srk news

Mine water management

Our perspective

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Open pit partially flooded after a heavy storm

Mining personnel have a different interpretation of the term "mine water management". For the rock mechanics engineer it is the de-pressurisation of a slope in an open pit, for the metallurgist it might pertain to the water contained in the process circuit, and for the tailings engineer, the waste circuit.

In this newsletter we have used the term in its broadest context to mean water impacted by the mining project, the impact of water on the mine, and the water managed within the greater footprint of the site.

We believe the management of water on a mining project will become ever more important in the future. In arid areas water is a scarce and expensive resource to the extent that some projects will stall because of a lack of water or because the cost of supply will be prohibitive. In high rainfall areas, the containment of contaminated water might not be possible without large structures and transfer systems, whose construction and operating costs will again be large. Treatment of water, both as supply and before release to the environment, has historically been expensive. Added to this is the ever increasing regulatory environment, which might make discharge impossible.

Water issues should be considered in an integrated way during design, start-up, operation and closure of a mining project. During design, failure to integrate the various components can significantly underestimate the time and cost of implementation. During start-up, extreme climatic conditions, unplanned during design, can cause flooding of construction works and initial pits or require additional water supply. Operational issues could include incorrect estimations of plant make-up water, or tailings circuit imbalances or changes to the volume and quality of water as process plants expand or change process technologies. Closure of any mine will include pit lake hydrology and chemistry, runoff from rehabilitated dumps and residual contamination of plant areas, amongst the issues of concern.

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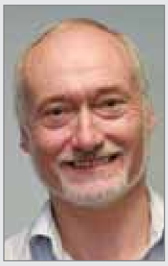
Our perspective *(continued)*

RICHARD CONNELLY



Richard Connelly MSc, C Eng, C Geol, and Principal Hydrogeologist in SRK's Cardiff office, has over 40 years' experience in mining hydrogeology and engineering geological aspects of groundwater and water supply. He specialises in mine dewatering and slope depressurisation, water supply, groundwater pollution, acid mine drainage, groundwater recovery after closure and environmental audits. Currently, he is helping to develop integrated teams of SRK experts in water management to provide best possible services to clients.

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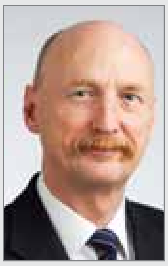
BRIAN MIDDLETON



Brian Middleton is a corporate consultant in SRK's Perth office. For the last 35 years, he has been involved in design, management and peer review of water projects. These projects include three major studies of the water resources of South Africa, undertaken for the Water Research Commission over the last three decades; the 65m high Ceres Dam; an environmental liability evaluation for a large chemical company; and numerous water management projects for mines and industrial complexes in many parts of the world.

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We have addressed many mine water management components in this newsletter, including the supply of water in arid areas, the protection of sources, depressurisation of pit slopes, water balances, storm-water management, water chemistry and last, but not least, disposal. We have tried to show where integration can save costs, in, for example, the use of boreholes for both hydrological and geotechnical purposes. We have showcased projects from various regions in the world. Some of the tools we use, including water balances, salt balances and risk assessments, are also discussed.

The partially flooded open pit in the picture is the result of poor implementation of storm water controls, and will lead to major expense in rehabilitation, as well as significant loss of production, and could have been avoided with due care.

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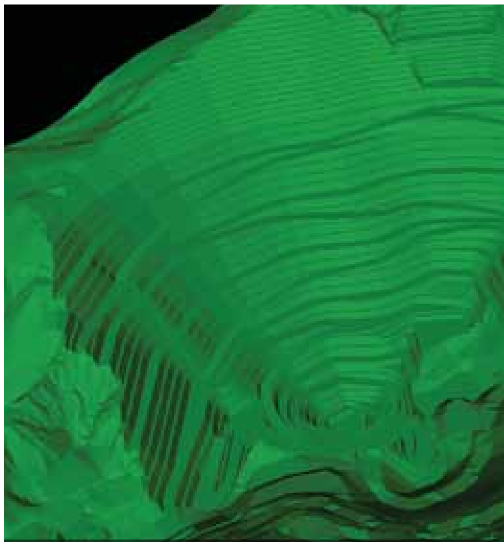
Artesian borehole



Proposed West Wall cutback layout in 3D

The Ok Tedi copper-gold mine in Papua, New Guinea is situated within a seismically active, mountainous region of extremely high rainfall. The current open pit is transected by several large faults, and the rock mass conditions are complex. Material permeabilities are variable, with considerable contrast within the major rock types and fault zones. The pit is being progressively deepened with ongoing mining, and a cutback of the West Wall is being considered, which would result in a final wall height of nearly 1000m.

The main factors affecting the stability of the West Wall cutback are:

- the quality of the various materials within the wall
- the position and nature of major structures
- the pore water pressure distribution behind the wall

Of these factors, only the pore pressure distribution can be adjusted to enhance

Drainage measures for ensuring the stability of the proposed cutback at Ok Tedi mine

Horizontal drainholes being drilled into the Ok Tedi West Wall

stability. In discussions with the client, SRK devised a phased modelling approach to assess the stability of the cutback design for the West Wall, and to investigate passive drainage requirements for ensuring stability. The modelling involved an iterative series of numerical analyses to assess the effectiveness of a range of drainhole designs with carefully selected spacings and lengths.

The phased modelling approach included the following steps:

1. Initial slope stability analyses of two sections, using small-strain finite element analysis (Phase² software) to determine the approximate position of the groundwater level (i.e. distance behind the face) and the pore pressure distributions required to maintain an acceptable factor of safety within the West Wall cutback design.
2. Unsaturated 2D and 3D finite element flow modelling, using FEFLOW® software, to determine the drainhole configurations required to achieve the pore pressure distribution that the initial Phase² modelling indicated will allow for a stable West Wall cutback. Identifying these requirements allowed the client to assess whether it was possible to implement the necessary drainage requirements within the time periods under consideration during the cutback.
3. Conducting confirmatory Phase² analyses, using the results from the FEFLOW modelling to provide better groundwater inputs and to confirm the lateral (i.e. out of section) spacing of drainholes required to maintain suitable wall stability. SRK performed the lateral spacing assessment using the groundwater conditions in sections halfway between the drainholes, as the 3D FEFLOW® modelling indicated.

IAN DE BRUYN

Ian de Bruyn has over 15 years experience in the geotechnical engineering field, over a wide range of projects in both the mining and civil engineering sectors. He has strong expertise in geotechnical assessment and in providing design parameters for open pit mining operations. He has worked on projects involving very large pits in challenging rock mass conditions. Ian's projects have involved site investigation, characterisation, analysis, evaluation, design, risk assessment and reporting at all levels – from conceptual through pre-feasibility, feasibility and working design.

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Based on the approximate expected mining period of the West Wall cutback, four excavation stages of one-year periods each were defined for this modelling exercise. Horizontal drains were activated sequentially in the model, together with the excavation sequence to simulate the proposed mining. The drainage designs required to maintain stability of the current cutback design at a suitable factor of safety were identified.

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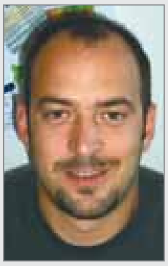
GOKTUG EVIN



Goktug Evin is a senior Hydrogeologist in the SRK Ankara office with over 8 years of experience. He specialises in groundwater flow, aquifer characterisation, including aquifer tests, 3D groundwater and transport modelling of both saturated and variably saturated media. Goktug has experience in GIS, remote sensing and spatial analyses. His mining projects include supervising hydrogeological site investigations, optimising dewatering systems, mine water supply and management and pollution control. He has worked on large-scale mining projects in Turkey, and on environmental and feasibility studies in northern Europe, Kazakhstan, and Saudi Arabia related to mine dewatering, pit depressurisation and pit lake hydrology.

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PETER SHEPHERD

Peter Shepherd is a Partner, Director and Principal Hydrologist in the SRK Johannesburg office. Having completed his BSc (Hons) in hydrology at the University of Natal, he has been with SRK since 1992. His specialisations include floodlines, dam hydrology, mine water management, river hydrology, water supply, strategic water assessments and flood management. Peter's recent mining projects were based around South Africa, as well as in the Democratic Republic of Congo (DRC), Botswana, Mozambique and Zambia. His project work has focused on flow monitoring, return water dams, stormwater control and mine water master plans.

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Designing field programs to maximise the capture of groundwater data

Installation of groundwater monitoring borehole

A good understanding of mine water management issues related to underground and open pit mines depends on collecting a comprehensive hydrogeological data set. Data collection is the most time-consuming and costly stage since it requires gathering substantial amounts of long-term seasonal data. With this data available, a conceptual model can be constructed and subsequently converted into a 3-dimensional numerical model to simulate and evaluate the mine development.

Where possible, SRK recommends that clients use exploration and geotechnical boreholes for hydrogeological purposes; this approach has many advantages. Exploration holes can be used for hydrogeological and environmental data collection, producing large savings in cost and time. Besides these advantages, it is possible to save on operational costs and protect the environment.

Operational cost savings. Drilling exploration holes can have adverse effects on mine development because they can link different groundwater systems hydraulically. In open pit mines, slope stability can be affected if groundwater seeps into sensitive slopes, thereby reducing stable slope angles or necessitating dewatering costs. In underground mines, hydraulic connection can lead to inflows and higher pumping and treatment costs.

The solution is to develop a preliminary understanding of the groundwater system integrated with a good exploration drilling management plan to ensure that boreholes are properly sealed after data collection if these leakage risks are present.

Environmental protection. When investigating sites such as waste dumps, tailings facilities and leach pads, special care must be taken to avoid opening up pathways for contaminants through investigation and exploration holes.

In recent years, SRK Ankara used many exploration holes for hydrogeological data analysis. At one of the largest gold mine projects (Koza Gold) located in Western Turkey, geotechnical drills with depths ranging from 200-400m were used. Important features were tested using

packer testing and holes were converted to piezometers to monitor phreatic levels or groundwater response during pumping tests. At the Kısladağ gold mine project, which will be the largest open pit mine in Turkey, a total of approximately 3000m exploration drills were utilised for hydro testing; a total of 100 packer test and airlift tests were conducted and holes were converted to piezometers for long term monitoring. For another feasibility study, the Yenipazar project, where a total of 1700m of exploration holes were converted to piezometers to monitor groundwater levels, the precise shape of the piezometric surface was modelled in a very early phase.

SRK advises mining clients to consider using all types of boreholes, particularly those developed in the early stages of a project for characterising the groundwater system. A properly structured and managed approach to borehole development can result in an efficient, environmentally-sound and cost-effective hydrogeological data collection program.

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Changing climate affects mine planning in South Africa

Research done in South Africa shows that change in the global climate is affecting the way local mines need to plan and build their infrastructure, particularly when it comes to water management.

Studies by Lumsden and Schulze show climate change is going to make the eastern parts of SA significantly wetter, and western regions drier. In the eastern areas of the country, this means mines will experience a disproportionate increase in the amount of water that spills into the environment, while mines in the western parts will need to manage their water resources with greater care.

Managing the on-mine water balance in drier areas is going to call for better re-use strategies, including continued improvement in the design and implementation of ways to keep water within the mine boundary, and to limit the amount of clean water that mines procure from municipal or other sources. Rustenburg Platinum Mines have already taken steps to reduce the amount of water abstracted from the potable water system. Initially, their allocation of water was greater than 50Ml/d but, after implementing water saving strategies, the actual potable water abstraction was reduced by 30%. Additional water saving strategies will reduce the potable water use by a further 20%. Not only is this reuse of water allowing the mine to expand operations, it is also allowing additional growth in the Rustenburg area.

In areas where more rain is predicted, mines face the prospect of breaking the law if their infrastructure cannot limit mine spillage into the environment. Facilities in these areas must be designed or modified to comply with the new parameters that climate change brings. The Amandelbult Mine has implemented stormwater controls to minimise the mixing of clean and dirty water so that even under significantly higher flows, the risk of flooding will be minimised. With flood hydraulics, doubling of the flow does not double the size of the canal; the addition can easily be managed with a bund about 500mm as the Amandelbult area has proved, i.e. it is not necessary to double channel size; new flood flow can often be met with nominal increase in height of containment wall.

Using the Lumsden and Schulze research, SRK scientists Phillip Hull and Hediya Ghassai predicted that a 40% increase in rainfall could more than double the amount of contaminated water a mine spills into the environment. As an example of this, a return water dam in the Eastern Limb area of South Africa must be built 30% larger than needed under present climatic conditions. Mines are starting to include climate change in their design but need always to keep in mind the implications of climate change for their site infrastructure.

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Water supply for mines in arid regions will become even more important in future

Managing salt levels in mine water

A water balance model is commonly used in the mining industry to monitor and manage the distribution of water within a mine; however, it is also vital to keep an eye on levels of salt in on-site water, especially as mine water is increasingly re-circulated in the interests of conservation. Water balance development is a core strength across all of SRK's global offices and water balance methods have been developed for every continent.

Mines use a water balance model to establish losses and determine how much inflow is required, mainly, to replace the evaporation and seepage from tailings facilities and return water dams. As mines comply with increasingly stringent water conservation regulations, they increase the amount of water that is re-treated and retained for use in the process plant.

This trend has generally had a positive impact on the levels of discharge from mines into their surrounding environments. The downside of this process, however, is that the salt level of on-site water rises steadily when it is not diluted by proportionate amounts of clean water from outside sources.

Under these conditions, certain dangers are introduced to the mining circuit:

- As the plant is designed for a certain minimum water quality, it may not operate optimally if salt levels impair this quality beyond a certain point
- High salt levels will corrode most metal components in a circuit, raising operational and replacement costs
- Steadily increasing salt levels will turn water into a brine that needs specialised removal from the site as a hazardous material

Salt balances developed for the Rustenburg area have seen the total dissolved salts (TDS) increase from about 1000mg/l ten years ago to about 4000mg/l, due mainly to efforts to reuse as much of the water as possible. This increase in TDS does not materially corrode the steel pipes but has been included in future budgeting and long-term replacement of steel infrastructure. Water treatment plants have been installed at Amandelbult mine to remove the salts and the water is used as potable water to reduce the mine's reliance on the already strained potable water supply to the area.

SRK employs a range of tools to monitor and control salt levels in mine water from a simple spreadsheet-based method that a mine can employ without specialist skills, to purpose-designed computer models that are more complex and costly.

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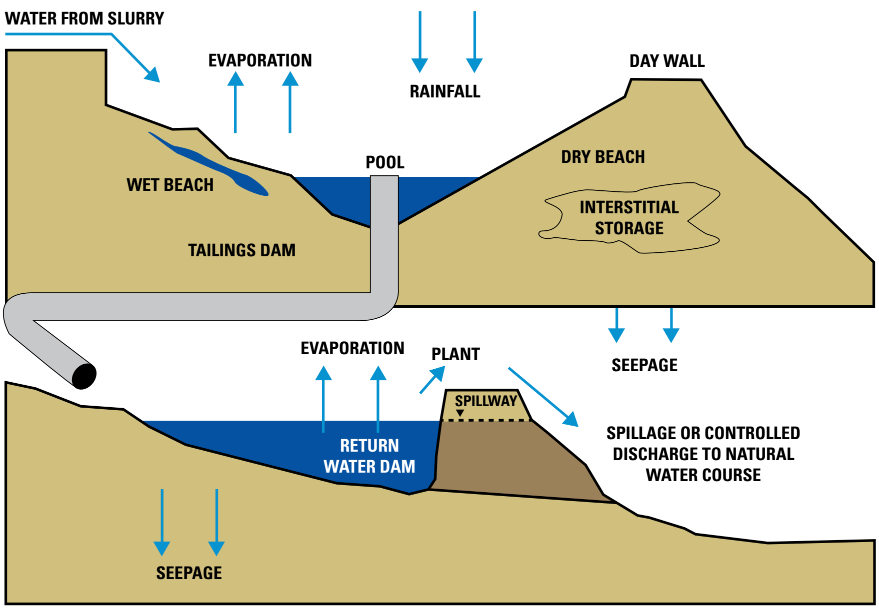

Water flows within a tailings dam and return water dam

Proposed mine site

The design of a mine water control system depends on many factors including:

- hydrogeological conditions
- dewatering or depressurisation requirements
- start, duration and rates of pumping at different stages of mining
- interaction of pumping infrastructure with mine planning and operations
- availability of drilling and pumping equipment
- contractor experience
- capital and operating costs
- production schedule for life of mine

The proposed mine site is located in Western Australia along a steep ridge. The ridge is made of steeply-dipping banded iron formations (BIFs), or iron-rich sedimentary rock, interlayered with felsic sedimentary and igneous rocks that host the iron ore mineralisation. The sub-vertical, high permeable BIFs act as a groundwater storage system.

Water control evaluation for an iron ore project in Australia

Mining will take place below the water table. The pit water control system must deal with the stored groundwater, rainfall recharge and the lateral groundwater recharge through un-mineralised BIFs, palaeochannels and open faults that cross-cut the area.

Based on the geometry of the formation and the design of the open pits that develop wider and deeper with time along the ridge, in-pit dewatering boreholes, along with interception boreholes located outside the pit perimeters, were recommended for the project. In-pit dewatering boreholes can interfere with the mining operations and affect the mine's efficiency. In order to minimise potential interference and support decision-making on the water control strategy for the project, an analysis was undertaken for several in-pit water control options. This analysis considered the location and orientation of potential boreholes, their longevity and replacement requirements, the estimated cost for each option, and the operational considerations during installation and operation of the system based on regional drilling experience and regional mine water control implementation. Next followed a qualitative risk assessment related to the planned dewatering system involving all stakeholders (project mining manager, project engineer, master driller, open pit mining engineers). The objective of the risk assessment was to categorise the possible implications and uncertainty associated with the design, provide detailed control measures for each identified risk and define residual risk after the control measures were implemented.

Using the above approach, SRK was able to present a recommended water management strategy for the project that met the requirements for dewatering and the mining operations in the most cost effective manner.

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SYLVIE OGIER-HALIM

Sylvie has over 10 years of experience in environmental geochemistry and hydrogeological projects in France and Australia. Her expertise lies in contaminants, groundwater investigations, extensive field sampling, and modelling. Since joining SRK Perth in 2008, Sylvie has been involved in geochemical and hydrogeological site assessment, developing hydrology and groundwater investigation requirements for iron ore, copper, gold and coal seam gas projects, fieldwork supervision, conceptual and numerical modelling, risk assessment, closure cost estimation, reporting and due diligence.

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LUKE ESPREY

Luke is a Hydrogeologist with SRK Perth and has approximately 15 years of field experience. His diverse skills set covers water resource studies and water allocation planning, catchment modelling, flood studies, plantation growth, yield modelling, and mine closure and rehabilitation. Luke's experience in mine closure and rehabilitation includes research in post-mining rehabilitation and consulting projects in both South Africa and Australia. Most recently, he has applied the SRCE Model on Australia-based mine closure projects.

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Collecting 3D data for dewatering of an underground uranium mine in Canada

ROGER HOWELL

Roger Howell is a Principal Hydrogeologist in SRK's Denver office, and has 30 years' combined experience in mining hydrogeology and exploration geology. He applies techniques of analytical hydrogeology, economic geology, and geochemistry, with his extensive field experience to the design and management of mine-dewatering, mine-water supply, water-disposal, and environmental-impact studies, primarily for the mining industry. Major projects have included hydrogeological characterisation beneath discontinuous permafrost at a gold property in Alaska, multi-year investigations to design and construct a perimeter-well dewatering system for a diamond mine in Northern Ontario; development of grouting and water-handling strategies for an underground platinum mine in Montana; and analysis of the stratigraphy and diagenesis of alluvial-pyroclastic basins in Nevada for the purpose of mine-water disposal.

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Installing grouted-in transducers

Predicting the volume and quality of groundwater inflows to a mine requires 3D characterisation of the hydrogeology in and around the mine site.

Full characterisation requires not only transmissivity, or measurment of the ability of rocks bordering the mine to transmit force and water pressure, but separate values of horizontal (Kh) and vertical (Kv) hydraulic conductivity of the units, and the spatial distribution of these values. With increasing distance from the mine, Kv values generally decrease in importance, while Kh and storativity values become more important.

Hydrogeologic studies commonly "piggyback" exploration or geotechnical drilling programs. Consequently, hydrogeologists, at least in early and middle stages of investigation, commonly make use of diamond-core holes, working inside small-diameter drill rods. For a proposed underground mine in northern Canada, SRK designed a program to test Kv across a thick sequence of cemented and recrystalised sandstones, with only an LF-50 core rig to install wells. Numerical pre-analysis showed that to produce sufficient pumping stress on the aquifer to determine hydraulic characteristics, would require a pumping rate of 10L/s for 3 days.

The pumping well (Figure 1) included sinking PQ drill rods to 300m, attached to HQ drill rods to 665m depth. These

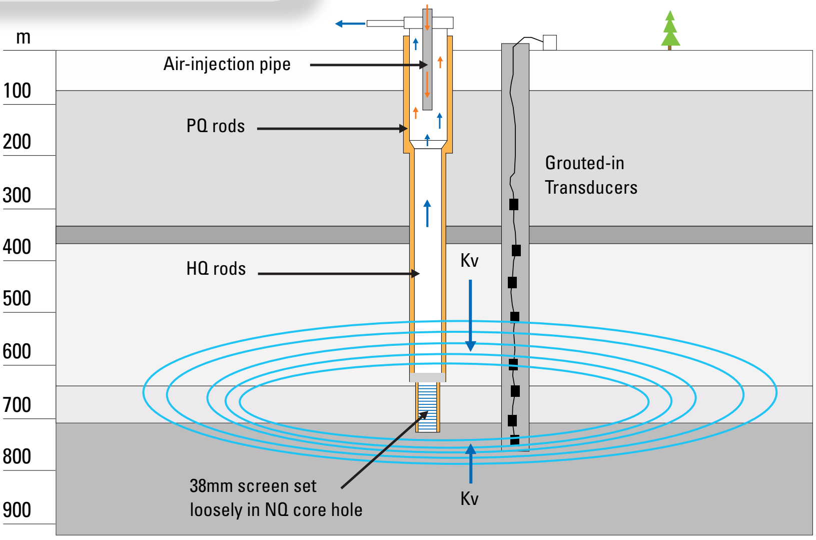

Figure 1: Pumping well and monitoring for test of Kv in deep sandstone sequence

rods were sealed with heavy drilling mud and cemented through the lower 30m. An NQ core hole was telescoped to a total depth of 715m, and a 38mm wire-wrap screen was lowered through the NQ rods to the bottom of the hole, sticking up loosely into the HQ rods. In a parallel core hole 18m from the test hole, packer testing defined a vertical profile of Kh, and eight vibrating-wire transducers were installed (photo above) to monitor the pumping test.

Pumping was achieved by airlifting in the upper PQ drill rods, and averaged 9.6L/s over the 74-hour pumping period. The PQ and HQ rods were cut and retrieved after the test. Pressure changes in the transducers were analysed using a simple MODFLOW model, and showed that high-angle fractures in the sandstones result in Kv values an order of magnitude greater than Kh values. The findings were used for numerical estimation of inflow rates under different mining and mitigation scenarios.

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Hydrogeologic challenges for data collection in the field

Mineral resources are often associated with complex geologic regimes that present challenges for conceptual thought, investigatory methods, data analysis, and numerical modelling. Geologic terrains that contain varied materials, mineralogic alteration, significant structure, hydrothermal activity, permafrost, and subsurface gas present challenging environments for a hydrogeologist.

In many instances, traditional hydrogeologic field techniques must be adapted, methods and equipment borrowed from other industries, or even equipment specifically manufactured for the task to ensure that the required quantity and quality of data is collected. The value of experienced field hydrogeologists cannot be underestimated as they apply the skills of the driller, engineer, plumber, general contractor and hydrogeologist under one hat.

Recent hydrogeologic field programs have yielded innovative solutions from many of our staff in Water Management. Three such adaptations are described in the following bullet points.

- Methodology development and installation of groundwater piezometers within high temperature hydrothermal and H_2S gas-bearing aquifers, utilising low-cost plastic materials, to depths over 500m
- Design and construction of artesian wellheads for arctic climates that allow for multiple instrumentation strings (thermistors, pressure transducers) to be installed down hole. Design also allows for simple groundwater sampling during the winter months, using a compressed air blow back system to remove water within the active zone that could potentially damage the wellhead and surface completions
- Design and coordination with a manufacturer to produce stainless steel cement baskets for HQ core-hole piezometers with internal diameters larger than presently available in the marketplace. The larger internal diameter in these cement baskets allow for completion of higher quality hydrogeologic tests and data collection in exploration drill holes

Adapting standard hydrogeologic methods or applying unusual techniques or adapting techniques from other industries is essential if we are to maximise the data collection and benefit to our clients. SRK is able to draw on the wide global experience of our water resources personnel to meet the specific challenges of a very wide range of geological and mining environments around the world. SRK can thereby assist our clients in making the best decisions for the operational, economic and environmental aspects of projects.

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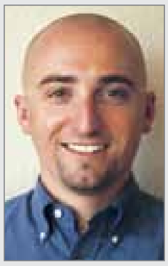
MATT HARTMANN



Matt Hartmann, P.G. is a Senior Hydrogeologist in the SRK Denver office with 10 years of experience in hydrogeologic characterisation, operational hydrogeology, and innovative drill program management. He combines his knowledge of hydrogeology with significant experience in drilling operations and downhole completion technology to design and implement field programs to investigate uncommon hydrogeologic regimes. His experience includes characterising high/low temp and gaseous groundwater systems, vadose zone and vapor phase studies, well field assessment and optimisation, uranium in-situ recovery development and operations, solution mining well design, and due diligence.

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Impact of quarry deepening on local groundwater users

A rise in demand for cement in South Africa led Pretoria Portland Cement to commission an EIA in 2007 to investigate the impacts of expanding one of its main limestone quarries. The quarry is located about 100km northeast of Cape Town, South Africa. SRK's Cape Town Groundwater Department, led by Partner and Principal Hydrogeologist Peter Rosewarne, was appointed to assess the risk to downstream groundwater users due to the deepening of the quarry and to predict the resultant increase in groundwater inflow and the amount and extent of drawdown.

PETER ROSEWARNE

Peter is a corporate consultant and partner with 35 years of experience in hydrogeology. He joined SRK's Johannesburg office in July 1982 and after working on various mining related projects in Gauteng and Mpumulanga he relocated to the Cape Town office in late 1984 to start up a groundwater section there. He now heads a team of 12 hydrogeologists, geochemists and technicians involved in mining, groundwater supply, nuclear sites characterisation, subsurface contamination and waste disposal related projects. Apart from the project described herein recent mining project locations include Skorpion zinc mine in Namibia, the Rystkuil uranium prospect in SA and Jwaneng diamond mine in Botswana.

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The quarry depth of 78m as of 2007 caused a zone of drawdown in groundwater levels in the surrounding shale aquifer, extending ~5km to the east but a smaller distance to the west, because of good recharge from the mountainous sandstone aquifer located there. Current groundwater inflow is ~200m^3/day, with an electrical conductivity of 260 to 310mS/m.

Using numerical modelling techniques, SRK showed that after 50 years of expansion, with the quarry at 180m depth, existing boreholes on the neighbouring farm to the east could be expected to dry up as drawdowns of up to 60m develop. The modelling also showed that quarry inflows could more than double by the time the quarry reaches full depth development of 240m after 75 years, with drawdowns of up to 100m. However, the model indicated that only a relatively few boreholes would be so affected.

Some of the mitigation measures SRK proposed included drilling new production boreholes to greater depths than existing boreholes (>150m) to tap deeper groundwater resources, deepening existing boreholes, supplying compensation groundwater from the extra inflows made into the quarry and providing compensation water from the plant's potable water supply feed.

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View of the quarry looking south

PROJECT	LOCATION
Orion South/Star	Saskatchewan, Canada
Olovskoye	Chita region, Russia
Goldfields	Nevada, USA
Paredones Amarillos	Baja California, Mexico
Elegest	Siberia, Russia
Elkon	Yakutia, Russia
Cerro Matoso	Columbia
Livengood	Alaska, USA
Silangan	Philippines
Hycroft	Nevada, USA
McLean	Saskatchewan, Canada

Groundwater flow in the vicinity of open pits and underground mines varies 3-dimensionally and with time. Assessing mine dewatering commonly requires the development of 3-dimensional (3D) numerical groundwater models, based on 3D geological, structural, and hydrogeological data, to fully characterise the groundwater flow. SRK often applies the finite-difference code *Visual MODFLOW-SURFACT* in mine dewatering projects. This code goes beyond the standard *MODFLOW* code to simulate saturated/unsaturated conditions (multiple water tables), open pit excavation (using seepage face cells and collapsing model grid), and dewatering wells using the fractured well package. The hydrogeological team at SRK Denver has used numerical modelling as an integral tool for the wide variety of mine dewatering projects listed in the Table above. All of these models were used to simulate passive inflow to open pits and underground

Applying numerical groundwater modelling for mine dewatering projects around the world

KEY COMPONENT
Two open pits penetrating very permeable deep sandstone groundwater system; comprehensive dewatering well system requiring optimisation
Underground mine intercepting a large volume of groundwater storage
Open pit excavating and pit lake infilling in environmentally sensitive area
Open pit excavating and pit lake infilling in environmentally sensitive area
Longwall coal underground mine under a large river
Deep underground mine within open taliks and subpermafrost groundwater system
Open pit excavating in vicinity of a large river
Open pit excavating and pit lake infilling in environmentally sensitive area
Two deep block caves with detailed simulation of cave/crack lines propagation to the surface
Open pit excavating numerous faults connecting with deep hydrothermal groundwater system
Evaluating freeze wall and grouting options for decline and underground mine workings

mines. Active dewatering options were modelled at Elegest, Orion South/Star, Silangan, and Hycroft; while pore pressures for slope/roof stability analyses were also used at Cerro Matoso and Livengood.

Potential environmental impacts to groundwater levels and surface water flows were modelled at Olovskoye, Goldfields, Paredones Amarillos, Orion South/Star, Cerro Matoso, Livengood, and Hycroft; with post-mining conditions, including pit lake formation or flooding of the underground mine modelled at almost all of the environmental projects.

Where active dewatering is required, the groundwater model was used to evaluate the most efficient dewatering option to reduce residual passive inflow to the mine (Cerro Matoso), and to define the optimal pumping rates and well spacings for the dewatering system (Orion South/Star). Where hydrogeological conditions are complex, the model was used to reduce both pumping costs and hydrogeological risks to the project (Elegest), optimising the mine plan.

In addition to predicting dewatering requirements and mining impacts, we have used 3D modelling to:

- Guide field investigations to test the most sensitive hydrogeological units and parameters (Goldfields, Orion South/Star, Livengood, and Hycroft)
- Analyse results of comprehensive testing programs where analytical formulas do not work (Olovskoye, Elegest, Orion South, and Cerro Matoso)
- Model block cave (Silangan) and longwall (Elegest) operations, where hydraulic conductivity values change in time and space above the mine area
- Conduct uncertainty and sensitivity analyses (in all of the projects in the Table above).

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VLADIMIR UGORETS

Vladimir Ugorets, PhD, is a Principal Hydrogeologist in the SRK Denver office, specialising in mining hydrogeology and groundwater flow modelling. He has 34 years of experience in hydrogeology, including 17 years in Russia and has been involved in numerous mine dewatering projects for pre-feasibility and feasibility studies, mine construction, and mine operation in US, Canada, Mexico, Russia, Kazakhstan, Indonesia, and Philippines. He has been involved in hydrogeological data analysis, developing conceptual and numerical groundwater flow and solute transport models, predicting quantity and quality of inflow into open pits and underground mines, estimating dewatering requirements and designing dewatering systems, predicting environmental impacts of mining and dewatering to water levels, streams, lakes, and swamp areas, and predicting pit-lake infilling during post-mining condition.

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Early stage hydrogeological assessments in Central and West Africa

Taking groundwater level measurements from an exploration borehole

The requirement to conduct a mine water assessment in the exploration to early feasibility stage usually has a dual purpose: focusing on initial engineering assessments (dewatering, mine stability, water supply, overall water balance) and on environmental and social aspects, typically in the form of an ESIA baseline study.

To meet these requirements it is often necessary to establish a common program of work, which involves developing an initial conceptual hydrogeological model (CHM), initiating a seasonal baseline water monitoring and sampling network, and implementing a preliminary hydrogeological testing program. Adopting a common work program to meet all objectives early in project development helps integrate and streamline the entire water assessment, so the findings can be assessed holistically. In other words, it saves on cost and time.

SRK has successfully developed this integrated approach to mine water assessment for many projects, a number of which have been located in the Congo basin and western Africa. This region is characterised by a tropical climate with contrasting dry season/wet season conditions, together with poor infrastructure, communication barriers, and widespread poverty and security issues, which are common to many parts of the continent. Adopting an integrated approach in this context provides huge benefits.

In one typical example in Congo, the early hydrological characterisation of a remote iron ore project was maximised through using existing exploration borehole infrastructure wherever possible, training site staff to maintain monitoring and sampling programs, and using portable hydrological equipment to ease logistics and minimise transport-related delays. The program included:

- monitoring groundwater levels from an extensive exploration borehole infrastructure (modified to function as standpipes) to provide hydrographs and water table distribution

TONY REX

Tony Rex is a Principal Hydrogeologist in SRK's UK office, where he manages the Water team. A Chartered Geologist with a PhD in geology and ore deposit geochemistry, Tony has over 25 years' experience in groundwater, environmental and brownfield management, combined with extensive business and project management expertise. Since joining SRK in early 2009, Tony has worked on a wide variety of mine-related water management and environmental studies in central and West Africa, Europe, Russia, Asia and South America.

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DAN MACKIE

Dan Mackie is a Hydrogeologist in SRK's Vancouver office, with over 10 years' experience, specialising in the physical hydrogeology of fractured rock and porous media systems. In eight years with SRK, Dan has been actively involved in open pit and underground projects, from exploration to closure, bringing an understanding of the full mine life cycle into his work. His project experience, from the Canadian Arctic to the Andes Mountains, has included a wide range of groundwater field and characterisation methods, numerical modelling, water management planning, engineering trade-off studies, effects assessments and closure planning.

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Lowering a submersible pump into an exploration borehole

- monitoring seasonal spring flows by constructing simple V-notch weirs
- sampling groundwater quality from springs and selected boreholes
- airlift testing rotary drill holes to provide groundwater yield data and identify broad aquifer characteristics
- downhole spinner testing to assess fracture permeability

At another iron ore project, this time in Sierra Leone, a portable, generator-powered submersible pump was used to carry out preliminary pumping tests in exploration holes at the pre-feasibility stage. The density of the exploration boreholes was such that drawdown responses in adjacent holes were detected, providing valuable data on groundwater characteristics and properties, which were subsequently used to predict early pit inflow rates.

In conclusion, evaluating the hydrogeological environment early in an exploration or project development program can provide invaluable information with significant cost benefits.

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Inflow water quality - Hope Bay, Nunavut

Mine water management in the Canadian Arctic involves a unique combination of technical challenges as a function of the geographical and geologic setting. Characterisation and planning for underground mine groundwater inflow management requires a thorough understanding of northern hydrogeology, as well as thermal effects, water quality and logistical challenges.

The Newmont Hope Bay Project, located in Nunavut, is planned to include multiple underground developments, all of which have technical challenges from the perspective of both groundwater characterisation and planning:

- Average annual air temperatures below zero degrees Celsius
- Permafrost (i.e., permanently frozen ground) to depths reaching 400m below surface and taliks (areas of unfrozen ground) below lakes
- Connate groundwater with salinities and metal concentrations often higher than sea water

The potential for saline groundwater inflow at many of the proposed underground developments at Hope Bay is a concern. Developments occurring within lake taliks, often within 100 to 200m vertically of the lake bottom, or below permafrost will not have the benefit of frozen ground to limit inflow. Regionally, some mines have experienced relatively high inflows of saline groundwater.

In 2010, an on-going groundwater quality sampling program was initiated within taliks and below permafrost. To develop a valid baseline, permanent installations were required capable of year-round operation through frozen ground. To provide this capability, SRK designed Westbay multi-level monitoring system installations, providing the ability to physically separate the unfrozen sample zone targets from the access pipe, which can pass through 400m of frozen ground. Using sampling tools passing through anti-freeze-protected access pipe, water samples and pressure data are collected from the target zones, allowing for development of vertical profiles of both water quality and pressure, after correction for density.

Results from repeat sampling have indicated that, at a minimum, inflow salinity will be typical of sea water concentrations. As part of QA/QC procedures, stable isotopes (oxygen & hydrogen) are collected to provide an additional comparison with drilling waters, to ensure that sufficient purging has occurred. Isotope data indicate water quality types different than drilling water, validating the sampling results.

The data collected has allowed SRK to better constrain predictions of potential inflow water quality, and provide valuable input to the development of site water management plans.

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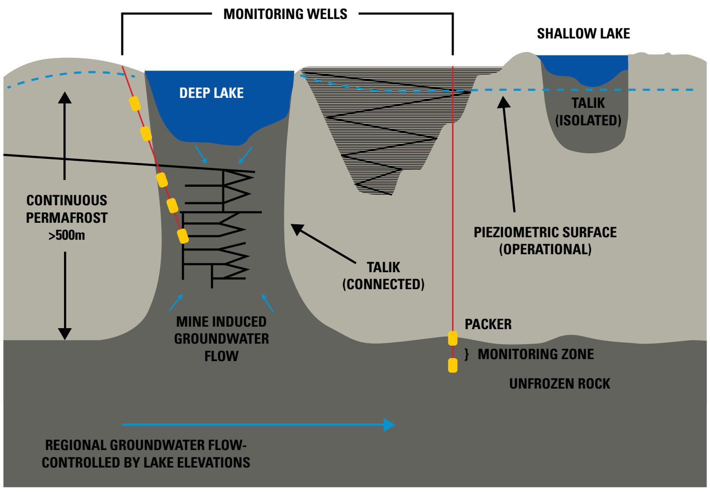

Surface water management in the jungle of Brazil

Beadell Resources Limited appointed SRK to prepare a feasibility study of the Tucano project located in the north of Brazil, in Amapá State, where the mean annual precipitation is approximately 2.4 metres.

The feasibility study included surface water management for the pits (Taperebá AB, Taperebá C, Taperebá D and Urucum) and the associated waste dumps. The main focus was to divert clean runoff upstream of the facilities and collect potentially impacted water downstream.

SRK identified three elements that required special consideration in this project:

- With the type of soils on site and constant rainfall year-round, finding the ideal scenario to manage sediment problems
- Locating surface water infrastructure with limited space and the existing and proposed mining facilities on site
- Given the proximity of the facilities to William Creek, identifying the minimum do-not-disturb area near the creek

SRK analysed the minimum particle size to be held in each of the retention ponds, using the results of site monitoring and geotechnical laboratory tests. Based on the results of the calculations, the expected values of total suspended solids (TSS), in most cases, were lower than the maximum TSS threshold; however, only approximately half of the turbidity values complied with the requirements, so adding flocculants was recommended.

The size of the surface water infrastructure was reduced by focusing on minimising the inflow of water from outside of the mine footprint boundaries, to deal with the limited space available. Additionally, including various lining materials, such as high-density polyethylene and riprap, minimised the design sections to optimise the land use.

Location of the sedimentation ponds was a high priority to reduce the project's impact on William Creek. Criteria included use of minimum catchment areas and minimum disturbance to the natural environment. The contacted water was collected in sedimentation ponds to allow solids to settle and, if needed, to add chemicals and flocculants. Clarified water from the sedimentation ponds will be discharged into the natural creek system that flows into William Creek.

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Sedimentation pond at Tucano project

Constant rate pumping test in the Arabian Shield

SRK has had extensive experience working on mine water supply projects in Middle Eastern countries, particularly in Saudi Arabia. The climate in this part of the world is mostly arid with very limited rainfall, runoff and recharge. It follows that one of the major challenges mines face is guaranteeing a sustainable long-term supply of water for the mine operation.

While there are some very extensive sandstone and limestone aquifers in the Middle East, which are particularly evident in the northern and eastern sides of Saudi Arabia, these sources have become severely depleted over recent decades as demand has vastly outstripped natural replenishment by recharge. With the exception of the phosphate and bauxite operations in the north of Saudi Arabia, most mining projects in the Kingdom are in the Arabian Shield on the western side of the country, at a considerable distance from any of the higher yielding sedimentary aquifers. For most mines located in the Shield, local

Mine water supply in the Middle East

wadi sediments and fractures in the crystalline bedrock provide the only sources of water; however, these scarce resources are also used by the Bedouin and local settlements and, therefore, are highly sensitive. Clearly, water for potable use by the local population invariably takes precedence over any planned industrial use.

Finding solutions to the scarcity of surface and groundwater resources and to strategic issues, such as local competition for the same resource, often requires an unconventional approach and considerable lateral thought. SRK has found that in this environment, it is especially important for the operator to tailor the mine production and processing to match the available resource and factor in any expansion programs at a very early stage to ensure that future water sources are reserved before being taken for other developments. Where the project requires more water than is available locally, then careful consideration must be given to improving management practices, to minimising wastage through paste technology, recycling water in the mine circuit, using advanced technologies like reverse osmosis, or the use of alternative supplies. For example, alternatives include piping water from more distant catchments, the sea, or by using grey water from nearby urban centres. Some of these solutions are expensive, so have to be considered within the framework of an overall cost-risk-benefit assessment. In some cases, it may be necessary to set up alliances with other mines, industries or local government to introduce economies of scale where water use would otherwise be prohibitively expensive.

SRK advises mining companies to consider assessing potential water resources at a very early stage, using all possible options to ensure that potential mine development is optimised to those available resources and not based on unrealistic expectations.

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WILLIAM HARDING

William Harding is a Principal Hydrogeologist with SRK in the UK. His 20 years of experience in hydrogeology related to mining includes Hydrogeological Impact Assessments supporting license applications for quarry extensions, well testing to characterise mine hydrology, numerical modelling to assess tailings seepage, and to design well fields for water supply and pit slope stability. His projects cover feasibility studies on pit dewatering for slope stabilisation, water supply, and mine water management. He has completed quantitative risk assessments of tailings waste facilities and performed due diligence for mergers and acquisitions.

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JUANITA MARTÍN

Juanita Martin P.Eng (Civil) is a Principal Consultant in SRK's Perth office with more than 20 years of experience in the coordination, design and supervision of civil engineering projects and in water management for mining infrastructure. Her experience includes the design of hydraulic structures for impacted and un-impacted runoff from tailings and waste rock dumps, retention pond and spillway design, the preparation of pond and tailings water balances, and tailings water management. Juanita has a broad base of experience from her work in climates ranging from the arid areas in northern Chile and Western Australia to the tropical areas in Venezuela and India.

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Water and chemical load balance for an underground mine in New Mexico

LARRY COPE

Larry Cope of SRK's Ft Collins office, is a Senior Hydrogeologist with a Master of Science degree, has 25 years' experience consulting to the mining industry. He specialises in aquifer hydraulic testing and analysis, hydrogeologic characterisation, mine water management, and environmental data management. Recently, Larry led the hydrogeologic investigations and mine water management at the Questa Mine in New Mexico, and currently he's investigating potential modifications to the mine water management system at the closed Homestake Mine, as that mine is converted to the Deep Underground Science and Experiment Laboratory (DUSEL) by the NSF and DOE.

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BREESE BURNLEY

Breese Burnley of SRK's Reno office has 18 years of experience in mine and municipal waste disposal site engineering, permitting, and closure. He specialises in planning design and implementation of water management facilities for closure of heap leach pads, tailings impoundments, waste rock dumps and landfills.

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V-notch weir to monitor rock pile discharge

Underground sump with flow meter

Developing a water balance for an underground mining operation can require a variety of measurement techniques to deal with the following challenges:

- Operational efficiency may result in mixing water sources that must be characterised separately to develop a detailed water balance
- Combining all waters in mine discharge may mask variations in flow and chemistry
- Operational activities can make components of the flow system inaccessible

Inflow from surface sources affects the otherwise relatively dry Questa Molybdenum Mine located in northern New Mexico. Mining by the block cave method has produced a subsidence zone that captures surface water drainage. Data collected for a comprehensive water and chemical load balance demonstrated containment by the underground workings. Detailed inflow mapping and chemistry of the various inflows enabled distinct sources of inflow to be identified.

The dewatering system was inventoried and instrumented at 14 locations with non-intrusive ultrasonic flow meters. Pumps were cycled using level switches to eliminate flow measurement interference from air bubbles entrained in the pipe flow by the pumps pulling air. Bag dams with v-notch weir plates collected and monitored inflows, and flumes were deployed in ditches with significant flows. The devices were fitted with data loggers for automated recording of data.

Field data logging instruments were adapted to the active mining operations where routine access to various monitoring locations is restricted. The unattended field instruments needed to be reliable in the presence of dust, high humidity and electrical power fluctuations.


Continuous monitoring of mine ditch flow

The data demonstrated that inflows balanced to within three percent of the measured mine discharge volume, indicating that virtually all inflow water was captured and contained in the workings. The chemical load balance, developed from quarterly samples at each flow monitoring station, enabled the sources of inflow to be identified.

Conclusions drawn from the investigation showed that 1) a high density of flow data and quarterly samples is required to address seasonal changes in inflow rates and chemistry; 2) creative solutions to adapt existing underground water management facilities can effectively monitor flows in detail yet minimise interference with operations; 3) ultrasonic metering of mine water pipe flow is viable and eliminates intrusive installations; and, 4) relatively simple data sets can provide critical insights to sources of inflow waters and chemical changes to them.

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Water management for closure, Nevada

This article describes 1) methods of locating abandoned boreholes within a side hill pit, and 2) the design and operation of in-line pH adjustment facilities for low-pH pit water.

Historic exploration boreholes in the base of Pit 1 at the Tonkin Springs Mine in central Nevada intercepted confined groundwater at depth. These boreholes were originally abandoned without sealing, which resulted in artesian groundwater flow into the pit base, contact with in-pit sulfide rock, and formation of a perennial "pit lake" in the pit base containing low-pH mine drainage.

SRK Reno developed a plan for locating and sealing known boreholes, including the construction of a system directing flows to the tailings impoundment to render the pit base "free-draining". During drying out of the pit base, SRK used survey coordinates and tracked "permanent" wet spots to locate open boreholes. The mine continued the process, closing more than 100 open boreholes over a three-year period, and reducing post-closure water management flow by up to 15gpm.

The pit sump is gravity drained via a pre-constructed HDPE pipeline that exits the low point of the pit and flows through an in-line pH-adjustment system and then to the tailings impoundment. The pipeline is buried below ground surface for protection against freezing and is laid within a secondary containment pipeline.

The in-line pH-adjustment system sits in a buried precast concrete vault. High-frequency measurements from flow and pH meters continuously adjust dosing pump speed and stroke length, adding caustic for a range of incoming seepage flow rates (0 to 52gpm). Caustic is injected into the pipe flow upstream from the meters, and water then flows through an in-line static mixer before reaching the flow and pH meters for continuous pH adjustment. A data logger is used to record and transfer pH and flow data to a laptop computer.

The pH adjustment system includes a sump-pump to keep the vault dry, a strobe to alert mine staff of power outages, a wall heater to prevent freezing/condensation, air vents with motion-activated fans to circulate fresh air, and sensors to detect pump diaphragm or caustic feed problems and automatic shut-off flow valves.

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DAVE BENTEL

Dave Bentel has over 30 years of experience providing engineering and environmental permitting services, and financial estimating services for mining facilities. He specialises in cost-benefit evaluations, using risk-based assessments of water and waste management facilities, and planning, design and implementation for closure and reclamation of mine infrastructure, processing plants, tailings impoundments, heap leach facilities, open pits and waste rock facilities.

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Caustic supply tank and in-line pH adjustment system – Tonkin Springs Mine, Nevada

Source water protection planning

A FIFA requirement for South Africa to host the 2010 Soccer World Cup was that host cities assure adequate and safe water supply for the event and visitors.

ANDREW WOOD

Dr Andrew Wood obtained a PhD in Pollution Control from Manchester University in 1983. After 5 years at the Council for Scientific and Industrial Research in Pretoria, he joined the Water and Environmental Technology (WET) group of SRK SA in 1989. Since that time, Andrew has specialised in minewater, waste and effluent management; waste minimisation and resource management, water and sewage treatment plant process design, the remediation of contaminated sites and risk management.

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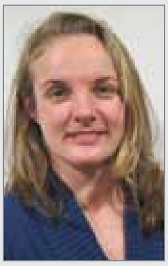
SARAH LYLE



Sarah Lyle is a Consultant Hydrogeologist with SRK in the UK. After receiving her master's degree in hydrogeology, she worked in South America for two years, where projects included hydrogeological mapping, numerical modelling and contaminant management for a large operating mine in Peru. Since joining SRK in October 2010, Sarah has worked on water management and characterisation studies in Central and West Africa, and mine-related environmental and feasibility studies in northern Europe.

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This requirement was in line with that of many municipalities in the United States to develop a Source Water Protection Plan (SWPP) for protecting and managing the supply of water to users and consumers, and is an initiative SRK has been working on with various industrial and mining clients.

The program has relevance for mining operations in understanding the vulnerability and sustainability of the water sources available to the mine, and the mine's impact on water source sustainability, while effectively collecting and managing information on their interactions within the water cycle.

A central component of the SWPP program is the Source Vulnerability Assessment (SVA), which is the process of assessing the vulnerability of the current water resources available to the mine on the basis of assured quality and quantity, in understanding the demands and threats to the available water sources, and identifying and determining alternative water sources that may be available to alleviate any threats to the primary resources, considering both groundwater and surface water as potential resources.

SRK has extended the SVA to consider the performance of on-site raw water treatment, storage and distribution facilities, and wastewater management and treatment facilities relative to corporate, international and national performance specifications.

Moving on from the SVA, a SWPP is developed, setting out a site specific water management vision, objectives and goals, action plans to meet identified vulnerabilities, resource requirements, time lines and budgets, monitoring, communications with authorities and associated interested and affected parties, internal and external performance audits, and continuous review and updating.

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Downhole flow logging

In hard rock mining environments, groundwater flow along fractures dominates. In order to understand the nature of fractures, and particularly those that are continuous and inter-connected within a wider fracture network, SRK employs specialist field investigation techniques. The opportunity to design and undertake such investigations within an integrated program of geotechnical and hydrogeological investigation can yield enhanced results. The collaboration enables a more comprehensive assessment of the groundwater regime around mines and specifically for open pits, pit slope stability.

For an open pit feasibility study in northern Sweden, SRK designed such an integrated study with the objective of understanding variations in horizontal hydraulic conductivity (Kz) with depth in the planned pit wall areas. Diamond-cored boreholes enabled the geological sequence – in this case fractured granitoids, diorites, phyllites, schists and skarns – to be accurately

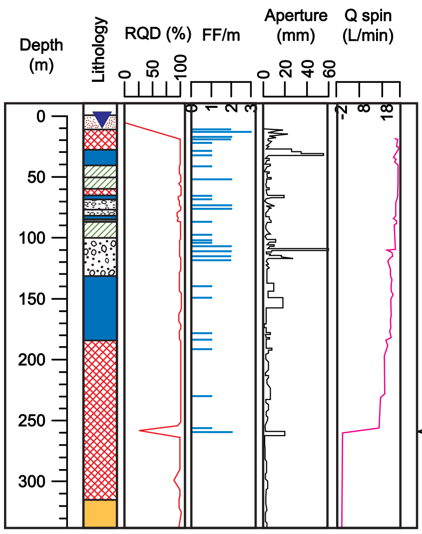
Integrated geotechnical-hydrogeological field investigations in Sweden

logged. The oriented core was logged geotechnically, for properties including Rock Quality Designation (RQD) and fracture frequency (FF).

The drillers were instructed to notify SRK's supervising hydrogeologist of any significant increase in penetration rate and any loss of drilling fluids during drilling. Such events indicate potential fracturing in the rock. In the example shown, evidence of fracturing occurred between 258m and 262m below ground level. A downhole acoustic televiewer (ATV) survey provided further detail of fracture characteristics, including fracture aperture at the borehole face.

When the drilling was completed, SRK used a downhole impeller flow-logging technique, known as "spinner" testing, to accurately assess the variation of hydraulic conductivity with depth through the sequence. The testing takes place under pumped conditions, using a portable submersible pump to quantify the induced flow (Qspin in L/min) from fractures down the hole.

In this case, more than 70% of the total flow was derived from a depth of 258m, corresponding to the main fracture zone. This, and other, flow horizons identified during the logging were then converted to a discrete measure of the fracture's permeability, using the total transmissivity (T) of the rock mass penetrated by the borehole.



Core log with spinner test results

The integrated study enabled SRK to evaluate the fracture characteristics of the rock mass accurately. Further, this approach led to the clear identification of an open fracture zone as the conduit for the majority of groundwater flow in the sequence. The application of these techniques enabled an improved understanding of the conceptual hydrogeological model and a more accurate prediction of pit inflows.

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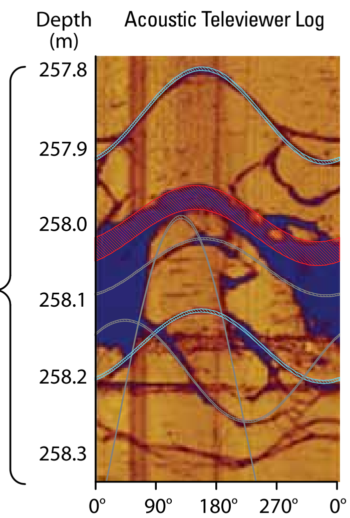

In-pit mine water control at the Grib mine in Russia

Drilling of hydrogeological boreholes and installation of pressure transducers

HOUCYNE EL IDRYSY

Dr Houcyne El Idrysy, PhD Hydrogeology, participates in high-level feasibility studies and projects related to groundwater resources evaluation and management. He is particularly skilled in modelling groundwater flow and contaminant migration, combining geostatistics, geology, GIS and numerical methods. His mining project experience includes the design and supervision of hydrogeological site investigations, optimisation of dewatering systems, mine water supply and management, pollution remediation and control. He has carried out projects that address landfill and contaminated land, assessing environmental impacts and risks of groundwater and surface water contamination related to mining, industrial development, agriculture, and waste disposal.

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SRK works with clients to develop effective strategies for managing surface and groundwater in open pit mines.

SRK recently completed a bankable level feasibility study for the Grib Diamond Mine in Northern Russia where many of the issues associated with controlling water in the open pit environment can occur.

The results of SRK's site investigation and numerical modelling of mine dewatering indicated that more than one depressurisation method would be required to optimise the pit slopes. The final design included a ring of vertical dewatering wells around the circumference of the pit to dewater the more permeable shallow formations, and several layers of sub-horizontal drain holes in the lower half of the pit to depressurise the less permeable strata. This design resulted in steeper, more stable slopes.

Given the environmental sensitivity of the nearby salmonid-bearing rivers, the project faced two significant water treatment and disposal challenges: the high incidence of suspended sediments in pit seepages with very poor settlement properties, and the elevated salinity of groundwater drawn from the deeper formations by the dewatering system.

SRK addressed the issue of suspended solids in water by using "Silt-buster" technology.

To solve the potential salinity problem during the final phases of mine life, SRK proposed two principal options:

Option 1. If only a small volume of brackish water is encountered in deeper formations, then the effluent from dewatering could either be disposed of directly to a nearby karst lake, or back in to the abstracted aquifer at a suitable distance from the dewatering operation.

Option 2. If the volume of brackish water is large, then it should be treated using reverse osmosis (RO) and the waste brine pumped to the karst lake.

There is a high cost associated with the installation and operation of an RO plant, so SRK introduced appropriate modifications to the dewatering design for Option 2 to delay its introduction. This for example included the use of bridge plugs to temporarily close off the lower sections of each dewatering well until such time that dewatering of the deeper formations was required.

In SRK's experience, the development of an effective water management strategy for open pit mines depends critically on close collaboration between the water, geotechnical and mining teams.

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Acid and metalliferous drainage

Sulfide bearing rocks in waste dumps, spent copper heap leach piles, ore stock piles, pit walls, coal spoil and dewatered tailings storage facilities can be long-term sources of water contamination. Sulfides, when exposed to oxygen and water, oxidise to produce sulfates and acid.

Under acid conditions a wide range of metals are more soluble. The resulting leachate is known by several terms, including acid and metalliferous drainage, acid rock drainage and acid mine drainage. Sometimes, interactions with rock neutralise acid. The resulting solution, though pH neutral, may contain high concentrations of dissolved solutes, e.g., sulfate and some metals.

In many instances, acid and metalliferous drainage have high level negative impacts on the environment and require high cost and long-term remediation and treatment measures.

SRK has extensive global experience in assessing the quantification of sulfate production rates, the prediction of leachate geochemistry, and the effects on receiving waters. We have also designed strategies to control the development of sulfide oxidation and have established methods to measure the effectiveness of the control strategies for clients.

Identifying the presence of sulfides in various waste rock types and ore across the deposit, on a sound statistical basis during exploration, and incorporating the management of sulfides into the early overall mine plan provides the best opportunity to meet regulatory and local community expectations, while maintaining control over water management costs.

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ANDREW GARVIE

Andrew Garvie, PhD Physics, is a Principal Geoenvironmental Consultant in SRK's Sydney office. He has 20 years' experience in assessing the potential of sulfidic mine wastes to oxidise and produce acidic and metalliferous mine drainage (AMD). Andrew has designed, managed and conducted site and laboratory investigations of the physical processes and geochemistry leading to AMD. Other project work has involved quantifying the effectiveness of AMD management strategies. His experience is international, including Australia, Indonesia, New Zealand, USA, Canada, China and Kazakhstan.

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Combined waste rock and tailings disposal facility at Martha Mine, Waihi, New Zealand. SRK staff evaluated the performance of the multilayer cover over the embankment constructed of sulfide bearing waste rock.

Water-related environmental studies for a coal mine project in Chilean Patagonia

SRK Chile has recently participated in defining the water base line required by the EIA to obtain an environmental permit for the Riesco Island coal project, and in other water-related works. Riesco Island is located 60 kilometers northwest of Punta Arenas in Region XII of Magallanes. The project involves a pit with an in-pit waste dump, external waste dumps, a stockpile at the port and supporting infrastructure. West of this project, the same company has started feasibility studies on another coal deposit. Because the local community has been very sensitive to the potential environmental impacts on Riesco Island, the studies have been carried out to a high technical standard.

BEATRIZ LABARCA

Beatriz Labarca, Principal Geologist from the Universidad de Chile, specialises in hydrogeology. She has over 12 years of experience in mine drainage issues and prospecting groundwater supply, and is an expert in simulating models of groundwater flow. Beatriz has a solid understanding of drainage aspects of fractures in underground and open pit mines and pressure pores in rock mass, in hydrological data management and basin balances. She has experience with design and construction supervision of pumping wells and observation piezometers, hydrochemistry, geophysical methods applied to hydrogeology, hydraulic testing, and legal consulting concerning water rights.

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The area has continuous rainfall, with average monthly values of 30mm and mean annual precipitation of 447mm/year. Studying the storm water management, conservation of the river water quality and protection of the peat and the watershed zones posed a great challenge.

Land forms in the project area are heavily influenced by the erosive action of old glaciers, generating deposits of moraine-type glaciofluvial materials, glaciolacustrine, drumlins, etc. The underlying bedrock comprises a folded sequence of Tertiary marine and sedimentary deposits that include sandstone intermixed with mudstones and siltstones (Loreto Formation). The several coal layers of economic interest are found in this formation.

The hydrogeological setting is dominated by two areas. The upper glaciofluvial layer is mostly an aquitard composed of heterogeneous material of predominantly low permeability. The lower layer is the Loreto Formation where the groundwater flows through zones associated with open joint systems or layers of high porosity within the sedimentary rocks.

SRK used its experience in fieldwork, including geophysical prospecting, piezometers drilling and installation, Lugeon testing and water quality sampling to understand hydrogeological systems and assess environmental impacts from future mining activities. Chemical and geophysical studies provided key information to interpret the hydrogeologic dynamics, as did the impact assessment study on the surrounding small lagoons and peat lakes. High tritium content, indicating younger waters in rock formation than in the glaciofluvial cover, helped to explain the recharge mechanism and provided valuable information for use in the future modelling of the pit dewatering.

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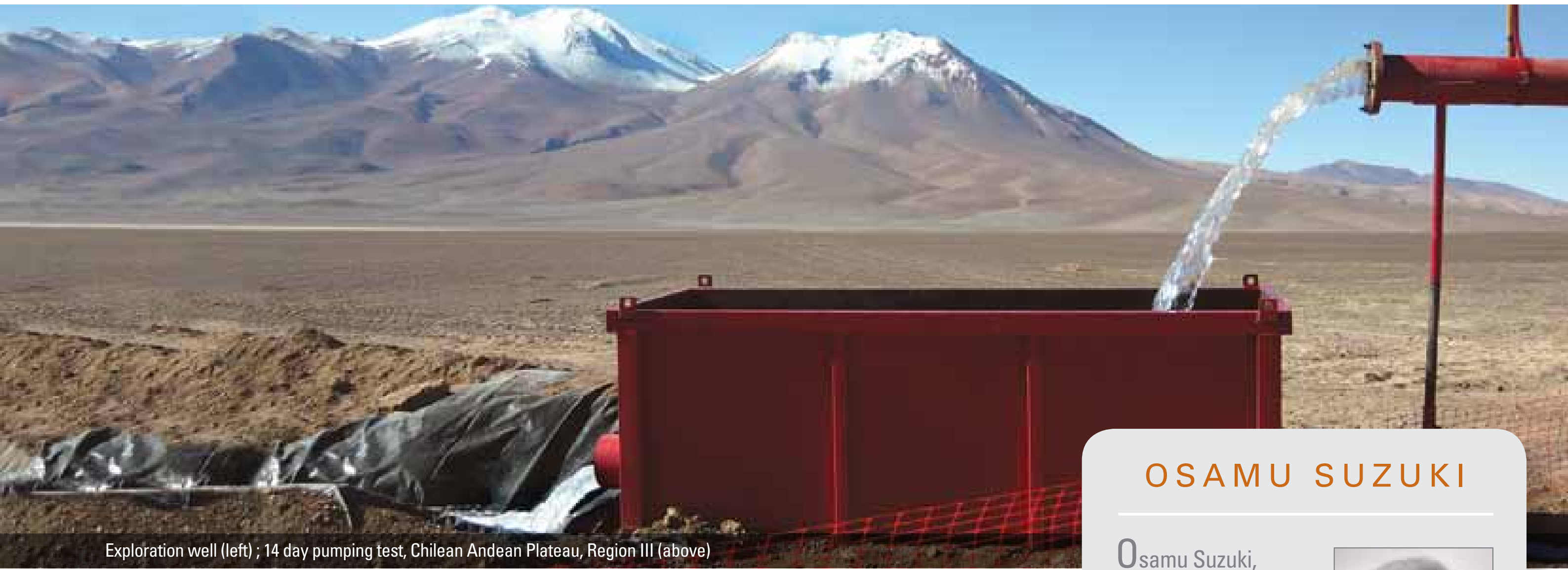
Large mining projects, currently being developed in Chile's northern region, are generally located in the Andes Mountains at altitudes of 3000+ meters above sea level. Possible sources of water supply for mining are the mountain aquifers and sea water. Due to Chile's geographic configuration, using sea water is always feasible, as the average width of the country in the northern zone is 150km to 350km. However, the great altitude for pumping increases the capital and operating costs.

Searching for water in the Andean aquifers is an alternative that poses a great hydrogeological challenge as these aquifers form part of complex geological systems. In a modern volcanic environment, periods of sediment deposition alternate between volcanic flows of different origins and poorly consolidated material of

Water supply: an increasing challenge in Chilean mining


Exploration well (left) ; 14 day pumping test, Chilean Andean Plateau, Region III (above)

varying grain size, and is structurally superimposed by a complex fault system which causes very deep and complex hydrogeological basins. Low rainfall in this high-altitude desert environment and the lack of meteorological stations to provide data on rainfall, snowfall and evaporation, make it difficult to predict recharge to the aquifer systems. On the other hand, some unique biotic ecosystems and water sensitive systems in the Andean valleys limit the ability to exploit these aquifers from an environmental point of view.

SRK has evaluated an aquifer located in Region III of the Andes Mountains at a median altitude of 4300 meters above sea level, which could ensure the water supply for a large mining project. The project, located approximately 125km from the well field, requires an average flow of 785L/s or 68 thousand m^3 of water per day.

The hydrographic basin, where a complex aquifer system has been identified, covers approximately 520km^2. Information was obtained from 16 pumping wells and 26 exploration and monitoring wells, as well as from the results of several geophysical, chemical and isotopic works.

The evaluation allowed SRK to define an aquifer system with excellent hydrogeological characteristics to support wells whose performance will surpass 100L/s. To verify that exploiting this aquifer will not cause adverse effects on environmentally sensitive areas, SRK built a numerical model of the aquifer operation, which demonstrated the feasibility of using the well field to supply the needs of the mining project with no measurable effects downstream.

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OSAMU SUZUKI

Osamu Suzuki, Principal Hydrogeologist with SRK Chile, is a Hydraulic Engineer with more than 38 years of experience in hydrogeology. In his 20 years as a consultant, he has led various projects for mining companies in groundwater resource evaluation and supply, as well as in technical aspects of water rights permitting and environmental studies related to water resources. Osamu has extensive knowledge of geophysical interpretation, water geochemistry, isotopic hydrology, and aquifer modelling, with in-depth training in laboratory and interpretation techniques of isotopic data at Waterloo University in Canada. He has served as a UNDP expert in hydrogeological projects in northern Peru and Costa Rica.

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Mine water management with GoldSim in Indonesia

Remote tropical mining location

SRK is carrying out a major water management study for a confidential client that is currently developing several coal contracts extending 150 km in Kalimantan, Indonesia. Our services cover water monitoring, supply, drainage, storage, diversion, discharge and closure planning over the life of the project and address design, costing and scheduling of all water and sediment management infrastructure. Given the complexity and scale of the project along with an average annual rainfall of 4500mm, key challenges lie ahead.

A fundamental component of any mine water management plan is achieving a representative water balance. This is especially difficult early in project development, as it relies on design specification data for forecasting water demand, and on environmental data for planning water supply, where information is often incomplete or inaccurate.

Typical demands include potable supply, process water, construction water, dust suppression and vehicle washing. All supplies must be identified and characterised for yield, reliability, seasonality and location. Balancing demand to supply yields over time becomes central for design specification, permit application, infrastructure scheduling, risk assessment and cost optimisation.

Modelling is used to evaluate risk and to identify and test strategies to secure a safe supply, integrating and optimising all of the mine water system flow, storage and quality processes. The resulting strategies determine infrastructural requirements, costing and scheduling.

Once the strategy is developed and documented, it can inform planning over the project life. With water usage increasingly constrained by social, environmental and statutory factors, the mine water management plan becomes important for operators and regulators alike, for all aspects of water usage, storage and discharge.

EWAN WILSON

Ewan Wilson leads SRK's new Mine Water Management and Environmental group in Australia. He is a Civil Engineer with a PhD in water management from the University of Birmingham. Ewan has 32 years' experience in water resources consulting in the mining, coal seam gas, industrial, public, aid and agricultural sectors. His experience includes providing support to all stages of mining development, from exploration through closure on projects in Africa, Asia, Australia, Europe, North & South America and the Pacific.

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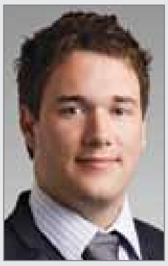
JAMES BLYTH



James Blyth is a graduate consultant with around seven years' combined academic and industry experience in environmental science and hydrology. Since joining SRK, James has worked on projects in Indonesia, Papua New Guinea and Queensland, which involved using the Monte Carlo modelling software, GoldSim. GoldSim has been widely applied to a range of work, including mine water modelling, reliability testing for freshwater sources and storage, and preliminary sizing and design of sediment ponds. Recent work includes modelling mine dewatering and supporting this with empirical estimates.

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SRK successfully applied the GoldSim package to the water balance studies: GoldSim is a modelling platform that supports dynamic probabilistic simulations.

The demand forecast was developed in liaison with our client and their design team.

Reliability estimates for the surface water storage and river intake were made using runoff models embedded in GoldSim to simulate operations using representative data in Monte Carlo trials. The trials reflected changing conditions in land use, runoff and infrastructure.

Model output was used to specify the river intake, pit sumps, water storage dams, sediment ponds and diversion channels.

SRK prepared a detailed preliminary water management plan, which the client is currently refining for subsequent project stages.

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Stormwater control on mines

South Africa's National Water Act of 1998 has highlighted the need to conserve its valuable resource in this water-scarce country. It lays down strict regulations on the discharge of contaminated water into the environment.

For the mining sector, the Act has required more effective control of stormwater – one of the main catalysts of contaminated discharge from mining areas. As part of the drive for best practice in this area, SRK assists clients with solutions that optimise the collection and containment of stormwater, and allow maximum re-use of water in processing. A key aspect of an effective stormwater control strategy is to isolate dirty water sources, such as workshop areas where oil may become mixed with surface water. Monitoring is also vital, to quickly establish the point and extent of any spillage from containment areas.

The water law has forced mines to focus on floodlines on or near their properties. In the context of climate change, mines need to proactively anticipate more frequent flood occurrences, which may exceed previous record levels. Mines' stormwater control strategies must address the safety of others – such as surrounding communities or downstream areas – if they are to remain compliant with the law. Flooding of tailings dams is a particular risk, and is strictly enforced by the Department of Water Affairs Dam Safety Office.

The drawing below gives a simple schematic layout of the requirements for the location and capacity of clean and dirty water systems. The basic principle of separating clean and dirty water is used in many countries and the criteria may vary from country to country (1:100 year is the norm in some countries). The regulation relevant to the drawing is presently under review in South Africa and the revised requirements will certainly require mines to implement additional stormwater controls.

It is not only external stakeholders that benefit from better stormwater control. Mines derive a direct and immediate value from the protection afforded to their own infrastructure by using better control mechanisms.

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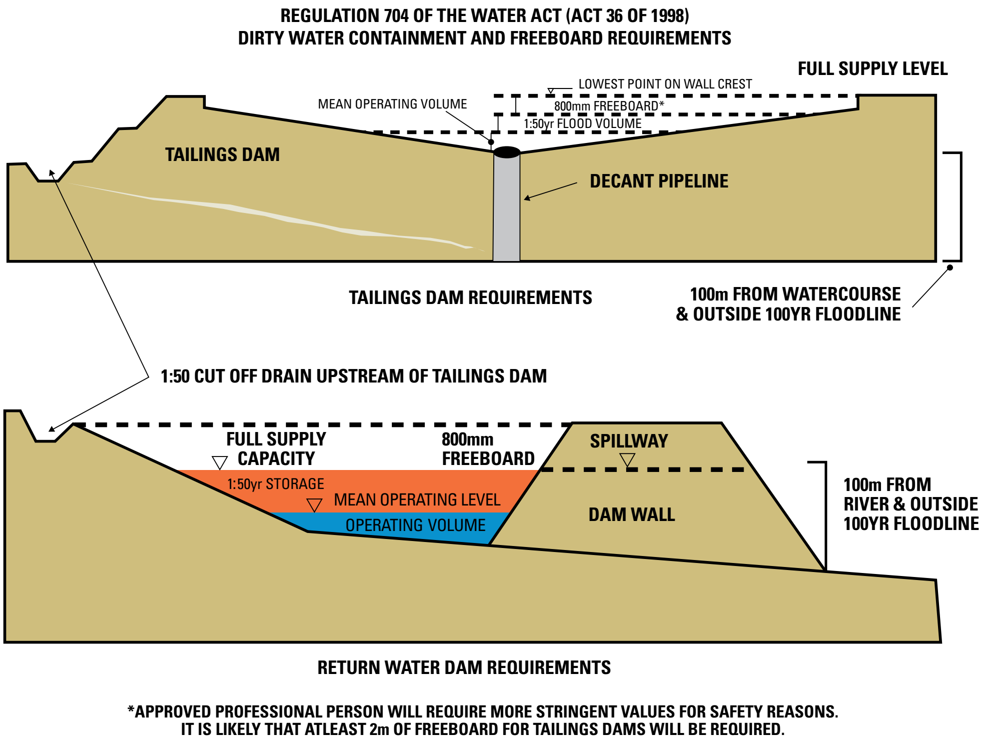

Managing sulfate impacts on water quality

Sulfate loading to a stream

TOM SHARP

Tom Sharp, PhD, P.E., is a civil/environmental engineer with 17 years of experience in mine water management, treatment, and remediation. Prior to joining SRK in 2011, Tom worked throughout the western US, both for mining companies and as a consultant to the mining industry. He has prepared site water and load balances, water quality models, water treatment evaluations and water management plans for environmental assessments, operating mines, mine closure planning and historic mines. He has also worked in operations commissioning and optimising the performance of water treatment systems.

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Sulfate is becoming more of a water quality problem for mining companies. Regulations governing sulfate concentrations have been flexible, and the unstated mitigation measure is often dilution of sulfate downstream. Federal water quality guidance in the United States characterises sulfate as a secondary contaminant with a maximum concentration of 250mg/l for drinking water. At the state level, sulfate concentrations may come into play when limiting total dissolved solids for water used for irrigation or livestock watering. In Canada, there is no federal but often provincial guidance for protecting aquatic life. British Columbia recently proposed a 30-day average sulfate concentration guideline of 65mg/l, and other provinces are also considering lower limits.

Regulatory scrutiny of sulfate is increasing and may affect mining operations and projects, as follows:

- In the southwest US, a sulfate groundwater plume impacting a drinking water resource is now actively managed by intercepting groundwater and incorporating its reuse into the mine plan
- In British Columbia, developing and implementing a sulfate management plan is now required for restarting a copper mine
- Sulfate concentrations in neutralised nickel laterite and copper leach solutions do not meet World Bank freshwater discharge standards

How can sulfate be managed to prevent impacts on water quality? The easiest solution is to limit the amount of water contacting sulfur-bearing material or process solutions. The most expensive solution is treatment. Treatment options include sulfate precipitation, ion exchange or membrane processes (e.g. reverse osmosis or nano-filtration) and biologically mediated sulfate reduction. All of these processes produce a residual sludge or brine that must be managed. Treatment costs for sulfate depend on site conditions, method, and sludge or brine disposal. Benchmarking studies suggest an operations and maintenance cost of $5/1000 gallons ($1.3/m^3), not

including sludge or brine disposal. Treating for sulfate is expensive and results from not planning for or managing sulfate impacts during operations.

The regulation of sulfate will only become more stringent. Sulfate loading will be questioned more frequently during permitting and become a greater environmental liability during operations and at closure. The time to begin managing sulfate is during mine planning. At a minimum, sulfate management should be incorporated into the operation's water management plan. Working with mine planners and operators to develop sulfate load balances is a good first step for predicting impacts, and these balances can be used to assess the benefit of mitigation alternatives. Comparing the cost of sulfate mitigation through improved water management to the cost of sulfate treatment can help justify proactive management to reduce sulfate treatment liability.

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Integrated mine water management

The success or failure of a mining project is often linked to site water management, or the lack of it. Risks to a project's success include tailings dam failures during storm events, slope failures related to elevated pore pressures, water in blast holes leading to inefficient blasting (adding costs and environmental impacts), lack of process water, and excessive closure costs.

To improve the long-term success of projects, mine water management should be integrated with other disciplines as part of the ongoing strategy during the design stage of mining.

As the opening article points out, overall water management on a mine site requires integrating all the components of mine design, operations, and closure. Too often, greenfield and feasibility studies ignore the connections between specific study tasks on a mine site, leading to a disconnect between critical path issues that materially impact the viability of a project (e.g., where proposed dewatering schemes ignore the impacts of discharging to the receiving environment). As a result, the overall feasibility of the project appears to be achievable until the details are considered together.

To avoid this problem and provide the operator with a water management plan that will work at site scale, the total mine plan should consider broad water issues from the initial design and construction through operations (including slope depressurisation, blasting impacts, dewatering volumes, and chemistry) to the water balance for the mill and tailings facility and water issues at final closure. To do this, the multi-disciplinary team must be coordinated from start to finish for a project's schedule.

An advantage that SRK has in this regard is the broad spectrum of multidisciplinary mining skills available within the organisation, which range from initial geological targeting to final closure design. Integration across all disciplines within SRK allows our water management specialists (hydrology, hydraulic engineering, hydrogeology, geochemistry, water treatment, civil engineering, tailings, environment, and closure design) to work coherently and cost effectively together, leading to an optimal outcome for mining projects.

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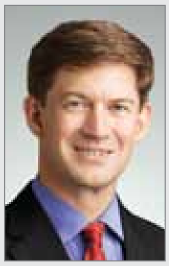
MICHAEL ROYLE



Michael Royle, M.App.Sci., is a Principal Hydrogeologist with over 25 years' experience in geology, groundwater instrumentation, and mining projects in Canada, PNG, Australia, Africa, USA, China, and Turkey. He has guided mining and groundwater resource evaluation projects, investigating rock mass characterisation, slope stability, mine dewatering, tailings dam seepage, and contaminant hydrogeology. Michael focuses on the design and interpretation of geotechnical/hydrogeological investigations, and deep groundwater monitoring programs.

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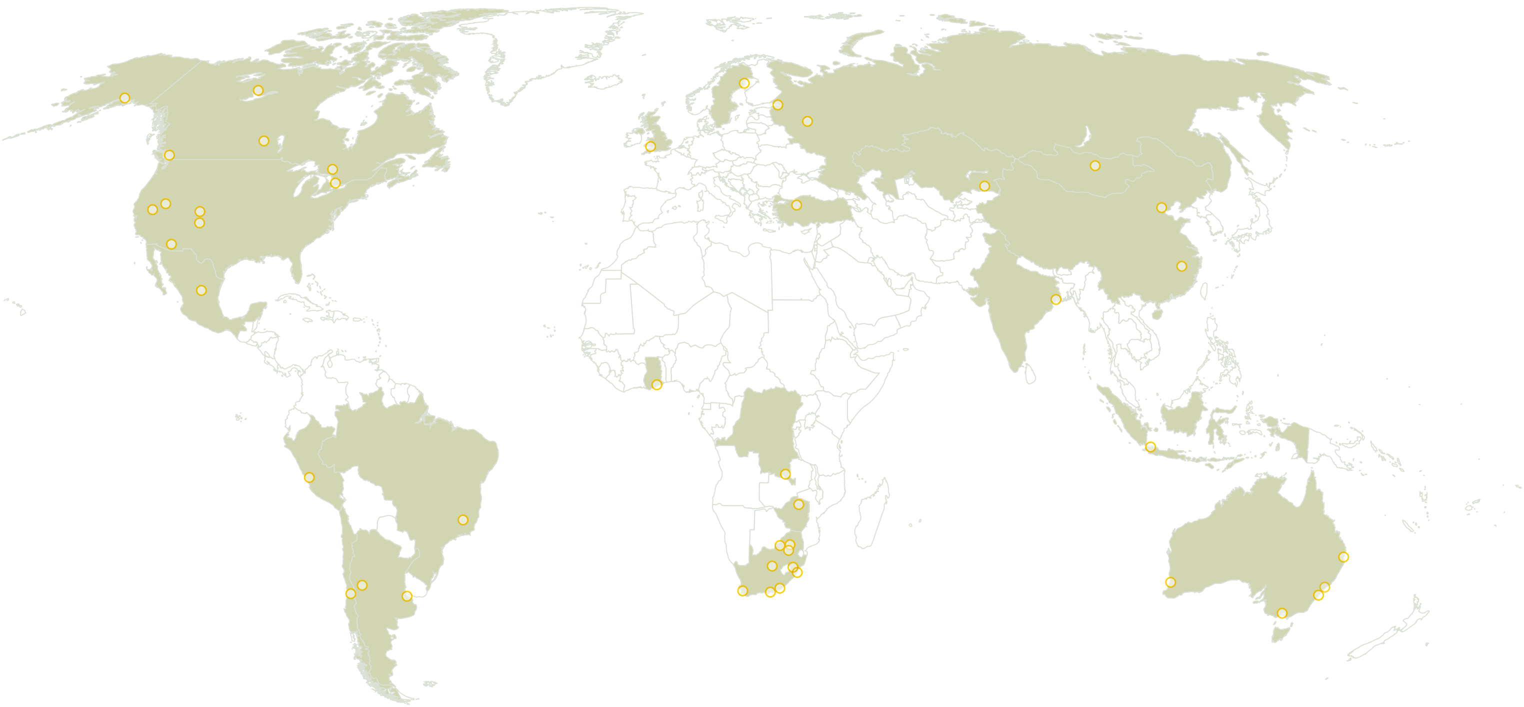
Typical interaction between pit lake & waste rock/source materials



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