srk news
Innovation Focus

Impact of innovation in the mining industry

No. 68
SRK Consulting's
International
Newsletter

HiveMap: mixed reality technology to collect and visualize data in real-time

Innovation drives progress across many industries, including mining. As global demand for minerals increases due to population growth, urbanization, and industrialization, the sector is presented with exciting opportunities to develop innovative solutions that enhance operational efficiency and promote environmental sustainability. Over the past 50 years in the mining industry, our team's ongoing efforts are dedicated to advancing performance in Mining 4.0 and beyond through innovations in critical areas.

Operational efficiency is one of the key areas where innovation is making a significant impact. Automation, artificial intelligence (AI), and machine learning are revolutionizing mining operations, enabling real-time improvements to high-productivity processes. AI-driven predictive maintenance reduces equipment downtime, optimizing performance and ensuring economic viability in a competitive market.

Safety remains paramount in the mining industry, with technological advancements enhancing worker protection. Wearable devices with real-time condition monitoring and utilization of remote-controlled or autonomous equipment are reducing risks in hazardous environments, creating safer workplaces.

...continued

Impact of innovation in the mining industry *(continued)*

Environmental sustainability is also benefiting from innovation. As regulations tighten, the industry is adopting more sustainable practices such as bioleaching and advanced waste management to minimize environmental impact. These innovations are helping to align mining activities with global sustainability goals, ensuring that the industry can continue to operate responsibly while meeting stringent environmental standards.

Innovation plays a crucial role in bolstering the economic viability of mining projects. By optimizing operational processes and enhancing resource efficiency, mining companies can lower costs and increase profit margins. Additionally, the adoption of novel financing models and strategic partnerships can attract investment, thus advancing new projects and ensuring long-term sustainability of the mining industry.

SEAN KAUTZMAN

Sean is a principal consultant (mining engineer) with SRK's Sudbury office. Over the course of 24 years within the mining industry, he has amassed experience in engineering, operations and project management. Prior to joining SRK in 2018, he worked for multiple mining companies in the US and Canada. His specialties include underground mine design, design and execution of operational improvement projects, incorporation of new technology, systems and processes as part of the Mining 4.0 transition, and due-diligence studies.

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The mining industry profoundly affects local communities, and innovation offers effective solutions to social challenges. Advanced community engagement platforms can improve dialogue between mining companies and local stakeholders, ensuring that community concerns are heard and addressed. Moreover, innovations in education and training can equip local residents with the skills necessary for meaningful participation in the mining workforce, fostering economic development and social inclusion.

As global regulations become more stringent, innovation is crucial for maintaining compliance. Cutting-edge monitoring and reporting technologies enable mining companies to meet environmental and safety standards effectively. Additionally, advancements in reclamation and rehabilitation techniques play a vital role in restoring mined land to its natural state, thereby fulfilling regulatory requirements and securing social license to operate.

As the mining industry continues to navigate a complex landscape of efficiency, safety, sustainability, and social responsibility, embracing innovation is essential. Innovative solutions are not just allowing the industry to overcome current challenges but also ensure its long-term viability, contribute to economic development, and minimize its environmental impact. In a rapidly evolving world, the mining industries continued innovation to meet the demands of the future.

This newsletter captures a view of the sector's journey. The array of case studies, technologies, and approaches discussed reflects the industry's commitment to overcoming challenges through innovation. As you explore these pages, you'll discover valuable insights into the industry's ongoing transformation.

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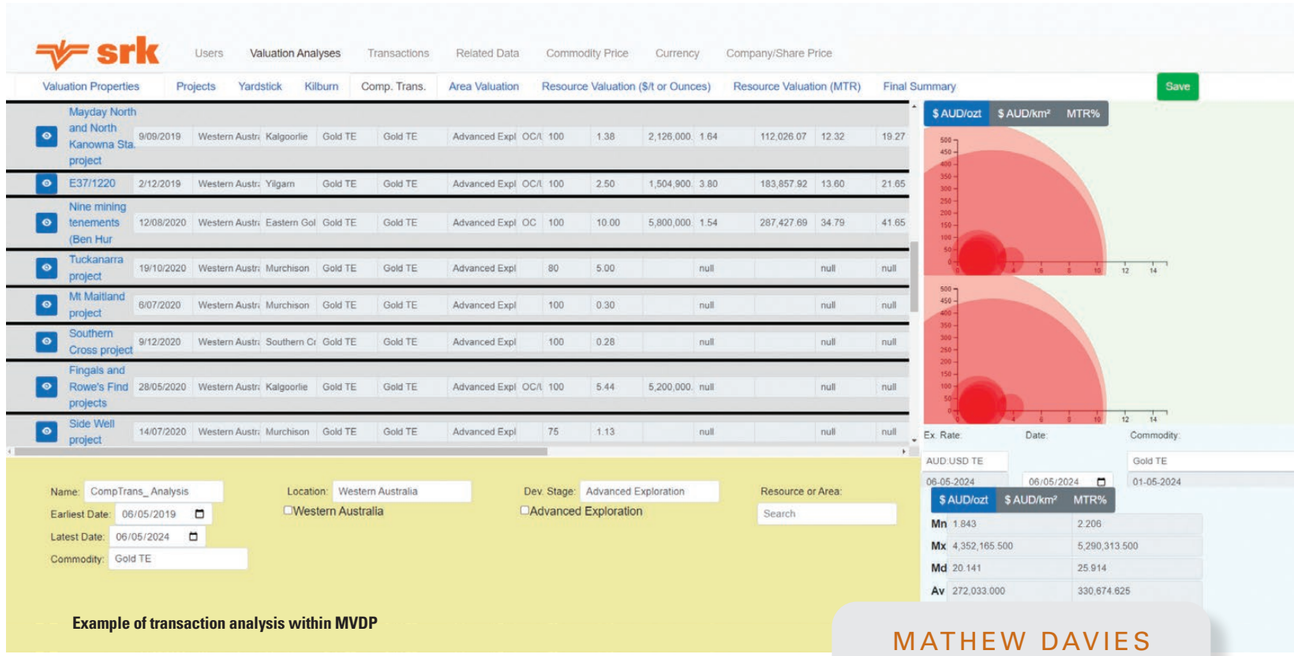
Mining and valuation data platform

The current methods of mining project valuation are akin to estimating a mineral resource using hand-drawn sections and a planimeter instead of modelling software. Typically, workflows for valuing mining projects (excluding discounted cashflow models) are onerous and rely on the compilation and analysis of various inputs in Excel spreadsheets.

Mining Valuation and Data Platform (MVDP) was created to address these issues. The MVDP is a centralised system that can access, filter, transform and normalise all historical and current transaction data for any commodity, in any currency, at any specific date.

This platform allows new data to be imported from proprietary databases to align with existing workflows. It supports mineral resource and ore reserve information collection at the resource, deposit and/or project level, handling any commodity type or combination, including complex polymetallic mineralogy.

A standout feature of the MVDP is its ability to incorporate and partially automate secondary valuation methods, such as the Yardstick and Geoscientific methods. This enables VALMIN Code-compliant valuations to be completed entirely within the platform. Additionally, the MVDP provides automated comparisons of these methods by asset and generates summary tables suitable for valuation reports. While data can still be exported for further analysis in Excel, using the platform promotes a standardised approach, reducing user error and ensuring that all valuations are saved with a permanent record and audit trail.



Example of transaction analysis within MVDP

The centralised database and repository of fit-for-purpose data allows all our consultants to benefit from the economies of scale achieved by SRK's global presence, and the best part is that the more it's used, the better it gets. The system effectively automates collaboration, as it makes gathered data available to all SRK practices, unlike a spreadsheet.

Future plans for the MVDP include adding other secondary valuation methods, such as the Geological Risk method and Multiples of Exploration Expenditure. There are also plans to develop spatial analysis and visualisation tools to integrate transaction data with spatial data, such as geology maps. This would enable the development of real spatially based methodologies. Additionally, incorporating additional datasets (mining costs, etc.) and potentially even a system for undertaking discounted cashflow models could be developed.

This platform represents a significant step forward for how SRK compiles, analyses and stores the fundamental data that is the backbone of the mining asset valuation work we do globally. These economies of scale can be applied to other disciplines, potentially increasing efficiency across the organization.

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MATHEW DAVIES

Mathew is a seasoned geologist with over 15 years in the Australian mining industry, including 12 years at SRK Consulting. His expertise spans public and internal valuation reporting for precious metals, energy minerals, base metals, and bulk commodities, expert witness work, due diligence reviews, and IGRs. Proficient in geological modelling and spatial analysis, Mathew has worked on projects from regional prospectivity assessment to mine site drill rig supervision, with onsite experience in NSW, QLD, Russia, and China.

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Incorporating ESG factors in a mineral asset valuation

SHAN CHUANG

Shan is a senior mining engineer. She specializes in pit optimization, mine design, and long-term scheduling. Shan has conducted scoping, pre-feasibility, and feasibility studies, as well as project valuation for both open pit and underground projects in China, other parts of Asia, America, Africa and Oceania. She is skilled in Deswik, Whittle, Surpac, MineSched and AutoCAD.

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ANTOINE CATE

Antoine is a data science and machine learning specialist with mineral exploration, structural geology, geochemistry, and 3D modelling expertise. He has field experience with various deposit types, including VMS, MVT, orogenic, and epithermal. Antoine specializes in processing and interpreting complex geoscientific data and applying data science and machine learning in exploration. Proficient in software like Leapfrog, ArcGIS, QGIS, and ioGAS, he is also experienced in Python programming.

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Integrating Environmental, Social and Governance (ESG) factors into mineral asset valuation is a key factor for sustainable investments. Traditionally, valuations focus on technical areas like exploration and mining, often not prioritising the ESG aspects, which can lead to ESG risks and potentially nullifying financial gains.

Many mining companies do not integrate ESG into their valuations due to the difficulty of quantifying ESG considerations into the valuation cost inputs. Frameworks like the Sustainability Accounting Standards Board offer guidance, but applying them can be time-consuming and costly. The challenge lies in translating abstract ESG impacts into specific cost implications.

To address these challenges, two simpler methods from the International Valuation Standards Council can be employed. The first is the market approach. This approach involves comparing ESG factors from similar companies and adjusting market inputs accordingly. By assessing the ESG performance of comparable companies, one can calibrate market inputs to reflect the target company's ESG performance. This method allows for a comparable valuation based on industry benchmarks and peer performance.

The second method is the income approach. This approach has been developed for several adjusted methods, and among these, two key methods are more straightforward:

Future cash flow adjustments by risk matrix: This method uses a risk matrix to evaluate ESG risks by combining the likelihood and impact of various factors. These assessments are integrated into cash flow models to reflect potential ESG-related costs and benefits. After obtaining the risk matrix numbers, these figures are factored into the cash flow adjustments, which is an inevitably subjective process, although those factors are evaluated by relevant experts.

Discount rate adjustments by ESG ratings: This method adjusts the discount rate based on ESG ratings from agencies such as Moody's, MSCI and S&P Global. Higher ESG risks lead to increased discount rates, reducing the present value of future cash flows. These ratings provide a structured way to assess ESG risks and quantify their financial impact; however, ESG ratings are usually an overall assessment of corporate performance rather than individual projects.

Despite the complexities and potential downsides, integrating ESG factors is crucial for mineral asset valuations going forward. It not only supports risk mitigation but also enhances the overall sustainability of the business.

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Automated core logging: creating value from core photo analysis

Core databases often span multiple decades and can represent thousands to hundreds of thousands of meters of core samples. Significant effort and cost go into collecting this core, yet historical datasets are often underutilized in advanced exploration and operational settings.

The increasing accessibility and power of machine learning workflows allowing mining practitioners to look at this historical data in ways not previously possible. By leveraging these technologies, SRK Consulting has developed innovative workflows to improve the utilization of core photo databases.

Over the past four years, SRK has been implementing automated classification of core imagery to increase data availability and spatial resolution for geological characterization. The specialist team includes structural geologists, resource geologists, and geotechnical engineers, bringing a diverse set of skills and industry experience to support their clients.

In addition, SRK has worked collaboratively with its clients to gain an appropriate understanding of the geological context. In some cases, certain parameters, such as a geological unit, alteration style, foliation or veining density, were not collected systematically or reliably because their importance was not clear at the time. Once the limitations of the current models are understood, a set of pragmatic classifications is proposed for implementation on existing core imagery.

The resulting solutions range from typical logging classifications to custom-tailored workflows that capture the most relevant aspects of a deposit.

To date, the team has processed over 1.5 million meters of core across many deposit styles. In many cases, the outcomes have directly supported downstream study work undertaken by SRK, further improving product quality for clients.

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LeRiche, A., Tims, S., Saunders, E., and Mohr, P. (2022). Geotechnical Domaining for the Aktogay Porphyry Deposit Supported by Machine Learning Techniques. In Proceedings of: International Slope Stability 2022 Symposium, Tucson, US

ANDREW LERICHE

Andrew is a senior rock mechanics engineer with over seven years of experience in open-pit projects. He specializes in geotechnical and structural geology assessments across various deposits. His expertise includes geotechnical investigation, slope design, and remote monitoring data interpretation. Andrew has managed field data collection and design studies for a number of global projects, in a variety of deposit styles. He also contributed to SRK's automated geotechnical characterization using machine learning, which was applied to several open pit and underground projects.

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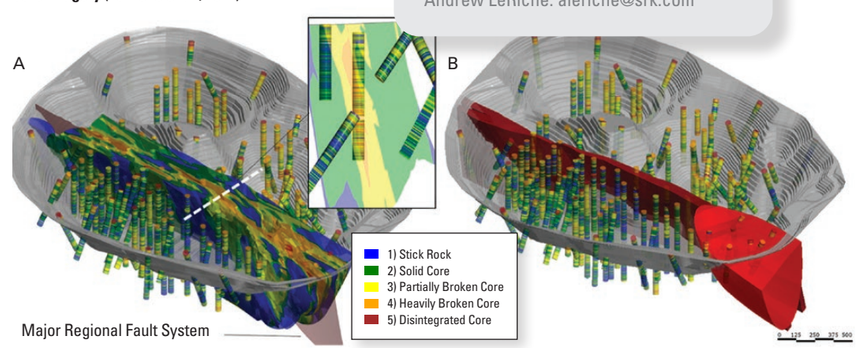
Automated geotechnical characterization from core imagery (LeRiche et al., 2022)



XRT sensor testing provides independent pre-concentration assessment

Pre-concentration opportunities are available for most operations to improve the grade of their mill feed and eliminate fine/soft contaminants or coarse/hard materials.

For a greenfield project, pre-concentration is difficult to evaluate due to a lack of standardised testing methods and sample top-size constraints. It's exacerbated by current testing practices, where sample preparation involves stage-crushing down to a manageable size, which destroys the opportunity to evaluate coarse beneficiation methods. Adrian is working to develop a standardised ranking test using ½ drill core samples. The objective is to consider pre-concentration at an early study stage and quantify the impact on project economics.

SRK Canada now offers X-ray transmissive (XRT) sensor-based testing in partnership with Base Metallurgical Labs (Base Met) in Kamloops, BC. Used in conjunction with crushing/screening, our XRT sensor testing rapidly and cost effectively assesses the potential for pre-concentration,

SRK's XRT Lab Machine at Base Metallurgical Lab

which can then be applied to scoping or prefeasibility studies.

The laboratory test can be done on 30–50 kg of ½ core samples, measuring the metal deportment by size at different levels of impact breakage, comparable to primary/secondary stage crushing. Integrating this protocol into existing comminution test protocols minimizes disruption to metallurgical testing programs. As well as estimating the grade by size response to crushing and screening, coarse particles are tested for sensor response, typically dual-energy XRT.

SRK and Base Met test and analyse sample results using a standardised procedure, which allows for benchmarking against other projects and operations. The goal is to enhance interpretation of scan results over time using machine learning.

Our XRT sensor testing can be included in metallurgical testing programs with minimal sample loss and no disruption. It can also be supported by larger-scale performance testing already being done by sorting equipment manufacturers. Plans are underway to include an X-ray fluorescence sensor to the lab capabilities at Base Met.

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ADRIAN DANCE

Adrian is a principal metallurgist at SRK Vancouver and has a Bachelor of Applied Science from UBC and a Doctorate in Mineral Processing from the Julius Kruttschnitt Mineral Research Centre in Australia. With over 30 years in his field, Adrian has both industrial and consulting experience, working at operations in Eritrea, Australia, Canada and Perú. With SRK, he is providing expertise in pre-concentration assessment, comminution optimisation and geometallurgical modelling.

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Tech-driven workflow automation in operations and construction


Operating Phase, Buriticá Mine, Colombia

Having well-defined workflows is crucial for any organization as these directly impact operational efficiency and the quality of decision-making. Standardized processes ensure tasks are performed consistently, minimizing human errors and facilitating the onboarding of new personnel. In this context, the SRK office in Colombia has achieved a significant breakthrough by integrating automated workflows and transforming data collection and processing.

The development begins with field data collection using third-party software like Survey123. Supervisors fill out detailed surveys on tablets, recording daily activities, volumes and observations. Once completed, the surveys are sent to a cloud-based database, a trigger is activated, and an automated workflow linked with a Power Automate and Gsheet is run. This workflow not only generates a PDF report sent via email, but also updates databases and dashboards in Power BI in real time.

The implementation of this system has had an immediate impact. The data is accurate and consistent, eliminating human error thanks to the use of multiple-choice lists and predefined fields. Moreover, the automation of workflows has standardized processes, ensuring that any new team member can quickly adapt to the established procedures without relying solely on personal criteria. This optimizes data collection and report delivery, maintaining uniformity and quality in procedures.

The next step in this implementation is to expand the use of this development to laboratory tests. The plan is to develop dynamic surveys that adapt based on responses, ensuring the necessary data for each type of test is collected. This will improve data accuracy and ensure that reports and dashboards reflect the most up-to-date information in real time.

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SANTIAGO ZULUAGA

Santiago is a civil engineer, specializing in project management with over five years of experience in site management, inspection, and supervision of works, as well as personnel management. He has knowledge of earthworks and mine tailings, supervision of construction processes in the mining industry, construction of industrial buildings, water management in residential and industrial complexes, and monitoring and tracking of state projects. His skills encompass effective communication skills, leadership, adaptability, and decision-making.

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VALENTINA GIRALDO

Valentina is a civil engineer, specializing in geotechnics with experience in the analysis, monitoring, and characterization of Tailings Storage Facilities (TSFs). She has participated in pre-feasibility studies, environmental impact assessments, and optimization of TSF designs. She has experience in site supervision, geotechnical campaigns, and laboratory programs, as well as database management. Recently, she has developed field applications to improve efficiency in geotechnical projects.

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Advances in engineering geophysics: improving mining consulting services

WESLEY HARRISON

Wesley is a principal geophysicist, which includes eight years of experience in processing, modelling, and interpreting geophysical data for groundwater and mineral exploration, geotechnical studies, and infrastructure investigations. He is skilled in electrical resistivity imaging, gravity, magnetic, seismic reflection/tomography, magnetotelluric, and ground-penetrating radar. Wesley has also worked with hyperspectral and radar satellite data for geotechnical studies. Wesley has developed mathematical equations to combine different datasets resulting in enhanced geophysical data for exploration and modelling.

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LINDSAY LINZER

Lindsay, is a corporate consultant and partner with specialist expertise in active and passive seismic methods ranging from acoustic emissions in the laboratory, mining seismology underground and in open pits, and seismic reflection surveys for mineral exploration and shaft sinking. She is an experienced WAVE3D modeller and has developed blast vibration modelling for vibration prediction in different environments. Since joining SRK she has become involved in the imaging and monitoring of engineering structures using electrical and seismic methods.

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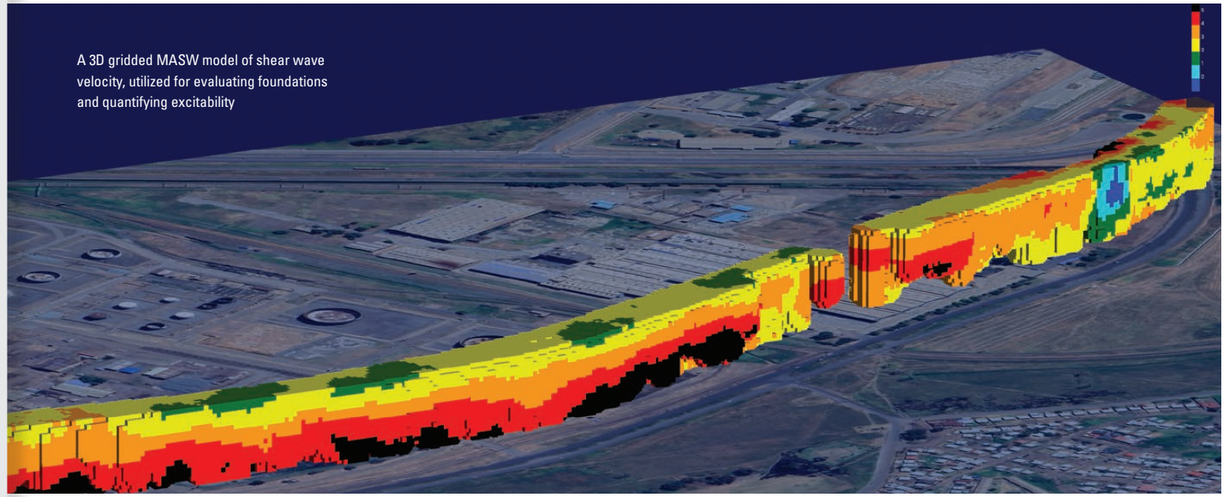

A 3D gridded MASW model of shear wave velocity, utilized for evaluating foundations and quantifying excitability

Engineering geophysics has become a crucial tool in mining and engineering consulting, driven by the need for efficient, sustainable, and safe practices. This article explores innovations in engineering geophysics at SRK.

The field of engineering geophysics has transitioned from 1D models to 2D and 3D geophysical data models. This evolution has been driven by advancements in methods like multichannel analysis of surface waves (MASW), electrical resistivity imaging (ERI), gravity surveying, and ground-penetrating radar (GPR).

Seismic surveys, including MASW and seismic refraction, are crucial for civil construction projects. They quantify rippability, determining appropriate excavation equipment and methods, which significantly impacts schedules and costs. The shear wave velocity profile, particularly the VS30 and stiffness parameters, is essential for seismic hazard assessments of structures like tailings dams and rock dumps.

ERI is widely used to identify subsurface boundaries, but its effectiveness depends on the applied array, survey protocol, and data processing. Innovations such as the maximum directional gradient algorithm have improved the delineation of material boundaries. Work is underway to develop 3D bulk Rock Quality Designation and Rock Mass Rating products by combining ERI, MASW, and geotechnical data using machine learning methods.

Gravity surveys are primarily used in engineering studies to detect cavities. However, the small gravity anomalies in these studies require accurate terrain and density corrections. New algorithms based on the Hammer net method have been developed to address this challenge, incorporating multithreaded parallel processing for improved efficiency.

GPR is extensively used in railway substructure surveys to assess track substructures. New software and workflows have been developed to process GPR data more efficiently, reducing turnaround times by up to 80%. This innovation provides crucial parameters for assessing railway ballast and sub-ballast quality. There is potential for expanding the software for use in road evaluations.

Despite these advancements, challenges remain in engineering geophysics. Issues such as insufficient data points in gravity surveys, incorrect ERI survey arrays and inappropriate MASW survey layouts can lead to inaccurate interpretations and flawed engineering decisions. Adhering to best practices and employing appropriate methodologies are essential for ensuring accurate and reliable geophysical survey results.

The innovations in engineering geophysics, many of which are being developed by SRK, have significantly enhanced the industry's ability to image and quantify subsurface features and conditions. By continuing to innovate while maintaining rigorous standards, the geophysical engineering field can further enhance its contributions, fostering greater trust and reliability in geophysical techniques.

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The role of virtual reality in shaping modern engineering

Technology is advancing by leaps and bounds, and provides the opportunity for engineering professionals to take advantage of the benefits it brings to projects. Among these new technologies is virtual reality (VR), which initially entered the market for entertainment purposes, like video games and virtual immersive experiences.

When presenting engineering projects, the goal is always to communicate effectively. By experiencing an engineering project in VR, the viewer can visualize the construction details and engineering works and understand not only the projected elements but also the current conditions of the area. Generally, VR presentations make use of federated models, meaning they include all disciplines: civil (roads, retaining work, bridges, gutters), mechanical (mechanical equipment), structural (steel structures) and urban furniture (traffic signs, trees, objects). For realism, the landscape is created using orthomosaics obtained by drones. In the end, the more detailed the 3D model, the more the immersive experience will affect the viewer.

The Prospect VR application offers important tools, like identifying dimensions, making annotations, inserting comments and taking photographs. It is compatible with well-known and widely used design programs such as Revit, InfraWorks, Bentley and Civil 3D, and its files can be exported into universal formats like OBJ and FBX. The software is fully compatible with Meta Oculus V2 or later versions of VR headsets. The best way to visualize the information or experience it is by using a computer with good hardware specifications connected to the VR headset via a cable. This way, the computer acts as the graphics processor and the headset serves as the display, preventing visualization issues or lag.

This tool has been relevant not only for clients, but also helps our designers and operators find and measure faults or construction problems that are not perceived in other forms of modelling.

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Carlos is a surveying engineer and technologist graduated from the Technological Units of Santander. His expertise is in the management of Geographic Information Systems (GIS) programs, BIM Modeling of roads and civil infrastructure. He is a certified RPAS pilot by the civil aeronautics authority, with theoretical and practical knowledge of geometric road designs, planimetric, altimetric, bathymetric surveys, and advanced drawing in specialized software such as CIVIL 3D, INFRAWORKS, REVIT, SUB ASSEMBLY COMPOSER, TBC, NAVISWORK, among others. He has completed studies in "Master BIM Management in Infrastructure and Civil Engineering."

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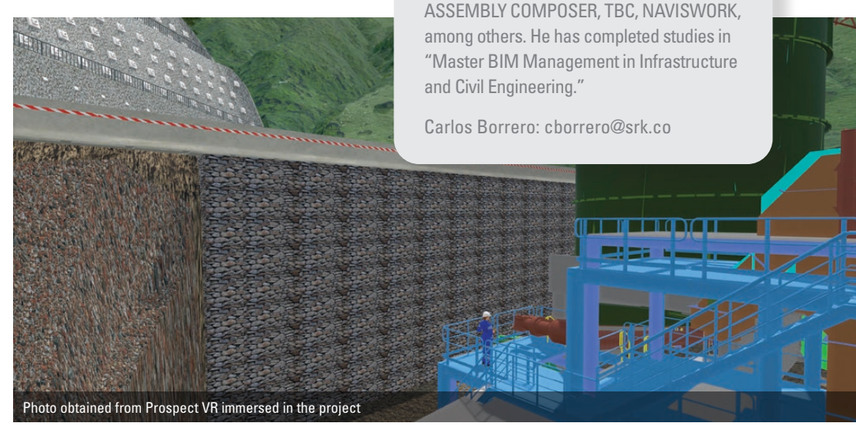

Photo obtained from Prospect VR immersed in the project

Transforming data into dynamic dashboards

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Alejandro has experience in data analysis and science, along with two years of solution development at SRK Peru. He has focused on projects involving the review, consolidation, and enhancement of models and databases, quality control evaluations of geological processes in mines, and the creation of algorithms and Machine Learning models. A graduate of the University of Lima, he specialized in statistics and programming, as well as in conferences on geology and mining. At SRK, he has focused on the development of customized applications, with experience in web environments and artificial intelligence models.

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ROEL CASUSOL

Roel has over six years of experience at SRK Peru, focusing on civil and mining projects, particularly in soil testing, foundation evaluation, and engineering designs for earth dams in tailings and waste rock deposits. He graduated from PUCP, where he obtained his engineering degree. He has participated in various specialized courses and conferences. At SRK, he has focused on geotechnical studies, with experience in geotechnical modeling and advanced seismic analysis.

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Dashboard usage is prevalent across all industries worldwide. Whenever there's a need to process data and display key graphs and metrics quickly, reliably, and in a visually appealing manner, a dashboard is created. It serves as a dynamic graphical interface showing crucial information on the status and trends of a particular process, aiding decision-making.

At the SRK Lima office, a tool was developed to centralize information for a mining company. The initial module was implemented using Power BI. However, due to the need for complex calculations and charts, programming beyond the capabilities of Power BI was required.

The mining company possessed ample data from prisms and inclinometers for monitoring three tailings dams, which were not being adequately analyzed. SRK was contracted to manage the data: cleaning, transforming, presenting and interpreting it using top computational tools. Based on initial evaluations, specific technologies were recommended, with Dash and Python as key tools.

Using a framework like Dash reduces development time, but requires users to adhere to the software's rules and formats. Dash allows comprehensive dashboard preparation, combining tools like HTML, Python, CSS and custom methods to represent any visualization, design, metric or table.

This approach has been applied only internally at SRK and in the specific mining operation scenario described; however, there is significant potential for broader application across other mining operations that need to leverage real data for informed decision-making.

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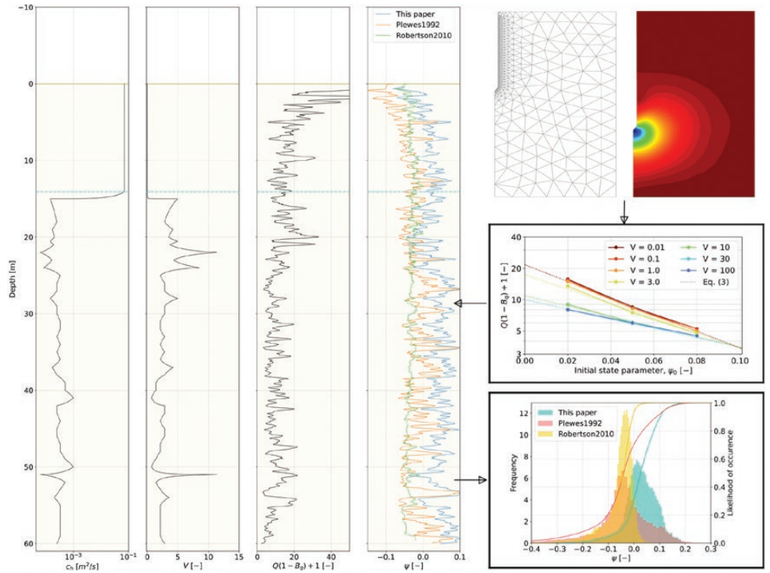
A numerical approach to determine the in situ state of tailings

Accurately estimating the state parameter ψ of tailings storage facilities (TSFs) is crucial for ensuring their stability, particularly in upstream-raised TSFs which rely on the strength of the tailings and are thus susceptible to flow liquefaction. Traditional screening methods often rely on empirical correlations, which introduce many sources of uncertainty in the analyses. To avoid this, a new method has been proposed to estimate the state parameter from CPTu data using a new tool: Pocket G-PFEM (Geotechnical Particle Finite Element Method). This advancement numerically simulates the penetration of the cone in a CPTu test, integrating the constitutive model that will be used in later design stages, thus eliminating many sources of uncertainty.

The G-PFEM is a computational framework developed by the International Centre for Numerical Methods in Engineering and the Polytechnic University of Catalonia. It is designed to solve large deformation problems in geotechnics. A pocket version, capable of simulating the penetration of the cone in a CPTu test, has been provided to SRK via a collaboration program.

The SRK Argentina team has proposed a procedure that estimates the state parameter by simulating the CPTu soundings using this tool. The procedure consists of five main stages:

1. Calibrate a constitutive model using triaxial tests with different initial state parameters.
2. Run CPTu simulations using G-PFEM with different state parameters ψ and dimensionless penetration velocities V between drained and undrained ranges.



LEFT: CPTu typical results using the new method to estimate the state parameter. UPPER RIGHT: Simulation of CPTu penetration using Pocket G-PFEM, showing the initial mesh and typical excess pore pressure field at the end of undrained penetration. MIDDLE RIGHT: Typical parameterisation of the relationship between normalised penetration velocity (V), state parameter (ψ) and CPTu results ($Q \bullet (1 - Bq) + 1$). LOWER RIGHT: Frequency analysis of the state parameter from 44 soundings performed in the same TSF. Comparison between the proposed method and other screening methods.

3. Parameterise the relationship between ψ, V and the normalised tip resistance $Q(1 - Bq)+1$ values that result from the CPTu simulations.
4. Calculate $Q(1 - Bq)+1$ from the CPT soundings and estimate V using the dissipation test data.
5. Use the parametrisation and the values obtained in step 5 to estimate the state parameter at each point.

This method has been applied to a geotechnical campaign involving CPTu tests and triaxial tests. The results indicated a more contractive behaviour compared to traditional methods, highlighting that screening methods may not be conservative enough.

While both the method and the tool are still in development, their potential is significant. They allow for a better understanding of the in situ behaviour of soils by combining lab testing, numerical modelling and CPTu data, overcoming the limitations of traditional methods. This advancement promises substantial improvements in the accuracy of geotechnical assessments and the safety of TSFs.

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Kevin is a geotechnical engineer at SRK Argentina. He is also an assistant professor of Structural Analysis and Numerical Analysis at the University of Buenos Aires. He specialises in the interpretation of geotechnical tests, numerical modelling, and Python programming. Kevin has been involved in key geotechnical projects, including the design and analysis of tailings storage facilities.

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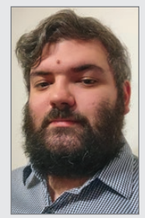
NICOLÁS TASSO



Nicolás is a geotechnical engineer at SRK Argentina. He is also an assistant professor of Strength of Materials and Numerical Geotechnics courses at the University of Buenos Aires. He specialises in numerical modelling of geotechnical problems, employing advanced soil models and utilising Python coding.

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FRANCO OBONI

Franco has over 30 years of international experience in risk assessment and management, from prefeasibility to closure. Franco specializes in tailings, open pits, closures and other mining industry aspects. His experience encompasses strategic planning, closure project risk assessments and risk-adjusted cost evaluations. Franco is a published author and regularly talks at universities, including for MBA programs. Franco focuses on bringing value and sustainability to clients and society as a whole.

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CESAR H. OBONI

Cesar has over 20 years of risk analysis experience, specializing in natural and man-made risk quantification. He provides integrated solutions for risk, corporate social responsibility, and societal acceptability, helping diverse organizations understand risk exposures. His mine closure expertise includes strategic planning and water risk assessments. Cesar combines technical expertise with a focus on societal drivers, optimizing risk for value and sustainability. Co-author of several books, he has presented his research in over 45 papers at international conferences and symposiums.

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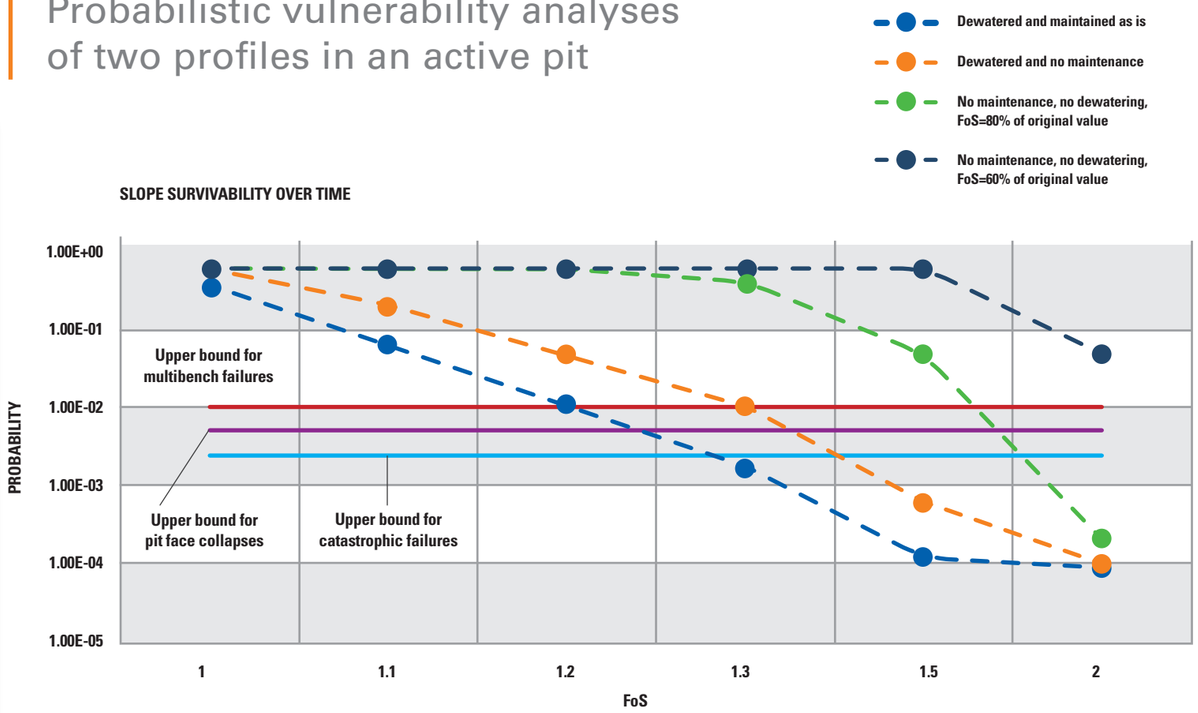
Probabilistic vulnerability analyses of two profiles in an active pit



To enhance the value of open pit QRAs (Quantitative Risk Assessments), we developed a probabilistic vulnerability analysis of open pit slopes. The analysis employs a previously published semi-empirical quantitative methodology to evaluate the annualized probability of failure (PoF) of potentially unstable slopes under varying factors of safety (FoS) and maintenance levels (Contreras, Oboni, Oboni, 2024).

The analysis is based on case studies of two pit profiles in a mine in Southern Africa requiring a stability assessment under varying operational and care scenarios. The analysis encompasses four scenarios representing different degrees of maintenance and dewatering:

- **Dewatered and Maintained "As Is":** Regular dewatering and maintenance activities depicting current slope stability conditions.
- **Dewatered with No Maintenance:** Release of monitoring and maintenance activities while maintaining dewatering efforts.
- **No Maintenance, No Dewatering:** Phreatic levels rise, reducing the FoS to 80% of its original value.
- **Further Reduction of FoS:** Extending the previous scenario with a FoS reduction to 60% of its original value, emphasizing the vulnerability of mine pit slopes under neglect or closure conditions.

Results indicate that maintenance practices, particularly dewatering, significantly influence slope stability, with decreasing levels of care leading to higher PoF. The analysis spans multiple time horizons, from annual assessments to long-term projections of five, 10, 20, and 50 years. Long-term projections reveal that while increasing FoS generally reduces PoF, scenarios with reduced maintenance and FoS exhibit persistent vulnerabilities, especially over longer time frames. This emphasizes the importance of quantifying the impacts of maintenance strategies.

Profiles in challenging geological conditions demonstrate heightened vulnerability, underscoring the necessity for tailored maintenance strategies. Comparisons with benchmark values from historical performance data of the global pit portfolio provide further insights into the effectiveness of current maintenance practices.

This analysis reaffirms the significance of contemporary standards of care within the examined pit. The approach is complemented by Bayesian updates, which allow for the integration of new data over time, refining model parameters and improving the accuracy and reliability of predictions to inform long-term operations and closure designs. This adaptive framework ensures that the analysis remains robust and reflective of real-world conditions throughout the life of the pit.

By facilitating risk-informed decision-making, the study supports efforts to achieve ALARP (As Low As Reasonably Practicable) conditions, enhancing the safety and sustainability of mining operations. The innovative methodology and its applications present a significant advancement in the field of mine slope stability analysis, offering valuable tools for practitioners and researchers alike.

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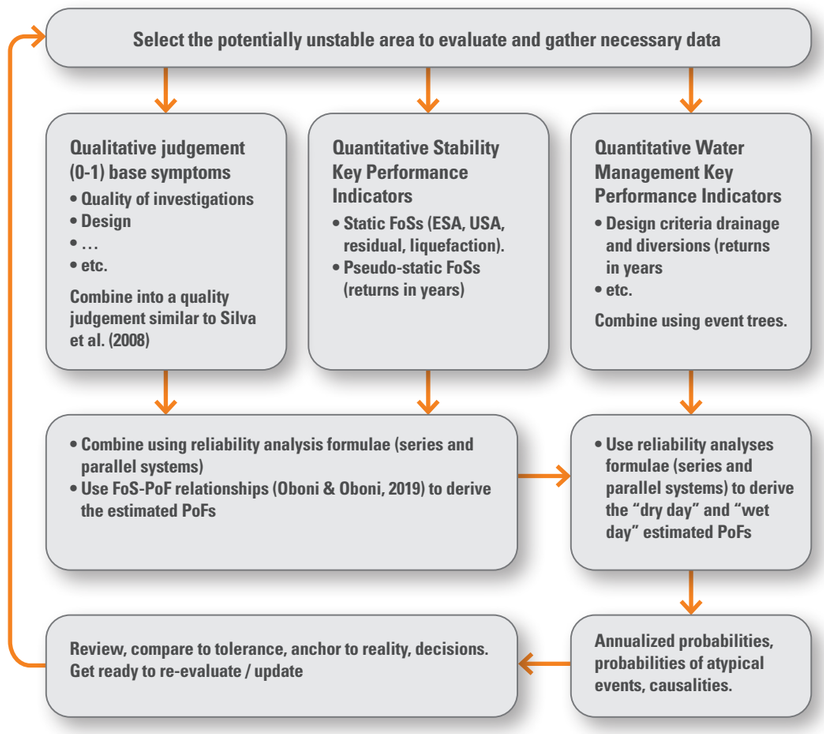

A probabilistic approach to determine downstream consequences in dam break analysis

FEDERICO GIURICH

Federico is a civil engineer who focuses on water management of mine waste facilities and the conceptual design of hydraulic structures, including the long-term assessment of water resources and the impact of storage facility breaches on surrounding areas. He has been involved in carrying out dam breach analyses, water balance studies, seepage studies in non-saturated media, and climate change assessments.

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IGNACIO EZAMA

Ignacio is a civil engineer with a solid knowledge of geomechanics and extensive experience in the development of geotechnical solutions in site-based and desktop applications. Ignacio has been involved in the development of numerous major geotechnical structures, from scoping through to detailed design and construction. Ignacio has worked on projects involving a broad range of tailings solutions, including thickened, filtered (dry stacks), cyclone, co-disposed and conventional facilities.

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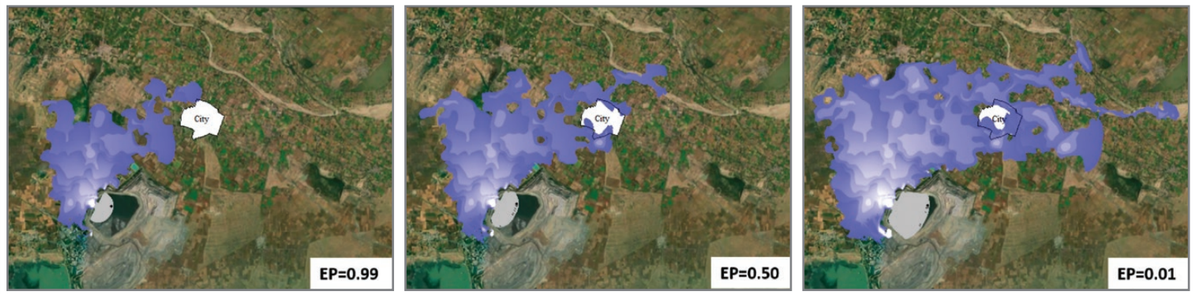

Inundation extents in a DBA considering three exceedance probabilities for the release volume (1%, 50% and 99%). Release volume estimated by applying the probabilistic method with failure surface given by the cone-depression method.

While the thought of a tailings dam failure is frightening for all stakeholders, even the safest engineered dam might fail. Dam break analyses (DBA) play a critical role in planning for these unlikely and undesirable emergencies. Given the uncertainties associated to these types of studies, mainly when it comes to tailings storage facilities (TSFs), any efforts to understand their implications tend to be widely supported in the mining industry.

Among the different sources of uncertainties, release volume plays a key role on the variability of consequences during a potential failure of a TSF. Instead of using deterministic methods, which typically estimate one single release volume for a DBA, SRK is developing a method that assesses the variability of the input parameters for release volume. Based on the cone-depression method, a generic failure surface has been defined, whose parameters are not treated as fixed values but rather as what they truly are: random variables.

These variables have been assigned probabilistic distributions based on the analysis of records of past failures. A Monte Carlo simulation process is then carried out, with the primary objective of obtaining the cumulative frequency distribution of release volume. As a result, the range of plausible values has an exceedance probability associated to it under the assumptions of the proposed method.

By picking up release volumes with different exceedance probabilities, different flood simulations can be modelled, thus providing the opportunity to plot incremental inundation maps. These allow analysts to assess the incremental downstream consequences instead of relying on one single scenario as in the traditional deterministic approach. Among other benefits of this method, emergency and preparedness plans can be better refined, and the TSF design can be enhanced.

The method that has been developed can be modified following the same logic, with the ultimate objective of defining a cumulative frequency distribution of the credible release volumes. The study of the uncertainty of other parameters involved in a DBA continues to be a subject of concern for SRK. While it is impossible to predict the specifics of an unfortunate event like a dam failure, estimating the range of credible consequences is wiser than just trusting one deterministic scenario.

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HiveMap: mixed reality technology to collect and visualize data in real-time

How it started

A modern theme is the increased usage of technology to support our lives and our work. SRK identified a need for better geological data collection tools for those who needed to map in the field, in open pits or underground. An early tablet-based application was developed in SRK Vancouver, but the software became rapidly outdated. SRK became aware of augmented reality tools developed at Simon Fraser University with Professor Doug Stead, and together we conceptualized the potential usage in mining.

The vision

Imagine standing in an underground mining tunnel, or on the surface in an exploration site, and with augmented visualization tools, seeing all previously captured data, drillholes, and as-built or planned mining infrastructure. These technological powers of visualization can revolutionize geological and geotechnical data collection all along the mining pipeline. SRK's Emre Önsel has developed augmented reality tools for geological data collection and beyond. We are just waiting for the expected hardware so that the vision can become a reality. Tablet-based augmented reality solutions are in the testing phase.

Delivering solutions now

In the meantime, Emre has developed and now upgraded the interface for the desktop and iPad tablet software, called HiveMap. This software is designed to import high-resolution drone or photogrammetry imagery to allow the user to map the virtual rock face with tools that mimic traditional geological and geotechnical mapping tools. This specific functionality is fundamental to SRK's objectives of providing quality mapping tools and enabling mapping in areas that would otherwise be inaccessible. The HiveMap desktop solution also provides geotechnical data analysis tools, including data selection, stereonet analysis of joint sets, and slope stability kinematic analysis.

The full value of the software becomes clear when considering the typical limitations we have when trying to collect data. In geological exploration, targeted drone surveys allow us to map inaccessible outcrops. In open pits, we can map the entire pit with drone images, not just the accessible benches. In underground mines, we can map closed or dangerous unstable localities.

SRK already has a limited number of HiveMap license user agreements, and is indebted to the amazing support provided by Newmont over the last few years of development. Newmont users have provided many reviews and recommendations to improve the product. HiveMap had an official marketing launch in September 2024.

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WAYNE BARNETT

Dr. Barnett is principal consultant, structural geology in SRK Vancouver. Wayne has over 28 years of experience in mapping, interpreting and 3D modelling structural geology and has performed the role of consulting structural geology specialist on all continents with active mining. He was selected as lead author, developing the Guidelines for Structural and Geological Models in 2021, and to update the current LOP guidelines book, and is contributing to, and peer reviewing the Arizona School Mines and Mineral Resources structural training courses.

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Streamlined hydrogeology data for greater efficiency

Having good data management is vital throughout the process of conceptualising hydrogeology and producing analytical and numerical models. With effective data management, scientists can devote more time to making meaningful data interpretations. At SRK, we strive to employ standardised approaches to streamline and automate the data management process with tools that can be adapted to any project.

Water datasets are typically large and involve ongoing monitoring information alongside periodic aquifer testing. Traditionally, water datasets have been largely composed of field measurements, which might vary between projects or scientists. Manually intensive tools are increasingly inadequate for creating repeatable and timely workflows to analyse these large, heterogeneous datasets.

At SRK, we approach data management from a "good in = good out" perspective. We believe it is essential to start with a solid foundation. We perform QA/QC on received data in its various forms to fit our standardised data storage structure. From this format, data is easily applied to our growing library of streamlined visualisation, analytical and modelling tools so that more time can be spent on conceptualisation and interpretation of the data. The standardised data format also allows for easy transformation into standard third-party software, enabling us to return data to our clients in a clean and improved format while maintaining high-quality data management practices. Finally, automated data handling cuts down on errors during all stages of the workflow, leading to reproducible results with a high degree of confidence and less rework.

Large datasets are becoming a more significant part of hydrogeology. The amount and frequency of data collection is increasing not only through automation and telemetry, but through the availability and applicability of multidisciplinary datasets. Increased regulator scrutiny and the potential for mining to significantly impact groundwater, surface water and associated users of this water are driving the importance of accurate water resource characterisation. It is therefore essential to set up data management systems that are scalable and allow one to make informed decisions to ensure that regulatory conditions are met. SRK's dynamic and scalable approach allows us to cater to our clients' data management needs, large or small, ensuring that clients get the best approach to handle water data for their operation and that they have the right tools to make the right decisions.

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BEN FISHER

Ben is a hydrogeologist and engineering geologist with experience in Australia and the UK. He manages hydrogeological and geotechnical projects in mining and civil industries, and is proficient in drilling methods and hydraulic testing. Ben's expertise includes borefield design, feasibility studies, water balance assessments, and regulatory reporting. He has worked on projects for Roy Hill Iron Ore, FMG, Rio Tinto, and more. Ben is skilled in ArcGIS, Leapfrog, and Python for data manipulation and visualisation.

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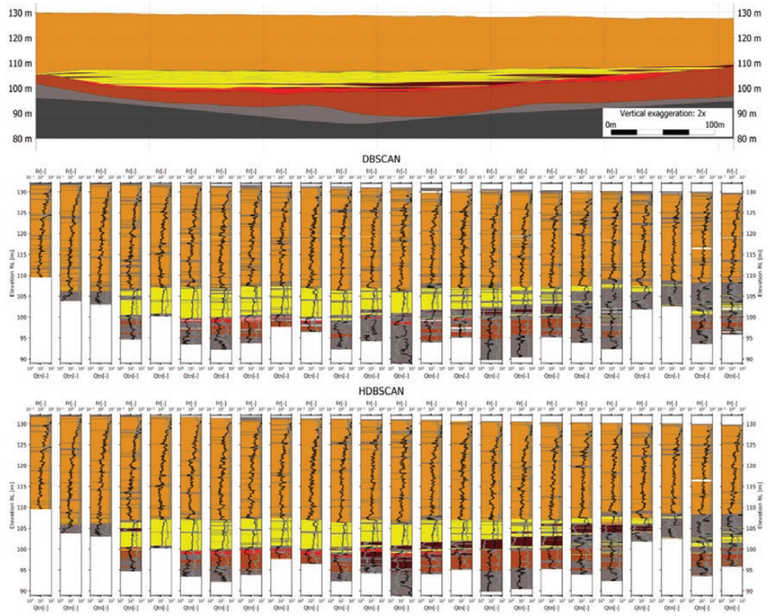
Machine learning applied to CPT interpretation

Geotechnical site characterization is the process of collecting in situ data to determine the characteristics of the subsurface, such as its material properties and spatial variability. This allows engineers to develop ground models needed to perform geotechnical design. To gather in situ geotechnical data, the Cone Penetration Test (CPT) is commonly used, as it provides a large amount of data relatively quickly. This data allows engineers to build ground models with more confidence, but it requires a significant amount of time to interpret it manually.

To decrease the time it takes to interpret CPT data, we explore the field of machine learning. Clustering methods, such as Density-Based Spatial Clustering of Applications with Noise (DBSCAN) and its counterpart, Hierarchical-DBSCAN (HDBSCAN) classify data into distinct groups, where each group consists of data points that have similar parameters.

These methods are particularly useful for analysing CPT data, as raw CPT data can be correlated to many different soil properties, which are often difficult to classify. Normally, an engineer uses their best judgement to manually separate the data into distinct groups of subsurface materials. This leads to a subjective ground model and can take a significant amount of time to complete. DBSCAN and HDBSCAN, on the other hand, can perform an analogous classification process in just a few seconds, leading to an objective ground model in a fraction of the time.



A ground model using manual interpretation of CPT data (top) compared to automatic interpretations using DBSCAN (middle) and HDBSCAN (bottom).

To illustrate this process, we use data obtained at a site containing a dam built over an 800-m-long shallow valley. This site was characterized using many in situ tests, including 206 distinct CPT soundings. Originally, a ground model was manually created for this site. This process took more than three weeks due to the vast amount of data and the variation of subsurface materials.

In comparison, both DBSCAN and HDBSCAN were used to classify data from a group of 24 CPT soundings along the crest of the dam. Three parameters were used: elevation, normalized tip resistance, and friction ratio. Any parameters can be used for classification purposes, but these three were chosen, as they are commonly used to classify subsurface material types (e.g., Been and Jefferies (1992) or Robertson (2016)). The results show that these clustering methods can classify soil similarly to a manual approach, but in much less time.

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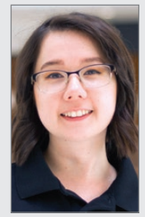
JODIE CROCKER



Jodie is a consultant at SRK Argentina and has worked with the geotechnical group on projects involving tailings management, site characterization and numerical modeling. She has a PhD in Geotechnical Engineering from the University of Texas at Austin, where she researched machine learning methods as applied to geotechnical site characterization. She plans to continue this research at SRK with the goal of creating innovative tools to help with future projects.

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LISANDRO ROLDAN

Lisandro is a senior consultant at SRK Argentina with over even years of experience in geotechnical engineering, specializing in computational mechanics. He has worked on projects involving foundations, tunnels, dams and tailings management. Lisandro holds a Civil Engineering degree from Universidad Tecnológica Nacional of Argentina and an M.Eng. in Numerical Methods from Universitat Politècnica de Catalunya. Proficient in programming, he aims to apply statistical analysis and machine learning techniques to improve SRK's workflows and contribute to innovative geotechnical solutions.

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Digital innovations in tailings dam management and performance monitoring

JAMES DUTCHMAN

James is a principal engineering geologist with over 10 years' experience and a demonstrated history in both the mining and energy sectors, across Africa and Internationally. His current role involves the management of Engineer of Record and tailings facility projects. To support clients, his focus has been TSF performance monitoring through the implementation of new instrumentation, monitoring techniques, digital integration, data management and communication, and data analytics. Aimed at advancing data and risk-based approaches to TSF management.

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HEATHER THOMSON

Heather, a principal tailings engineer, has 14 years of expertise in tailings and mine waste management. She focuses on TSF projects, from design and construction to operations and closure. Notable achievements include designing an integrated tailings storage and hydropower facility in PNG and engineering a TSF from concept to closure. Heather is dedicated to sustainable and innovative engineering solutions.

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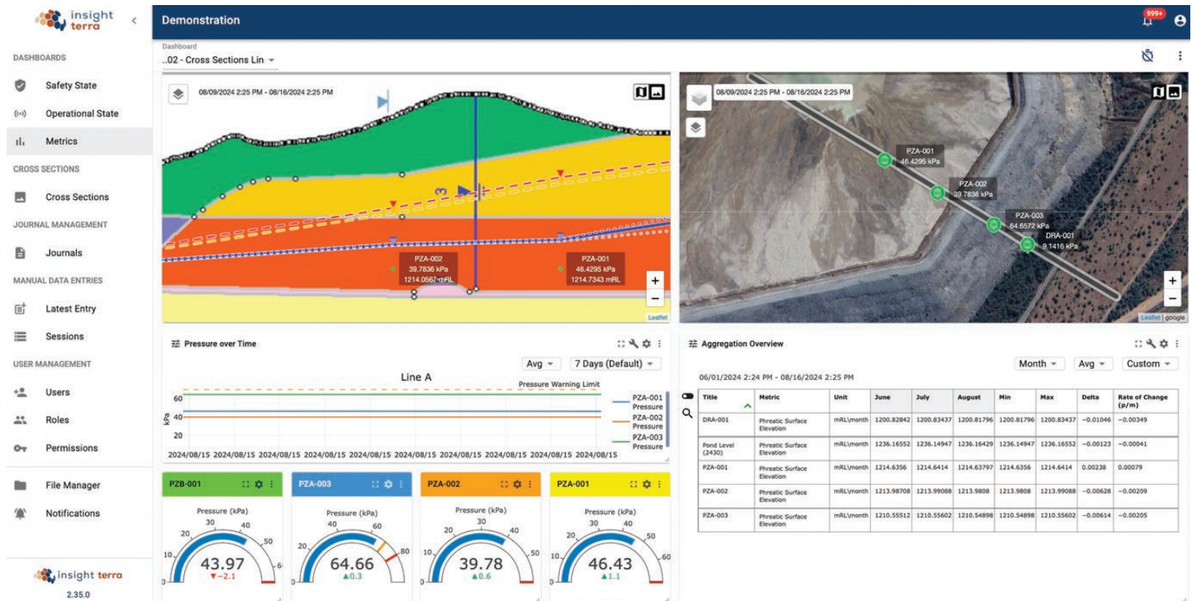
Example TSF Digital Dashboard (Courtesy of Insight Terra, https://www.insightterra.com)



Since the introduction of the Global Industry Standard on Tailings Management (GISTM), the mining industry has experienced a clear trend towards digital transformation aimed at enhancing governance and best practices in tailings dam management. The adoption of new and advanced technologies and digital solutions has been rapid but is still evolving. This presents significant opportunities for continued innovation and improvements in Tailings Storage Facility (TSF) performance monitoring and overall TSF risk management.

The adoption of technologies and digital systems across stakeholders has been essential to achieving an increased understanding of a facility's risk profile. This focus has led to the introduction and implementation of a wide range of monitoring and digital solutions.

Remote-sensing methods, such as interferometric synthetic aperture radar, are now widely used to monitor ground movement. These methods work well when combined with global navigation satellite systems and ground radar solutions. Drone and aerial surveys, offering high-quality thermal and LiDAR payloads, are commonly deployed. Autonomous aerial solutions further improve the frequency and accuracy of data acquisition. In situ monitoring instruments, such as vibrating wire piezometers and inclinometers, have become standard tools for TSF monitoring. Additionally, new solutions like fibre optics and passive seismics provide further options to meet specific client or engineer needs.

Implementing an effective monitoring framework must be approached on a case-by-case basis. This involves a thorough review of the TSF, identification of data gaps and the implementation of appropriate solutions to enhance performance monitoring and safety. Correctly implemented solutions and integrated software platforms enable digital dashboards to provide real-time actionable insights into critical data. Rapid data collection, aggregation, transformation, validation, processing, storage and visualisation allow prompt communication of operational performance changes to stakeholders, tailored to end-user requirements. This represents a significant improvement over past workflows.

These advancements in capability driven by technology will continue to play an important role in sustainable tailings dam management and performance monitoring. They are essential for achieving higher standards of governance and operational assurance. We have already seen the benefits of accurate data gathering, increased data visibility and auditability, ensuring better analysis, insights and risk management. Leveraging current and new technologies such as machine learning and artificial intelligence coupled with industry collaboration and innovation will certainly play a strategic role in the next phase of this digital journey.

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Unplugging the future: elevating stakeholder engagement with 3D-printed models

They say if you want to test how well you know a subject, try explaining it to a 5-year-old. As a tailings engineer, explaining concepts like tailings deposition strategies or dam breach assessments can be challenging. Meaningfully communicating such concepts to a variety of project stakeholders is not always an easy feat, let alone to my 5-year-old.

In today's environment, meaningful engagement with stakeholders is crucial, as projects often face pressures from communities, regulators and others. For tailings management, meaningful engagement isn't just beneficial—it's required for compliance with the Global Industry Standard on Tailings Management (GISTM). Tailings operators must consult and listen to stakeholder perspectives in a manner that involves measures to overcome structural and practical barriers to the participation of diverse and vulnerable groups of people.

Technological advances have offered new forms of communication. You could put on a VR headset and immerse yourself in a drone flight over a mine site anywhere on the planet. Despite the digital age's immersive technologies, there's value in stepping back from screens. Tactile learning experiences offer an alternative pathway to reconnect with the physical world.

What began as an innovative experiment quickly revealed the power of 3D-printed mine site models for communication. Having physical models of my projects on my desk saw conversations with colleagues shift from computer screens to hands-on interactions with the miniaturised sites. Bringing 3D models of site topography, along with 'dam fill material' (aka modeling clay) and 'tailings' (aka water beads) to student nights and conferences has offered visitors an interactive taste of tailings dam site selection studies. Physical models have allowed our clients to improve communication with a variety of stakeholders, from illustrating site closure concepts in internal workshops to engaging with the community in pop-up events to explain expansion projects.

By harnessing the tactile and visual appeal of physical models, we can move beyond dependence on screen time to a universally understandable approach. The impact of 3D-printed physical models as tools for meaningful engagement? Well, not only can my 5-year-old explain how a closure spillway works, but he now dreams of becoming 'a miner' when he grows up.

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3D model of the MMG Rosebery 2/5 tailings storage facility at their community pop-up.

GreenTailings: innovation in mine waste management

Toxic mine tailings and industrial waste are associated with negative environmental, social and governance (ESG) impacts. These are costly to manage and carry legacy liabilities and risks, deterring investors. Mining companies and their engineering and scientific teams must find a balance between ESG requirements and financially sustainable operations.

Addressing source issues, not just symptoms, helps project teams understand core triggers causing negative ESG outcomes and devise solutions that eliminate or contain them sustainably. This reduces legacy risk challenges, which can be converted into financial metrics. Understanding these metrics benefits waste producers and boosts investor confidence.

MATTHEW GORDON-WATT

Matthew is a registered professional civil engineer with 24 years in civil/geotechnical/tailings engineering, based in the SRK Johannesburg.
Experienced in consulting, construction, operations and innovation in waste management/tailings treatment.
Skilled in project planning, business development, risk management, and geosynthetic applications.

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Two key elements drive the negative ESG legacy of mine tailings waste: toxins or heavy metals in the waste stream and the liquid content that enables leaching. Where these exist as wet slurries, this carries inherent risks, including liquification that may result in dam failures.

GreenTailings 1.0, a term coined by the author, is a chemical solution for a chemical problem. It is a proven technology, scrutinized for nearly a decade, merged with geotechnical design criteria, principles and feasible tailings handling procedures. A scalable mechanical plant treats incoming slurry streams via a rapid chemical process, removing water and encapsulating individual tailings particles. The treated waste stream is now dry and inert. Before and after treatment, an audit process measures hazardous/toxicity levels aligned to engineered outcomes.

This approach reduces environmental and social impacts, which in turn reduces or removes current and legacy risks. SRK can offer a novel, yet practical, tailings handling alternative by designing and commissioning the treatment process with its technology partner, then managing the tailings placement process with the client and contractor. Governance is handled via a client/consultant agreement, using Global Industry Standard on Tailings Management (GISTM) and/or client standards as the basis.

GreenTailings 2.0 is a secondary value-add process — but that's a story for another day!

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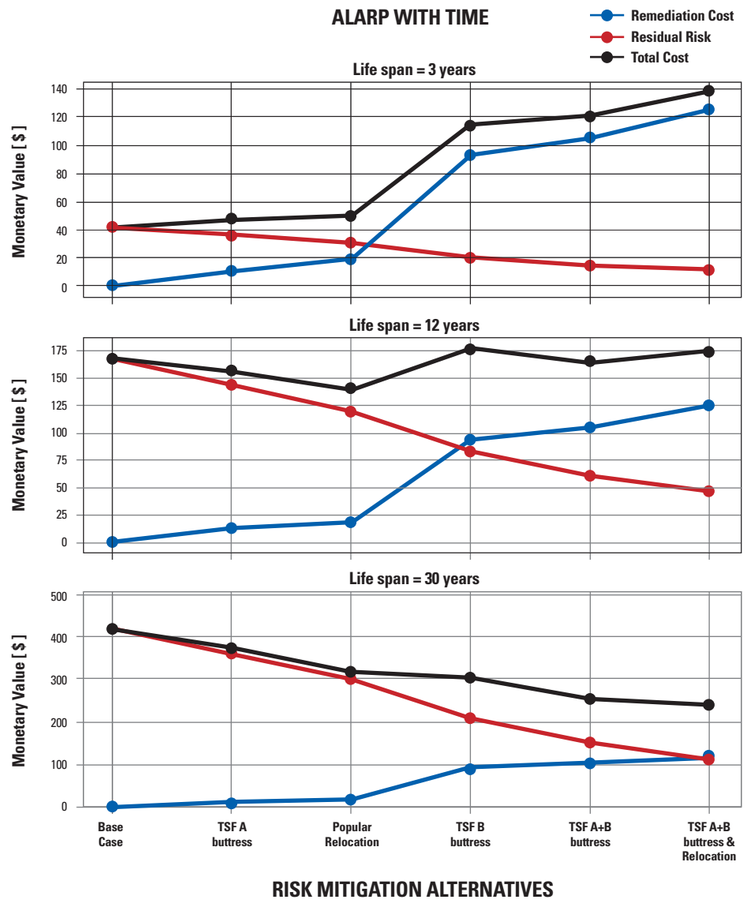
Incorporating lifespan considerations into ALARP decision-making

The consideration of ALARP (As Low as Reasonably Practicable) features in several state-of-the-art guidelines, such as the Canadian Dam Association, the Mining Association of Canada and the Australian National Committee on Large Dams, as well as in GISTM/ICMM. ALARP considerations can be applied to any project involving the selection of an appropriate level of mitigation, including the operations and closure phases of pits, dumps, and tailings storage facilities. In some literature, ALARP represents the trade-off equilibrium between remediation costs and risk reduction benefits. However, in its most modern definition, ALARP means that a residual risk, i.e., the risk after mitigation, shall be as low as reasonably practicable. To be considered ALARP, one requirement is to demonstrate that the cost involved in further risk reduction would be grossly disproportionate to the benefit gained. Demonstrating ALARP status—specifically locating the minimum ALARP point (LMALARP)—is crucial for owners, engineers of record, the public, insurers, lenders, and regulators.

Choices based on LMALARP can yield better decisions, enhance values of projects, and avoid overspending mitigative funds. However, LMALARP should not be seen as a static process, as it has to encompass various time horizons along the life of a project. The short-term ALARP may differ significantly from the long-term ALARP due to uncertainties, changing system conditions, and external factors, such as evolving land use in the vicinity of the facility.

This short article, based on the full paper by the same authors, showcases a high-level overview of how to quantitatively incorporate



lifespan in the ALARP assessment when looking at a specific mitigation program, and/or to compare different remediation options. To do so, annualized quantitative risks must be evaluated for each mitigative alternative, as well as the cost of the various mitigative actions. For each time horizon, the result is the crossover point between remediation costs and risk reduction benefits, which represents the minimum theoretical ALARP point. Various considerations can then guide decision makers to select the point where the cost involved in reducing risk further would be disproportionate to the benefit gained.

This process has been applied to existing facilities and has shown how the optimum solution varies not only when the weighting of different consequences (environmental, financial, reputational, etc.) is shifted, but also when the lifespan of the structure is considered.

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OSVALDO LEDESMA

Osvaldo is a principal consultant in the geoenvironmental engineering division of SRK Canada. He is a civil engineer with over 12 years of experience in geotechnical engineering for infrastructure and mining. He has been involved in the design of foundations, large urban excavations, tunnels, earth embankments, and dams for projects in Argentina, Perú, Mexico, and Canada.

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ANDREW GARVIE

Andrew has undertaken ARD assessments since 1992. He has developed measurement techniques and instrumented numerous dumps to quantify oxygen supply processes that enable sulfide mineral oxidation that leads to ARD. The studies have been conducted in coal spoil piles, waste rock dumps, and heap leach piles. He has planned and undertaken comprehensive studies to forecast and provide evidence of the performance of ARD management strategies, including dump reprofiling and covering, waste layering, and in-pit disposal.

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PAUL HUBBARD

Paul is a principal consultant in hydrogeology with 19 years of experience in mine water management. His expertise includes mine dewatering and depressurization assessments, seepage analysis, and solute migration and groundwater impact assessment. He has worked on numerous hydrogeological projects in the context of mining, waste management, and contaminated land. Paul has a broad field experience, which has been used to deliver field programmes as well as staff training in methods such as sample collection, hydraulic tests such as packer, pumping and spinner tests in addition to pumping well and VWP installation.

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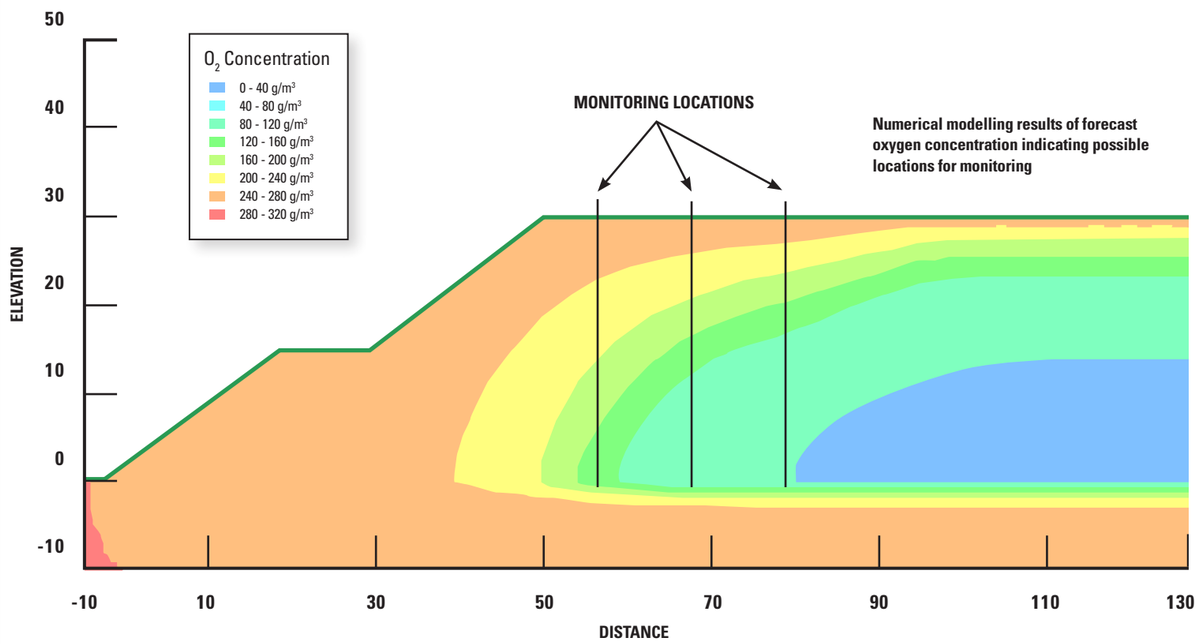
Acid rock drainage: measurement of key landform parameters controlling development



Acid Rock Drainage (ARD) can be generated by mine waste landforms, for example, waste rock dumps and tailings storage facilities. Closure costs related to the management of ARD can be significant and may last for many years. These liabilities can be reduced by addressing a root cause of the problem at the time of landform construction: oxygen supply to the reactive sulfide minerals.

Oxygen is transported from the atmosphere to the interior of landforms by gas advection and oxygen diffusion. The landform material properties that control the rates of these processes are intrinsic permeability and oxygen diffusion coefficient, respectively.

Rates of consumption of oxygen are determined by material properties such as sulfide sulfur content. Because the oxidation reaction generates heat, temperature changes and the peak temperatures in a landform depend on oxidation rates.

SRK has developed a suite of measurement tools that can be used at mine waste landforms to characterise the rates of oxygen supply (including permeability and oxygen flux meters), rates of oxygen consumption (oxidation rate meter) and oxygen and temperature distributions within the landform.

Changes to landform geometry, waste dump lift heights, and waste compaction to lower intrinsic permeabilities can all reduce oxygen supply. Numerical modelling can be used to guide designs. Measured parameter values are used as inputs to numerical modelling to aid landform design and to confirm that parameter values used at the design stage are achieved in practice.

Numerical modelling provides a means of estimating acid and sulfate generation rates for specific locations within a waste landform and the landform as a whole. These rates can then be used to forecast the water quality of the seepage from the landform.

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Waste rock flow impact on effective mine decommissioning strategies

Waste Rock Storage Facilities (WRSFs) can be a significant source of contamination, especially in long-term mine closure scenarios. Mine wastes can oxidise and leach metals through various processes, including the oxidation of sulphides and release of metals, a process referred to as Acid Rock Drainage (ARD). These contaminants can eventually reach the base of the waste dump and emerge as surface water or migrate into groundwater.

WRSFs are generally unsaturated deposits with highly heterogeneous materials. Depending on the intensity of inflows and the layering of material within the WRSF, infiltrating water will take preferential flow paths. Therefore, not all of the rock mass in a WRSF will come into contact with infiltrating water, and not all inflow pathways will be comparable. Only materials within zones of preferential flow paths will contribute to the solute load downgradient, while those accessing fine-grained paths provide higher concentration loads.

Understanding the proportion of rock mass in contact with mobile water and the differing types of flow processes is crucial for determining the potential overall rate of solute mobilisation and the resulting impacts downstream. Typically, geochemical modelling approaches often make simplistic assumptions about fluid contact with waste rock. The contact mass is typically given as an assumed contact factor to fines material, which is not directly linked to rainfall or infiltration data. The flow that may pass through macropore routes is typically not assessed. This approach limits the remediation scenarios that aim to reduce infiltration, such as the application of soil covers, which may also change flow pathways and waste rock mass in contact with water. To better characterise hydrologic processes within a WRSF, studies must account for factors like climate and weather conditions, cover types, dump geometry, particle size distribution and deposition structure. Often however, assessments are made of proposed sites where measurements and samples cannot be taken or existing sites where data availability is nonetheless limited.

To support the assessment of water flow through WRSFs, particularly new or existing facilities where data may be lacking, SRK is putting together a set of guidelines and a parameter database tool. The guidelines will give advice for detailed assessment and inclusion of cover systems, as well as methods for high-level initial appraisal. The parameter database will be compiled from documented studies and enable users to see information from similar WRSF designs or climates to their project, which may be useful as inputs to their calculations.

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