on many other mines.

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RAYMOND MAYNE

Ray is a Principal Environmental Scientist with 11 years of experience. He has been involved in environmental and project management and has assisted clients in South Africa and internationally with developing closure liability assessments and mine closure plans. More recently, Ray's interest in mine closure has resulted in his taking a role in strategy, integration and project management on a large mine closure rehabilitation project. This role entails facilitating closure strategies and designs, and implementing rehabilitation measures. In doing so, Ray manages a large team, including client representatives, SRK staff and various sub consultants.

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Bora is a Practice Leader in the Ankara, Turkey office. He has over 20 years of experience as an Environmental Engineer dealing with various aspects of environmental issues. His specific expertise covers environmental impact assessments, mine closure and reclamation studies, and air quality and noise assessments. Bora has experience in the mining, energy, and oil sectors through projects in Turkey, the US, Central Asia, South and Central America, Africa and Europe.

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Ghana closure studies

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Carl, MSc, BEng, CEng, MCIWEM, CWEM, is a Senior Environmental Engineer and Cyanide Code Technical Expert Auditor (Mining) with over 15 years of experience. His background in environmental management includes working in Ghana and Europe within the mining industry. Carl specialises in applying environmental and process engineering to a wide range of problems, including: active and passive mine water treatment; mine closure and SRCE costing; ESIAs; project management; mineral processing; and characterising mine wastes to assess ARDML.

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Ghana's world-class gold mining industry is well established. Numerous in-country mine-related regulations and requirements are enforced; however, post-closure requirements are less well regulated and generally only meet the minimum standards required by financiers of the mining operation. Currently, the Ghanaian government is reviewing mine closure standards in collaboration with mining companies, the Ghana Environmental Protection Agency, Minerals Commission, and the Chamber of Mines.

SRK recently updated the closure plans for two gold mines in Ghana and implemented a truly global multi-business practice approach with an experienced team from the UK, South Africa, Australia, North America and Ghana.

Clearly, an update was required for the mine-wide water balances; this information is imperative for developing post-closure land use design. It includes detailed hydrological, hydrogeological, and geochemical studies to meet the volumetric and chemical criteria for sustainable post-closure land use.

Extensive stakeholder engagement was conducted to develop the correct mine closure plans. Stakeholders included locally affected communities, regulators, NGOs and neighbouring mining operations. Using closure strategies, post-closure land uses and objectives, the plans provided the best

But the operation's corporate and site personnel suggested a first principles approach. The global SRK team's first task involved developing a first principles approach for both operations; significant synergies were achieved (particularly with respect to unit rate and demolition costs) by completing the two projects at the same time. A first principles approach gave the operation's corporate team confidence in the cost estimates produced for each operation.

The first principles approach and subsequent cost development within the Standardised Reclamation Cost Estimator (SRCE) model enabled the operations to comply with corporate policies and provided robust, defendable cost estimates that could be updated accurately. Several countrywide initiatives are being explored to establish a more standardised approach to mine closure costing.

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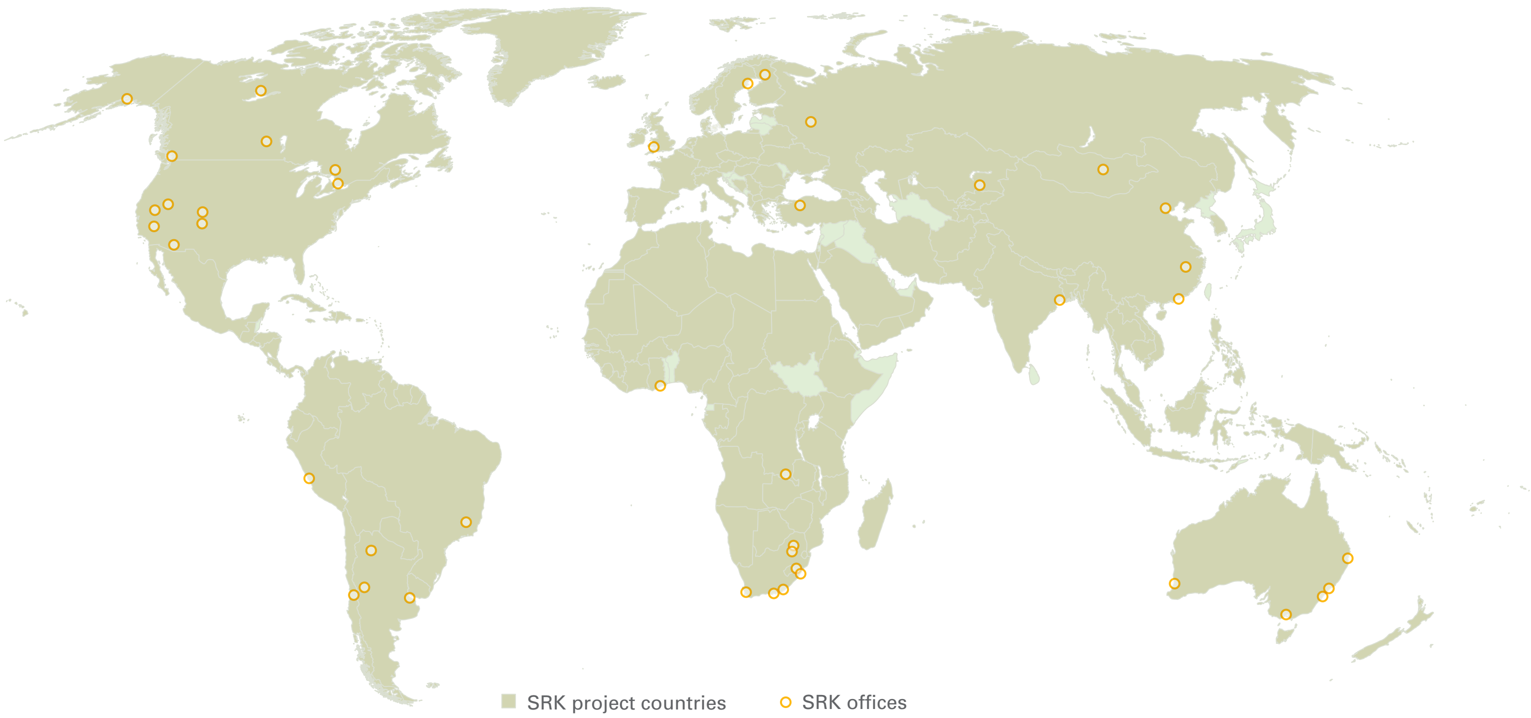
practicable solution for the local stakeholders. This is particularly important in West Africa where entire communities depend on mining operations. When several mining operations close at the same time, they can have a significant impact on the local communities. Significant economic and social impacts can result if mine closure planning and alternative livelihood strategies are not carefully aligned.

Previous mine closure cost estimates at the operations relied on a unit rate approach. Its calculation uses an area of a facility that requires rehabilitation, without taking into account specific slope angles and topsoil requirements.



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