A fine treat

Mine water is commonly re-used and recycled in mineral processing. Ailbhe Goodbody examines the technology and the main challenges, and why the practice is set to keep growing

"In the near future, recycling rates for North American mines will average between 30% and 70%"

Re-use of mine-influenced water is now recognised as best practice worldwide, and the majority of major miners have embodied this principle within their codes of conduct. In many cases, the advantages of re-using or recycling mine-influenced water are substantial. However, each situation needs to be evaluated individually as not all mining processes lend themselves to cost-effectively re-using water.

It's common to recycle and re-use return water from tailings, and from waste disposal and storage facilities. Modern mines capture affected mine water and re-use it within their mining, mineral processing, and waste handling and disposal operations.

Jes Alexant, mine-water treatment leader for Stantec, says: "With increasing regulatory and treatment requirements, it is not unreasonable to project that, in the near future, recycling rates for North American mines will average between 30% and 70%."

Cost can be a major advantage. Alex Gallagher, associate director of Wardell Armstrong and a specialist in water management, geology and hydrogeology, notes: "Working on a tonne-for-tonne rule, where a 10Mt/y processing plant needs 10Mt of processing water, recycling and re-using water can bring correspondingly massive savings."

David Kratochvil, president & interim CEO at BioteQ, adds: "The cost of treating wastewater for discharge into the environment is typically higher than the cost of treating it for re-use, as the water being discharged has to meet lower and more stringent limits so that it doesn't harm aquatic life and the environment."

In contrast, when mine water is re-used in a closed loop, the water-quality requirements are more relaxed. As a result, many mines recycle as much water as is practical given the site-specific conditions.

Also, water that has already been through a processing circuit will closely resemble the chemical constituency necessary for that process. Joe Tamburini, mine-water treatment lead at Tetra Tech, says: "Organic chemicals are often added in precise dosages to flotation circuits for optimal product recovery, but not all the organic material is lost to the product stream and some remains in solution. Therefore, it makes financial sense to re-use the water in flotation as much possible to minimise the amount of supplemental organic chemicals added."

There are also environmental and social impacts. Taking less water from rivers or aquifers means less competition with local communities for the water they need to feed vegetation or livestock, and there is also less risk of depleted river flows, changes in erosion patterns or reduced oxygen availability.

It also appeals to socially responsible investors who follow the Global Reporting Initiative (GRI) and statistics about water use and sustainability that are now making their way into companies' annual reports. New mine development is very capital-intensive and large institutional investors are increasingly paying attention to sustainability.

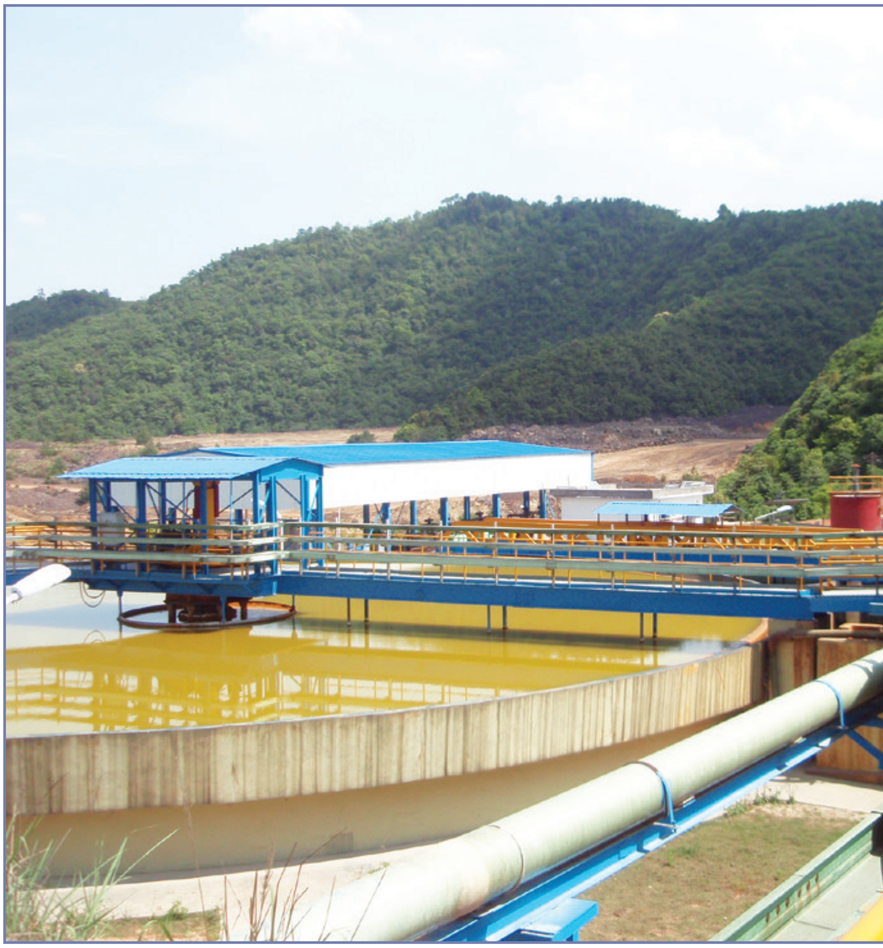
Gallagher comments: "The last thing investors want is negative stories of wells running dry because the mining companies they're funding are being profligate with water resources."

CLIMATE AND LEGISLATION CONSIDERATIONS

Both climate and legislation have been important drivers for the increase of water re-use that has been seen in mining over the past decade.

The less water there is, the more pressure there is on resources, so as a result mines located in extremely dry regions are often at the cutting edge of mine-water management practices that include extensive recycling and re-use. Take-up of re-use is particularly high in water-stressed regions such as Australia, Peru, Chile, southern Africa, the southwest US, parts of Mexico and Asia.

Kratochvil says: "Mines located in



BioteQ's ChemSulphide plant treats mine drainage with high copper concentrations to recover the copper as a high-grade concentrate that is sold to offset treatment costs water-scarce areas may not have access to the volume of water required for mineral processing as demanded by the size of the deposit and the magnitude of recoverable metal, as is the case for deposits in northern Chile."

Some mines may be located in areas of relative water scarcity where mining competes with agriculture, other industries and local communities for the same finite resource. In these situations, water access directly translates into the ability to generate revenue from metal production. Water availability, and its cost, can affect the viability of new mining projects, so re-use is increasingly factored into project design.

For example, alternative water sources such as seawater may be required. This leads to increased capital and operating costs for mines due to the need to invest in desalination and pumping of desalinated water over long distances to mine sites, or pumping of seawater and upgrading mineral-processing circuits to enable operation in a highly corrosive salt-water environment.

In wetter climates such as Canada, recycling is maximised in order to reduce the amount of water that needs to be treated and discharged. Even though water in the surrounding environment may be plentiful, limits on discharge volumes may mean that a mine will draw only the water it needs and recycle and re-use as much as possible to stay within the discharge limit.

Even mines in wet regions can face a shortage of water of the appropriate quality, for example if rain or run-off water has high sediment concentrations. Dan Dupon, lead mine-water engineer at MWH Global, adds: "In other cases, space constraints may limit the mine's ability to store run-off, so even though it is a wet area, the mine may be faced with seasonal shortages."

Legislation also contributes to water treatment and recycling. For example, lawmakers in Chile are discussing a bill that would force mining companies to run all copper mines using desalinated water from the Pacific Ocean. This would be imposed on miners that consume more than 150L/sec of water.

New regulations for water discharge are either under consideration or already in the process of implementation in the US, Canada and Peru. There are a significant number of mines in these countries located in areas with high precipitation, resulting in a positive water balance and the need to treat wastewater for discharge.

As a wealthy but partly arid country, Australia is generally a bastion of good practice. The CIS countries of central Asia also tend to follow strict licensing and regulation protocols. Others that put great emphasis on recycling water include Sweden and the UK, which are driven by regulatory policies and country-specific legislation.

"Mongolia is an interesting case," says Gallagher. "Combining a nationalist government with strong local movements protective of their environments, it's not a country that's afraid to hold mining companies accountable."

As well as prevailing legislation, local or regional politics can also play a big part. Gallagher explains: "Left-leaning governments will tend to favour the needs of local communities, including their rights to water, above the demands of multinationals. At the other end of the spectrum, there are examples of governments driven by personal financial gain."

TREATMENT TECHNOLOGY

The level of treatment that is typically required before water can be fed back into the processing line varies depending on the characteristics of the mine water, the mine's specific processing and water-quality needs, and on the beneficiation processes used to extract the ore – there is no typical treatment level.

Most water that is recycled is not treated, and goes straight back into the process. Dupon observes: "Not every process at a mine requires drinking-quality water. Thus, applying a fit-for-purpose approach means that water is treated only to the level needed, so that it can then be recycled."

Where removing sediment is the main issue, the technology can be remarkably simple – it is often sufficient to remove suspended solids from the water for re-use. This can be achieved in thickeners and tailings ponds. In the case of a coal plant, for example, it's mainly about allowing the sediment to settle.

If there are lots of clay particles, then chemical flocculants can be added – typically, mechanical coagulation/flocculation plants are used to control pH and remove metals.

Tamburini says: "It may be sufficient in a heap leach to recover the solids via settling ponds or clarifiers and recycle the leachate back to the heap with few contaminants impacting product recovery."

Other mine-water treatment technologies can be broadly classified in terms of the pollutants contained within the impacted mine water. Often, the reclaimed water needs a near-neutral pH and a low potential for precipitation of nuisance compounds such as gypsum. This can be achieved by lime and limestone treatment, gypsum crystallisation and clarification to remove suspended solids.

For acidic/low pH water, lime and limestone treatment is a common method, but it is also possible to use other alkali solutions. Lime addition is used to remove the bulk of dissolved metals and some sulphate to reach levels acceptable for re-use. Constructed wetlands can also be a good way to introduce alkalinity into mine water.

For water with heavy metals, such as iron, aluminium and manganese, lime and limestone treatments are also common. Andre Van Niekerk, principal water engineer at Golder Associates, suggests: "The key here is to create a biological sulphate reduction that allows sulphide precipitation within the minerals. Constructed wetlands are often used to achieve this."

In addition to lime, anti-scalants may be required to prevent scale formation in pipelines.

When the water re-use system includes the storage of water in tailings ►

"Not every process at a mine requires drinking-quality water. Applying a fit-for-purpose approach means that water is treated only to the level needed"

Golder Associates has been involved in several cutting-edge mine-water reclamation and re-use projects

ponds, additional treatment to destroy cyanide – if used within the mining process – and the by-products of cyanide destruction may also be required. Cyanide destruction using the sulphur dioxide process is used at many gold mines.

Furthermore, technology for mine-water treatment has transitioned during the past decade from 'traditional' lime-based treatment for the neutralisation of acid mine waters towards membrane technologies such as reverse osmosis (RO) and nano-filtration.

Martin Williams, principal geochemist at Schlumberger Water Services, says: "This has to a large extent been driven by the requirement for low sulphate and total dissolved solids levels in both process waters and environmental discharges."

Recycling or re-using water in concentration circuits can lead to a build-up of dissolved solids such as chloride. Often, the re-use rate is limited by how fast dissolved salts accumulate before negatively impacting product recovery. In this case, RO or similar technology may be required.

Issues to consider when determining specific water influent quality for a treatment process include the ore minerals targeted, the geochemistry results obtained from kinetic testing, the processes selected and the reagents selected for that process.

The requirement for treatment of water for re-use in metallurgical processes varies in accordance with the process flow-sheet involved. For example, fluoride-rich waters need to be avoided in some types of iron-ore plants, so RO is commonly used.

Also, specific mineral processes such as flotation may require the removal of additional compounds. However, removal can interfere with different parts of the flotation process, for instance, if selected organic compounds that interact with flotation agents are removed.

In conventional sulphide flotation, the primary constraint on feed chemistry relates to mineral precipitation potential, most commonly involving calcite or gypsum.

In virtually all cyanidation processes, gold recovery is sensitive to the concentration of chloride. This becomes increasingly acute in processes designed to achieve high gold-recovery efficiency. Consequently, feed-stream requirements tend to be more stringent in 'vat leach' carbon-in-pulp (CIP) and carbon-in-leach (CIL) processes than for heap-leach gold operations.

"The difference between levels of constituents present in wastewater and site discharge limits usually determines how difficult or easy it is to treat"

Heap-leach operations are the most forgiving as they can often accept waste/bleed streams from other operations directly without treatment.

CHALLENGING WASTEWATER

The difference between levels of constituents present in wastewater and respective site discharge limits usually determines how difficult or easy it is to treat. Consequently, the capacity to customise is a very important aspect of wastewater treatment in the mining industry. The best way to minimise capital project and operational costs is to target treatment for specific contaminants as required.

Paul Hoeferlin, manager, business development at Veolia Water Technologies, comments: "One of the major challenges is permitting and designing a treatment system based on assumed water quality from the exploration drilling. There always tends to be something unexpected or different in the actual mine water."

Some of the most challenging aspects of reclamation relate to desalination, as salt water is one of the most difficult to treat. It needs a large input of energy to remove the salt, so micro-filtration or large RO plants are often used. This generates a brine stream that amounts to 10-30% of the original stream of wastewater, which must be disposed of in evaporation ponds by concentrators or crystallisers.

Mine drainage water containing salt water is challenging to treat from a cost standpoint, but the degree of treatment required varies. For example, where high concentrations of dissolved chloride would be problematic to processing, the water requires more treatment. The corrosivity of salt water to certain types of piping and equipment material also need to be considered.

In some cases, it may be possible to discharge the salty water and blend it with large quantities of fresh water and still meet standards.

However, freshwater acid rock drainage (ARD) often contains multiple contaminants that require different treatment steps.

Alexant says: "Treatment of acid rock drainage that does not contain seawater would generally be less challenging from a cost standpoint, but possibly more complex."

The treatment of ARD can be undertaken using active technologies, such as alkali dosing, and passive systems, for example using sequential anaerobic/aerobic systems.

"There is a threshold of acidity load within the water that will dictate if passive treatment is viable, but passive systems usually require a large land take," explains Ian Hutchison, director at SLR Consulting International. "Hybrid systems, which use active technologies as primary treatment and passive polishing wetlands, have proven to be successful in some countries where less space is available."

Advances are also being made in source control, whereby the source of the acid generation is treated in-situ within the mine or waste.

The use of passive systems is increasingly viewed as being preferable, due to the relatively minor operating and maintenance costs when compared with active treatment.

FACTORS TO CONSIDER

Factors that need to be considered in the re-use or recycling of mine water include:

- Climatic fluctuations;
- Both short-term storm events and longer-term dry and wet cycles;
- Availability of local surface water and groundwater supplies;
- Water quality of the mineral-process stream;
- Infiltration and leachate from waste piles;
- Tailings depositional methods (filtered, thickened, conventional);
- Catchment areas associated with the

tailings and other mine facilities that generate impacted waters needing management;
- Impacted water storage and discharge requirements; and
- Clean-water demands.

Hutchison says: "An integrated water-management system is then developed to optimise the amount recycled, and the amount of freshwater make-up and storage requirements to deal with extreme wet and dry climatic fluctuations."

Other factors that play a role in re-using wastewater for mineral processing include future water demands and changes in water quality (both influent and discharge), the variability of influent water, the life of mine, CAPEX versus OPEX, and ease of operation.

Kate Koerber, marketing manager, mining and primary metals at Veolia Water Technologies, recommends: "The best way to manage these factors is to discuss the plan of action with your water-treatment provider."

The feasibility of treatment at different levels and for different recycle percentages must be calculated for every mine on a site-specific basis, but the biggest factor is usually cost.

BioteQ's Selen-IX mobile pilot plant is used to pilot selenium removal from mine water to very low ppb levels

Kratochvil says: "A major factor to consider is what residual by-products will result from the recycling. For example: will there be liquid brine or solid waste; what quantity of by-product will be produced; and what will its characteristics be, including long-term stability and toxicity? This information will dictate additional costs associated with its storage and disposal."

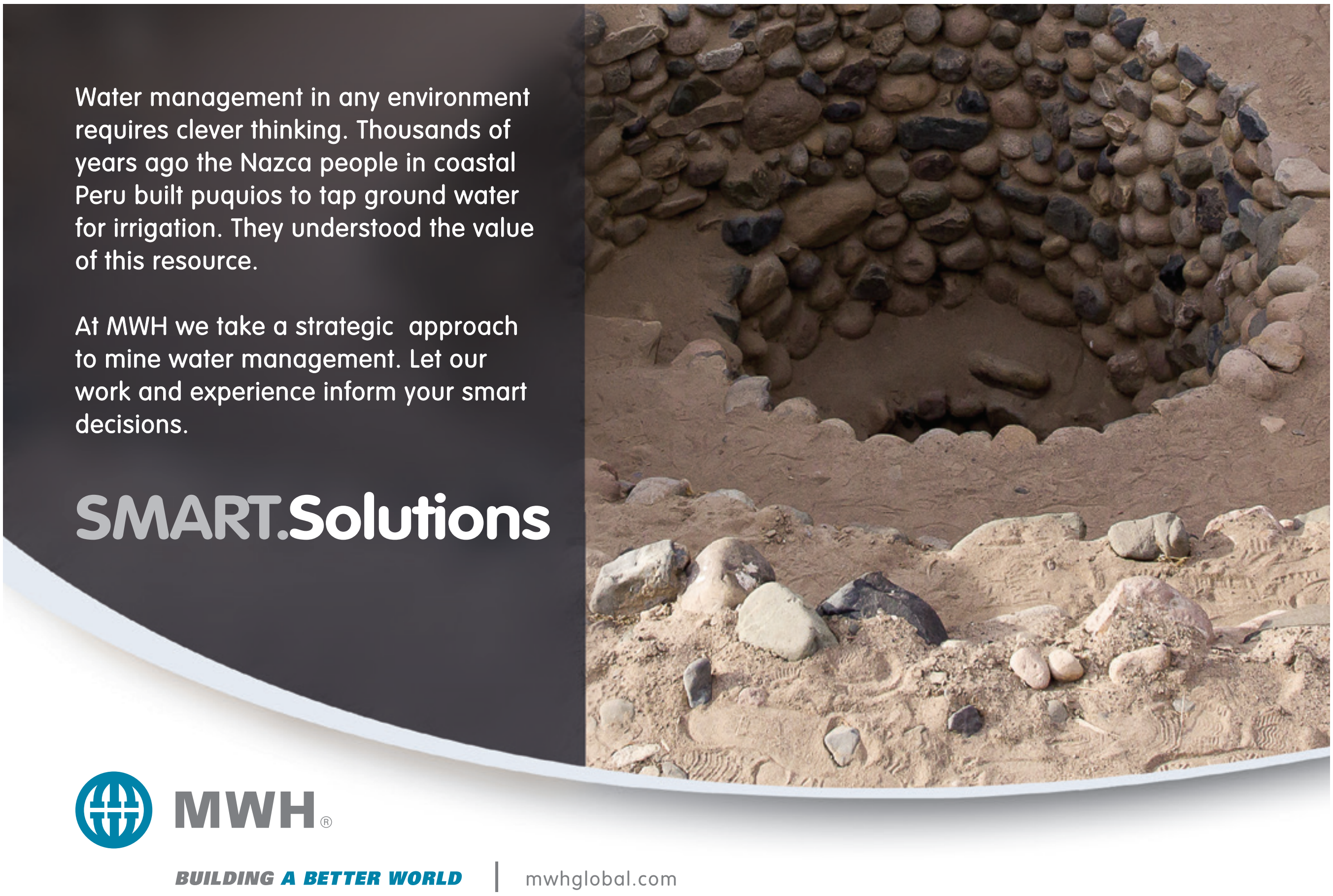
The source of the wastewater is another key issue. If recycled directly within the processing plant – for example, on a continuous washing circuit – it won't have to move far, and grey water shouldn't need much treatment.

Gallagher cautions: "If it is from the tailings plant or waste dump, the cost of transportation and treatment could be far higher. And water from the pit sump may not be re-usable at all in view of the hydrocarbons and nitrates it can contain."

Another critical aspect that is often overlooked in preliminary stages of a water-management project is the waste stream from the process. RO works well to remove a myriad of contaminants. However, if the mine is not equipped to handle the 35-50% waste coming off the treatment process, then RO can become costly. High-density sludge processes use a lot of lime and produce large quantities of solid cake that must be transported and disposed of in lined repositories. As a result, understanding waste streams is vital to deciding whether a recycling project is viable.

"A major factor to consider is what residual by-products will result from the recycling"

Scaling is also of concern when RO is used in treating mine water for re-use. Tamburini says: "We have witnessed first-



ARD downstream of seepage at the Novat-Rosu tailings pond, Romania
Photo: Wardell Armstrong

hand how an improperly designed or operated RO treatment facility can form scale on the membrane and render the treatment process unsustainable."

Scaling of process equipment and piping can adversely impact the goal of recycling water for re-use if an improper chemical precipitation process is selected for treatment.

It is also important to consider the volumetric aspect of water recycling – there must be sufficient levels of water available to satisfy the different mineral processes. Van Niekerk declares: "As a result, it is vital to understand the integrated water balance of a mine before proceeding with recycling and re-use activities."

The relationship between the life of mine, ore processing and supply of available water (or the need to recycle) must also be considered when evaluating the total project lifecycle costs, including closure and post-closure periods.

In addition, small changes in chemistry can have significant impacts on metal recovery or water-treatment costs. Dupon says: "Even though a robust water balance allows you to understand water volumes and flow data, one has to know what's in the water to make best use of it. A robust chemical-mass balance model is essential."

Not all process waters are suitable for blending – some may be better treated on their own when there is an excess. Knowing the chemical make-up of the process water is crucial for making decisions about how best to recycle, treat or repurpose it.

Finally, a major consideration that is frequently overlooked in the design of treatment systems is the long-term evolution of mine or process water quality. Williams comments: "Schlumberger has encountered many instances in which water-treatment design has been founded on 'today's' operational water chemistry. This can, however, change dramatically as a consequence of either changing ore mineralogy or a progressive build-up of conservative solutes in process-reclaim circuits.

"It's our experience that retro-fitting treatment systems to resolve these problems can be more costly than designing for the long term from the outset. This, of course, requires the appropriate predictive capacity and expertise."

"As the cost of water increases, and new technologies facilitate treatment, miners are likely to recycle even more water"

THE FUTURE

Dealing with water at mining sites will remain challenging far into the future. Dupon says: "As the cost of water increases, and new technologies facilitate treatment, miners are likely to recycle even more water."

Increased human reach into remote areas combined with global climate change has made drought conditions more severe for longer periods of time in arid climates. In other regions, large precipitation events cause more frequent flooding, which challenges existing storm-water mitigations.

Williams declares: "With increasing cost and scarcity associated with fresh-water supplies in many major commodity-producing regions, the economics of water supply also now dictate that re-use must be maximised."

Scarcer water supplies will make water management increasingly political, and in some cases a source of conflict. The need to do the right thing – and to be seen to do so – will become more important than ever.

Van Niekerk says: "Competition for scarce water resources in mining areas will lead to increased competition in the

SLR Consulting worked on Argonaut Gold's Magino project

recycling sector. This is compounded by local regulatory pressures, global expectations on conducting sustainable mining, and increased calls for responsible use of limited resources."

As society re-evaluates the true value of water, miners must remain in step and adopt practices appropriate for the region in which they operate. Dupon explains: "Miners can't move their mine, so must continue to seek ways to improve their performance, including how they use water."

The mining industry now receives more stringent scrutiny from regulators and stakeholders with respect to its sustainability and environmental performance, so effective re-use of water will be crucial.

In the future, ore-processing metallurgists and mill operators must work closely with water-quality engineers, including resources specialists and treatment engineers. Alexant advises: "Coordination is critical to avoid excessive contamination in ore processing and lost value."

Hutchison says: "Some interesting developments are now taking place at mines close to urban developments, where city wastewater is being recycled to the mine as well, forming an integrated mine, industrial, commercial and residential water system."

Solar-powered treatment plants could possibly provide energy for RO, reducing the consumption of fossil fuel and the need for expensive infrastructure. Gallagher suggests: "How about doing more to treat wastewater and recycle it back into the environment from where it came – minimising the net amount that's lost and therefore the environmental impact?"

Another potential trend is an increase in water recovery from tailings by enhanced dewatering and a switch to dry stack tailings instead of wet impoundments – this could be where the majority of the water yet to be recovered by the industry could come from.

"Miners can't move their mine, so must continue to seek ways to improve their performance, including how they use water"

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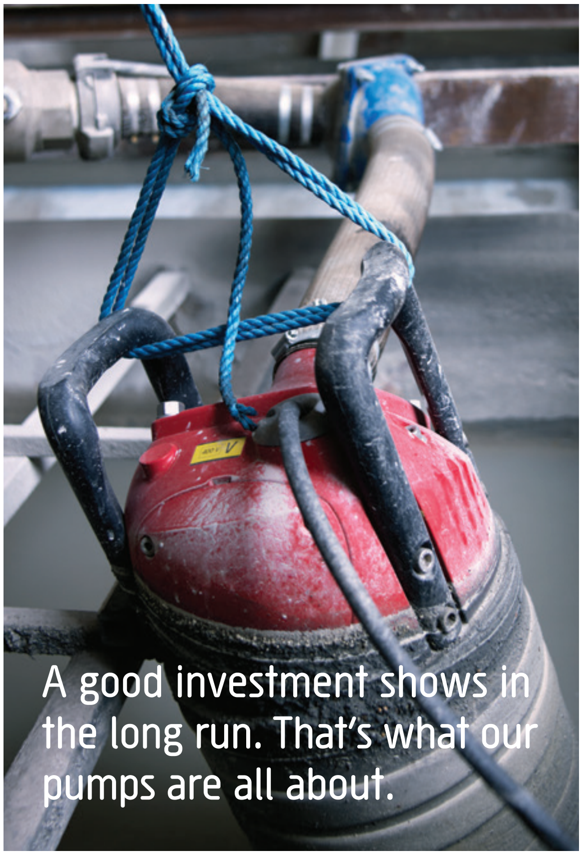

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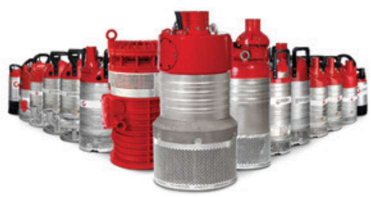

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Recent projects

BIOTEQ

BioteQ has been involved with mine-water treatment projects to meet both discharge and recycling requirements. These include:

- Sulphate removal at a large iron-ore operation in Minnesota, US, where environmental discharge is subject to a 10mg/L sulphate limit;
- Selenium removal to below 5ppb from waste rock seepage from coal and base metal deposits in Canada;
- Arsenic removal from smelting and refinery plant effluent in South America. Removing arsenic allows wastewater to be recycled and is more cost-efficient than removing the arsenic down to levels suitable for discharge;
- Optimising selenium and arsenic removal from a zinc/lead refinery in Mexico to allow water re-use. The selective removal of selenium and arsenic also increase the purity of the final refinery product; and
- Feasibility of the partial selective removal of sulphate from a copper heap-leach solution in South America.

"Based on some of the projects we have been seeing, wastewater recycling is one of the areas where BioteQ is becoming increasingly active," states Kratochvil.

"The common elements between water re-use and treatment for environmental discharge applications that make BioteQ's proposal attractive are the selective removal of only the constituents of concern and the capacity to customise water treatment to site-specific conditions and requirements. This approach reduces the amount of reagents, power and waste by-products while maximising water recovery."

GOLDER ASSOCIATES

Golder Associates has been involved in several cutting-edge water reclamation and re-use projects, including one at Optimum Coal in South Africa, where reclaimed mine water was converted into a clean supply of drinking water for communities in neighbouring areas.

Golder designed and engineered the entire water-management system associated with getting mine water to the plant, dealing with sludge and brine wastes, and supply of reclaimed water to a town, and secured all regulatory approvals, including the environmental impact assessments.

Van Niekerk says: "The designs had to take into account various aspects such as geological formations, existing services, proximity to existing and future mining, and the presence of local settlements. Another challenge was that the Golder team had to negotiate the project authorisations with four different regulatory authorities.

"Despite the challenges, the project was very successful."

SCHLUMBERGER WATER SERVICES

A central component of Schlumberger's minerals-sector work is the development of tools to optimise operational re-use of water. The company is involved in such work on all continents.

Typically, the company's approach centres on the development of integrated models to represent the physical water balance and chemical mass balance of mine-water management systems. These models can be applied to predict water availability and chemical quality over the life of the mine. They also serve to simulate the performance of alternative treatment technologies, to size storage infrastructure and assess the benefits of blending waters from multiple sources within a single operation.

Williams explains: "This integrated approach to life-of-mine water re-use has been applied to save Schlumberger's clients substantial amounts of money at locations extending from Africa to South America."

Passive settlement lagoons and reed beds are an ecologically friendly way of treating mine water, such as this one at Caphouse Colliery, UK
Photo: Wardell Armstrong

SLR CONSULTING

SLR operates the long-term water-management systems at a closed gold mine in California, US, where an RO system is used to treat excess water from a closed heap-leach pad before discharge. The brine is disposed of as a liquid waste, and SLR is evaluating the use of a salt concentrator, or crystalliser, to reduce longer-term brine-disposal costs.

At another closed gold mine in California, SLR operates a water-blending system that is used to discharge excess water containing salts, arsenic and selenium among other metals. Wastewater is stored in the pit during the dry season and released by an automated system of valves, pipes and diffusers into the local stream during winter flood periods.

SLR is also completing the design of a gold mine in northern Ontario, Canada, where engineered wetlands are being developed.

SLR has developed techniques for assessing the candidate substrates for bioreactors, which can successfully treat acid and metalliferous mine drainage. Projects in Australia and the UK have used this approach where treatability testing is used to assess the optimum combination of organic (such as manures/saw dust) and inorganic compounds (such as carbonates) to treat the acidic water.

STANTEC

Stantec provided an engineering study and design for a treatment system to recycle mine water for a major gold mine in eastern Canada. The system, including an enhanced coagulation/settling system, was designed and constructed within six

A heap leach pad and ponds
Photo: Tetra Tech

months and stress-tested a year later to allow for even higher treatment capacity. By minimising fresh-water intakes from the supply stream, the client was able to expand its operations.

TETRA TECH

Tetra Tech designed a treatment system that allows a flotation circuit to waste a portion of the recycled water and discharge it to a local river while meeting the necessary discharge limits. This process minimised the amount of waste pumped to tailings and the associated costs with that facility.

Tetra Tech also has several examples of re-using water after a treatment system to remove arsenic and radium to acceptable US Environmental Protection Agency potable-water levels.

VEOLIA

Veolia Water Solutions & Technologies recently worked on the second phase of the Bennett Branch project in Pennsylvania, US. Veolia conducted treatability studies and developed a high-density sludge-treatment process and system design for treating acid mine drainage.

Crown Solutions, a business unit of Veolia Water Solutions & Technologies, pilot-tested a 5.7L/min RO system at PotashCorp's Aurora phosphate mine in the US that was scaled to match the hydraulics of the proposed system.

The final results of the eight-week pilot test showed good filtration results, good operation of the water softener and good operation of the membrane system. The RO system produced high-quality water and showed no signs of fouling or scaling. Based on the results, the mine gave the green light for the installation of the full-scale RO system.

WARDELL ARMSTRONG

Findings from a recent pre-feasibility study that Wardell Armstrong did in Scandinavia indicated that the company will need to consider re-circulating water through a nearby lake to maintain its amenity value.

For another project in Kazakhstan, where the amount of water available from a local aquifer is almost exactly equal to the make-up of water required to meet processing demand, the amount that can be recycled could make or break the project. Wardell Armstrong is currently producing the bankable study.