Acid mine drainage at São Domingos, a deserted open-pit mine in Mertola, Alentejo, Portugal

In the flow

Water is a key resource for the mining industry, and mines require comprehensive water-management plans to be able to operate safely and sustainably. Nia Kajastie reports

> "Miners need to create an effective, comprehensive strategy that stretches from mine design to reclamation"

Water forms an essential component of both mining and mineral processing. Following these activities, however, the water that is left over can be a potential source of pollution for the surrounding environment. Moreover, a shortage or surplus of water, due to variations in temperature and rainfall, can create additional challenges at mine sites.

With all these variables in the mix, there is no simple solution for sustainable water management at mine sites. Nonetheless, to be able to mitigate risks and reinforce their social licence to operate, miners need to create an effective, comprehensive strategy that stretches from mine design to reclamation.

Although, pre-planning can only go so far in changing environments like mine sites.

"Reconciliation of planned versus actual operating conditions is critical to effective mine water management," says Michael Gabora, DHI's mine water practice lead and principal hydrogeologist.

"Moving from permitting to operations can be a challenge. Often what was planned may not work in practice, and design or water-management changes are needed, e.g. you might have dewatering rates that are twice what you expected. Having experienced water managers is crucial for navigating the start-up period and initial mine operations."

Accordingly, Gabora believes that water-management decisions require an understanding of today's conditions as well as knowledge of historical operations.

One could view water issues as only one of the many challenges facing today's mine sites, ranging from deeper, lower-grade orebodies to energy consumption; however, these areas are often interlinked in one way or another.

For example, issues such as the complexity of ore can make it more difficult to dewater material due to the fine-grinding process. "Basically, meaning that more material needs to be processed now, which in turn means more energy, increased cost of water, increased cost of spares and wears, etc," explains Niclas Hällevall, Metso's vice president for beneficiation solutions.

Water issues could also be exacerbated, today and in the future, by the effects of urbanisation, rising standards of living and anthropogenic climate change.

"Climate change is resulting in wider fluctuations of drought and flooding, impacting mine production. Miners are having to focus on resiliency planning, and this requires a focus on holistic and proactive water-management planning, rather than the reactive emergency response of the past," highlights Dennis Gibson, Black & Veatch's chief technical officer for mining.

Andrew Watson, vice president of Stantec's mining business, agrees that climate change poses a risk, and the industry is recognising that there could be "much longer-term trends and much greater variability than past data suggests".

Inevitably, water management is also under scrutiny due to recent dam failures and other environmental incidents that are directly linked to the water contained in tailings storage facilities.

Overall, as mining operations can cover vast areas of land, their impact on the local watershed could be considerable.

Among the potential sources of water pollution from mining, in addition to seepage from tailings facilities, are process wastewater, waste dumps and metal-concentrate processing facilities, lists IDE Technologies' project manager Roi Zaken Porat.

"Consequently, one of the major environmental hazards recognised in the industry is mine-impacted water or acid mine drainage (AMD), characterised by neutral to low pH and heavy metal content, which is an environmental issue, as well as a challenging and costly task faced by mining industries around the world," he notes.

Due to incidents that have caused widespread environmental damage, and even led to fatalities, the regulatory environment is getting stricter for miners. Stakeholder groups are pressuring them to use less water and to limit the environmental impact of their operations.

"As a result, mining companies are placing ever greater importance on water management to meet their own increasingly ambitious corporate objectives and maintain their regulatory and social licences to operate," says Gabora.

Looking at the big picture, Veolia's senior process engineer Marc Laliberte also believes that social acceptability is the key challenge that mining operators face today.

"In locations where mines have been operating for a long time this might be less critical, but for developing a mine in a new site? That's a major challenge," he says.

"We find that projects where the developer takes the time to listen to the community and address their concerns, that those projects have a much greater chance to move forward."

As such, water management is getting more complex and should be among the key considerations for the development of new sites.

FRESH START

Water-management planning should be addressed at the earliest stages of a project. Corné Pretorius, Black & Veatch's director of mine water management, suggests a multi-pronged approach to this programme; one covering safety, production and sustainability components to ensure social licence to operate is obtained and retained.

He explains that operators need to develop a thorough understanding of "the dynamic nature of both water quality and quantity projected for all future phases of the mine".

The unique properties of each mine site mean that some might have a surplus of water to deal with while others suffer from shortages. Thus, for their water programmes, some operators have to consider how they can manage excess water during major precipitation events, while other operations need to look for reliable supplies of water for the long term.

"This means stress-testing all assumptions that are made about the water supply," says Watson.

"In addition, demographics of the communities around a mine must be considered, as well as the fact that communities may increase pressure on the mine in the future".

Accordingly, when planning for all phases of the mine, it is critical to aim for the lowest possible impact on the environment.

"To make this more challenging," Laliberte adds, "you need to allow for changes in production at the mine and, most importantly, climate change. In locations where there is not a long history of weather data, this might become especially challenging."

What is clear is that responsible water management, which looks at conservation, tailings and mine

Veolia has developed and implemented biological treatments to nitrogen toxicity that work in adverse conditions and in very low temperatures

Mine water treatment plants ensure excess mine water is suitable for environmental discharge

reclamation, is becoming increasingly important for mines.

"The water-management programme for a new operation needs to be addressed by all stakeholders, and it must be a bottom-up, rather than a top-down approach, taking into consideration site-specific conditions," says Hällevall.

"It's no longer a matter of finding the most technically suitable equipment or solution, it is about transformation into sustainable development. The mining companies need to improve the conservation of water, chemicals and ore, as well as look for opportunities to reprocess tailings and generate value by extracting any remaining minerals."

These goals are further driven home by changes in laws and regulations, as well as public concerns over risks caused by mining practices.

"Non-compliance with waste-handling plans is a matter that can lead to a mine shutdown, which leads companies to invest heavily in relevant pollution-prevention plans," stresses Porat.

"On top of that, companies are also concerned with the quality of water used for mining applications, as well as the ability to recycle water and reuse it in the most efficient manner possible. It is therefore of critical importance for mining companies to treat their mining effluents and maximise their water recycling."

Naturally, management of water is not only critical for current, active mines, but also for the stages after mine closure.

"The phase during and after mine closure is crucial to maintaining the benefits and minimising negative impacts," says Dr Ing Oliver Stoschek, DMT's head of hydrogeology and water management.

"This can be achieved by not only reacting but taking a proactive approach by addressing problems early. Proactive, integrated water management is the key for sustainable water management. It takes into account chemical, biological, ecological and quantity issues for the water."

WATER SCARCITY

While not all mining geographies deal with water-scarcity issues, a Columbia Centre on Sustainable Investment report from 2014 noted that about 70% of mines operated by six of the largest mining companies in the world were located in water-stressed countries.

In these water-scarce areas, mining companies struggle with finding and employing reliable water supplies.

"Considering the variable hydrology issues being driven by climate change, mining companies need to be proactive in implementing an adequate storage system that can serve as a contingency in the event of supply downtime, which will help mitigate the risk of production losses due to a lack of water," Pretorius says.

Many mines struggling with a dearth of water sources also only have access to saline water.

"This makes water management challenging, both for corrosion prevention and in order to allow for eventual reuse of water," Laliberte notes.

The industry has, however, witnessed advances in desalination of both brackish water and seawater.

"Current desalination technology relies on reverse osmosis, which pumps water through semi-permeable membranes. Although cost-effective in certain geographies and applications, this technology has traditionally been limited, as it relies on high levels of energy and still leaves a resulting brine," Pretorius says.

"But new desalination technologies are in progress, and researchers are investigating new types of membranes and vaporisation methods, which may pave the way for future adoption."

Another possible solution for water-stressed areas is managed aquifer recharge (MAR). Gabora says MAR is currently being adopted by municipalities and communities to improve water security and minimise evaporation of water from reservoirs.

"This would allow for miners to store water during wet periods in aquifers for extraction during dry periods. Such an approach can concurrently reduce the hydrologic impacts to the groundwater system and improve water security," he explains.

Laliberte adds: "Another issue is that, while water may be scarce on average, it may be overabundant at specific times. Safely managing the excess while trying to recover as much of it as possible for future use is a challenge."

A Veolia-designed Zero Liquid Waste system installed at a mine site

CONSERVATION

As discussed, due to the scarcity of water in many mining areas, it is becoming more critical than ever to conserve this valuable resource.

A regularly updated water-use strategy is thus necessary; one that also takes into account the hydrological and hydrogeological conditions of a site.

"A comprehensive water balance including fresh water and process water use is needed for an integrated water-balance model for the entire water-management circuit, including all groundwater and surface water components, all water flows and interdependencies and meteorological background conditions for average, dry and wet conditions," explains Stoschek.

Indeed, the first step in improving conservation is understanding how water is used, stored and moved around a mine.

"This requires a highly monitored system (e.g. flows, water levels, etc.) that can be used to support a robust water balance. An accurate and regularly updated water-balance model can be used to evaluate management scenarios (e.g. hypothesis testing) that can be used to support decisions that reduce water use," Gabora says.

The second step would then be to get everyone on board by creating a corporate culture that values water conservation.

"Mine staff know that simple steps like minimising excess storage, minimising contact water and double-handling of water save both money and reduce the water footprint. However, these contributions must be prioritised, valued and rewarded by management," Gabora advises.

Conservation will also reduce mines' fresh water intake, while simultaneously minimising discharge of mine-impacted water into surrounding lakes and rivers. After all, large volumes of mine-impacted water can cause failures and environmental incidents at mines.

"It's crucial for mines to account for water in inventory, the total draw from external sources and the total quantity discharged to the environment. The goal? Make all these smaller," stresses Watson.

Porat believes new technologies and an efficient water-treatment strategy can help miners overcome many of the potential impacts of mining effluents and can also help produce high-quality water from the mine-impacted water.

Water could also be conserved in tailings management by exploring dry-stacking methods.

"Less water in tailings not only helps in recycling significantly more water to the concentrator, but also allows to reduce fresh water footprint compared to traditional tailings impoundments," Hällevall says.

To help mitigate mining's impact on water resources, many of today's miners are considering alternative water sources and treatment practices.

"When it comes to conservation, the industry is focusing on recycling ►

Having less water enter the tailings system will lower the risk of failure and create less mine-impacted water

> "With the highly publicised tailings failures of the last decade, many mine owners are being urged to implement dry stacking"

and reuse to help increase fit-for-purpose usage towards net-zero water use. Fit-for-purpose water use should be carefully explored to help reduce fresh water demand throughout the entire life cycle of the mine, from exploration to closure," Gibson says.

This could be in the form of reusing effluent from a mine, or from a different company, for another operation. Accordingly, Gibson recommends collaboration among miners to develop "catchment-wide water-management solutions that incorporate other off-takers and users". In this way, one user's waste stream could become an input for another.

"Mining companies are also setting fresh water use reduction targets that are supported by specific action plans, typically on a five-year horizon. This transparency is encouraged by community and regulators alike and goes a long way to engendering positive relations between affected parties," he adds.

WATER IN TAILINGS

Tailings consist of a mix of water, residual chemicals and ground rock, which are by-products left over from recovering minerals and metals from mined ore. They are often stored in tailings dams that come in different forms, such as the upstream design of the dam at the centre of the fatal Brumadinho disaster in Brazil at the beginning of this year.

Other options for tailings storage include paste/thickened tailings and dry stack/filtered tailings. Pretorius notes that, with the highly publicised tailings failures of the last decade, many mine owners are being urged to implement dry stacking.

"Because this may not always be feasible, it is even more important to design tailings facilities in such a way that the water balance can be effectively controlled over a wide range of climate and process conditions," he says.

Laliberte agrees that, as tailings impoundment areas can be seen as a major liability, the key issues related to water are to equalise the flow of water during events such as spring freshets and heavy rain events, and to make sure that tailings are managed in a way that their contamination will be as limited as possible.

Overall, having less water enter the tailings system will lower the risk of failure and create less mine-impacted water.

"The facility operator should be able to discharge clean water to the environment and prevent the risks associated with retaining mine water in tailings facilities beyond what is needed for conveying and placing the mine waste," Pretorius adds.

Watson explains that the long-term aim is to have a well-consolidated and stable landform, and that "this is best achieved by having a drained mass of tailings that is less susceptible to liquefaction".

Thus, some mining operations choose to employ dewatering to produce thickened tailings. This could be for various reasons, including lack of pond space that might cause overflow and surface water pollution, says IDE Technologies' Porat.

"Alternatively, it could be the need to blowdown some of the tailings water to ensure regulatory demands are met (for chemical

concentration of metals and minerals in blowdown). Whereas for others, especially in arid locations with little make-up water sources, dewatering is a tool for reusing tailing water instead of allocating new, high-cost make-up water," he continues.

Due to the various constraints on the design of tailings storage facilities, there is no one-size-fits-all solution. However, Hällevall says Metso sees dry stacking as the most promising and sustainable tailings-handling solution.

"And it's not only about tailings. Reprocessing should be considered as a part of tailings treatment. It is an opportunity to help in environmental reclamation, while at the same time offering an attractive investment opportunity. Treating legacy dams as a potential source for converting 'waste to value' is an essential part of our solutions," he adds.

DIGITAL SOLUTIONS

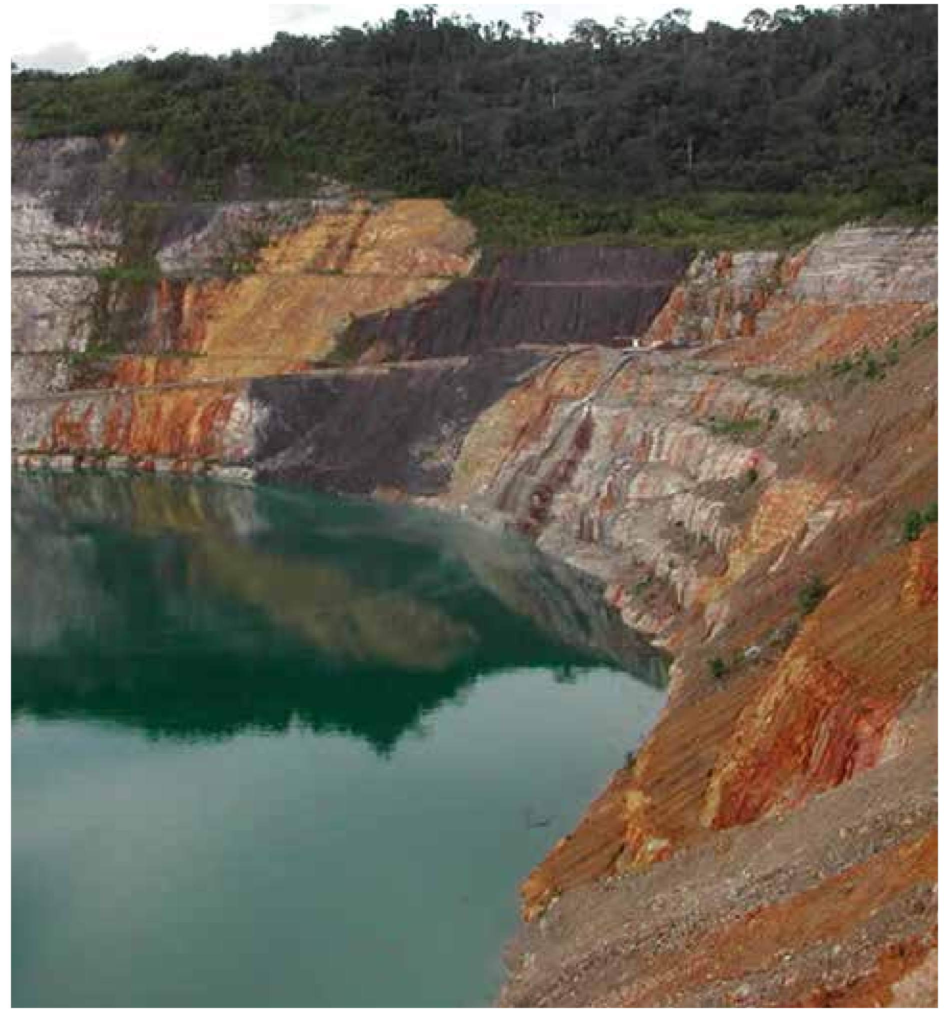
"What gets measured gets managed," notes Stantec's Watson. Indeed, having access to data, which can nowadays be obtained in near real time or even real time, helps mine operators make informed decisions and manage risks. And water management is no different to, say, fleet management, in that data can be collected through sensors, then monitored and analysed via various digital platforms.

"Internet of Things (IoT), digital twins, artificial intelligence, etc. Buzzwords or solutions?" asks Stoschek. "Digital systems can indeed help in saving money and optimising production.

"The latest technologies can help follow a raindrop through the system by monitoring water levels, pumping volumes, process water volumes, discharge volumes and water-treatment plants."

Sensors can be linked to things such as flow rate, water quality and slurry density, among other things. Naturally, the sensors alone don't form a full digital system.

"The data needs to be available online, stored in a central place and analysed automatically. Then data is accessible via dashboard anywhere, anytime and from any device, and can be used to optimise the water flow in a mine. At this stage, an expert can use this detailed knowledge about the water balance to define optimised strategies," Stoschek says.



Managing pit lakes is a key component of mine remediation

So, in effect, when a remote-sensing network is paired with data analytics, miners are offered better situational awareness.

"[This enables] operators to better monitor process information (e.g., identification of inefficient water circuits, leak minimisation, pressure regulation); create simulations; offer insight into water balance simulation; provide water-quality data; and monitor the health and status of assets such as pipes, pumps and valves," lists Black & Veatch's Gibson.

With this data at hand, miners can monitor, forecast and adjust operations to potentially boost efficiency and remove unnecessary waste. In addition to affording them a 'real-time' view of data, these types of tools also offer real-time post-processing of data and updates of predictive model results.

"Having your predictions of future conditions updated on a continuous basis leads to significantly improved decision-making. Furthermore, the automation of many of the analyses required to see the data in the required formats provides valuable time back to water managers; time they can use for understanding the dynamics of the system and testing hypotheses that ultimately lead to better decisions," explains Gabora.

While remote monitoring has come a long way, on-site support is still often required.

"This makes sure [water management] is more focused and that whoever is on-site has the right tools to correct the issue," highlights Laliberte.

"Veolia has developed an all-in-one digital service called Aquavista that helps assist mines with real-time remote monitoring of their water-treatment systems. It is accessible at anytime, anywhere, which is beneficial for remote mine sites to efficiently manage their water treatment equipment."

With digital twins of operations, the industry is basically one step closer to fully autonomous systems, which would include the introduction of artificial intelligence. Thus, the final step towards full autonomy is data being analysed by self-learning algorithms.

"[For digital twins] data will feed a numerical model of the whole water circle in a mine. The computer and models are powerful and can digitalise detailed water networks and run them in a short time to provide a forecast," says DMT's Stoschek.

"The mine water forecast depends on the accuracy of the weather forecast and can provide a prognosis up to seven days; e.g. dewatering can be optimised by knowing historical and forecasted volumes, the water storage pond can be managed more effectively, and diversions can be planned."

Digitalisation, as Hällevall sees it, will transform the mining industry at an accelerating pace by providing a higher level of dynamic information.

"Digital technologies, such as advanced control systems (ACS) using self-learning functions, provide customers with a solution to monitor the operation of their filter," he points out as an example.

"Other software tools, such as multidimensional simulations, allow mines to operate closer to the efficiency frontier by constantly monitoring, reacting, adjusting and optimising the process – resulting in better throughput with less water and energy usage."

POOR PRACTICES

So, what about the worst-case scenario? What are some of the consequences of poor water management? As we've seen, some water-related incidents can pose a risk to workers' lives, local communities and the environment. Moreover, accidents and the damage caused could cost miners their social licence to operate.

"There are several examples of mines being forced to stop operation or even close for substantial periods of time due to 'poor' water-management planning," Pretorius confirms.

According to Watson, poor water management can lead to limitations on the scale of an operation – if there is too little water to operate or too much water to store, water becomes the limiting factor for the mine's growth.

"Poor water management issues can lead to operational upsets that impact cash flow or long-term liabilities that impact the balance sheet. Finally, poor water management practices can result in environmentally impaired sites that can't be relinquished after closure," he adds.

Mines might have to halt operations due to inadequate water supply, failure of tailings storage facilities, flooding, operational failures

A Veolia Zero Liquid Waste facility

"Poor water management issues can lead to operational upsets that impact cash flow or long-term liabilities that impact the balance sheet"

Tailings consist of a mix of water, residual chemicals and ground rock

or spillage into the environment, Pretorius explains.

"These failures can seriously affect a mine's reputation, revenue through loss of sales, operational costs (e.g., energy, labour and treatment requirements), as well as regulatory, community and shareholder trust, which may take years to recover."

In fact, in some cases, mines can be fined or shut down by regulators.

"There are many examples where failure to perform has led to fines, permit revocation, significant environmental impacts and the loss of a social licence to mine," DHI's Gabora says.

Veolia's Laliberte, in turn, believes that most operators would immediately think of potential fines or having to reduce activities.

"But, in my opinion, the major risk of poor water management is losing social acceptability," he continues. "If the local communities lose confidence in the mine operator and decide to actively oppose operations, because they are afraid of the consequences of the continuing operation of the mine, this is usually the beginning of the end."

Pretorius adds: "Because mining operations have the potential to significantly impact groundwater resources in their surrounding environment, mining companies need to give serious consideration to sustainable yield and water-quality impacts, impacts of surface discharge or depletion on local communities and the health of the environment."

THE FUTURE IS HERE

As has become abundantly clear, water is crucial for mining. Without it, operations cannot operate nor produce the resources the world demands.

And the future of water management – well, in many ways, it's already here, Watson claims.

"It will have the attention of board members and investors; it will include real-time sensing and reporting of flows, and information on water inventories and quality; fresh water will be off limits to miners in arid regions (like Chile), so the cost of water will be greater; and the industry will make more efficient use of much less water; and miners will be taxed or otherwise charged for the quantity of water touched by the operation," he lists.

And he's right; many of these points are already on the agenda for the mining industry.

Some mining companies are also becoming increasingly proactive and forward-thinking as they embrace new technologies and digitalisation.

"The key that will unlock the full potential, however, will be learning how to best gather, manage and analyse this information in such a way that [the sector] can alleviate ongoing asset-management challenges," notes Gibson.

"The use of data analytics and increasingly sophisticated modelling tools is sure to improve the management of mine water. Plus, new water-treatment technologies and solutions will only continue to develop and improve."

Gabora agrees that the future will be driven by the digital transformation of water monitoring and reconciliation systems that provide decision-makers with a combination of real-time information and continuously updated predictions of future operating conditions.

"This requires the integration of data across various disciplines and data silos within the organisation, which can be a challenge. However, these efforts are rewarded if these powerful tools are used to support decision-making by reducing costs, minimising water-related safety risks and protecting the environment," he says.

Stoschek also believes that mine water management of the future will incorporate more effective water treatment.

"The discharge from a mine needs to be of drinking water quality," he stresses. "This water can be used for irrigation or water supply of nearby villages. Further on, the mine water can, to a certain extent, replace water from melting glaciers. By having a continuous discharge from the mine, it can help rivers to be filled with water even during summer and keep them ecologically active."

The focus on mine closure and post-closure strategies, sustainability and miners' social responsibility will grow in importance. This, again, means looking at other options than traditional tailings storage facilities. ►

> "The major risk of poor water management is losing social acceptability"

IDE Technologies on water treatment

Mine-impacted water is often produced when sulphide-bearing material is exposed to oxygen and water to form sulphuric acid. The longer this type of wastewater goes untreated, the more costly and challenging the problem could become. Other than sulphate, there are usually elevated levels of calcium present in mine-impacted water, as dolomitic rocks dissolve into the water. These two ions, which can be close to their saturation threshold, make it very challenging to treat mine-impacted water.

The existing sulphate-reduction technologies can be divided into the three main groups:

- Removal of sulphate by membrane technologies such as reverse osmosis, nanofiltration or electrodialysis. These technologies produce a highly saturated brine that should be further treated before disposal;
- Removal of sulphate by salt precipitation such as gypsum precipitation through ion exchange removal, precipitation of insoluble sulphate salts through chemical saturation and precipitation to produce gypsum (calcium sulphate dehydrate), barite (barium sulphate) or ettringite (a hydrous calcium aluminium sulphate mineral). These technologies consume an enormous quantity of chemicals and might add other ions (such as chlorides) to the water; and
- Biological sulphate reduction to sulphide under anoxic conditions.

The recent regulatory demand in North America, the UK and elsewhere to achieve low sulphate concentrations of 250-500 mg/L makes it difficult for existing technologies to meet the challenge while remaining economically viable, explains IDE Technologies' Roi Zaken Porat.

Therefore, it is necessary to develop new technologies to address the new challenges. The main challenge of minimising the quantity of produced wastewater is wastewater chemistry itself. As the concentration of wastewater salts increases, there is an increased risk of treatment process failure due to the precipitation of salts on all available surfaces.

A recently developed technology by IDE Technologies, an Israeli-based specialist in advanced water treatment solutions, is the $MAXH_2O$ desalter, which contains a reverse-osmosis (RO) system with an integrated salt precipitation unit that overcomes this limitation. This technology gradually removes low solubility salts (such as calcium sulphate) in the salt precipitation unit, while concentrating them in the RO system, with minimal usage of chemicals. The produced brine can be blended with RO permeate, or can be treated in a high-density sludge process with lime addition to maximise the removal of components.

"Eliminating tailing dams removes the risk of dam failures and potential loss of lives and property. In addition, it eliminates the possibility of groundwater contamination, while preserving both the surface water and the groundwater by eliminating leaks and acid leaching," Hällevall says.

"At the same time, water is getting scarce. Water conservation is a must. In 2018, less than 5% of tailings were dewatered in one way or another. The figure speaks for itself – the industry needs sustainable transformation."

As such, he believes dry tailings will be established as the industry standard within a few years.

In the future, there will also be an even greater need for improving community relations.

"[It] is going to be more important, not less important," Laliberte says.

"As mines are opened in more remote areas, issues such as water scarcity or climate change are only going to get more challenging.

"Finally, one major issue for social acceptance is how to address orphan mines' rehabilitation. Present mine owners can say that they are not responsible for past errors, but the public may not see it this way. Again, if the local communities get set against the mine operators, the continuing operation of the mines becomes difficult if not impossible.

"One interesting way is to redevelop old properties when possible, taking advantage of newer ore-extraction technologies to recover valuable material from old waste and solving at the same time old water-management issues."

"The future will be driven by the digital transformation of water monitoring and reconciliation systems"

Metso on filtration

Metso has just launched a new filter for tailings dewatering. Development of the Metso VPX filter was all about making it "ready for the future". By eliminating restrictive technology and design (e.g. hydraulics), which is standard in today's filters, it's open for new opportunities, says Metso's Niclas Hällevall. The most important changes in the VPX design are:

- There are no hydraulics – instead, high-pressure closing is achieved with electro-mechanical screws. This means less maintenance and higher safety;
- Metso increased the working pressure to 25bar compared to the industry standard of around 10-16bar, but it can go beyond that if required. Membrane pressure and air blow is optional when needed. High pressure means higher capacity or lower moisture content (which equals higher water recovery);
- The modular design of VPX means that the filter can be scaled to any size. When using the electro-mechanical screws, it is not limited in size or length. Metso can also add an extra module to an existing VPX filter to increase the capacity. The modular design also allows easy shipping in standard containers;
- Advanced control system with self-learning functions. AI will soon be standard; and
- Variable and fast opening and closing time with the rack and pinion system.

All combined, it is not just about the size. A well-designed smaller unit can give a higher capacity.

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Aspermont Media, Ltd, 21 Southampton Row, London, WC1B 5HA, United Kingdom

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Chairman Andrew Kent

Annual 3-user subscription (*Mining Magazine* digital)
UK £315 **Europe** €395
US/rest of world $465 **Australia** $575

Mining Magazine, ISSN 0969 - 3769 (USPS 001 -430) is published 10 times each year with combined issues in Jan/Feb and July/Aug by Aspermont Media, Wework, 1 Poultry, London, EC2R 8EJ.

The US annual subscription price is US$465. Airfreight and mailing in the USA by agent named WN Shipping USA, 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA.

Periodicals postage paid at Jamaica NY 11431.

US Postmaster: Send address changes to Mining Magazine, Air Business Ltd, c/o Worldnet Shipping USA Inc, 149-35 177th Street, Jamaica, New York NY 11434, WN Shipping USA, 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA.

Subscription records are maintained at Aspermont Media, 21 Southampton Row, London,WC1B 5HA, United Kingdom.

Air Business Ltd is acting as our mailing agent.

ISSN 0308-6631
A member of BPA Worldwide