Waste not, want not

In today's world of water scarcity, successful waste-water management is critical

Ore is extracted using a variety of techniques, all of which have the potential to generate waste water. In addition, a number of mining-related processes can generate waste water or contaminate local water resources, including: the transport and storage of overburden and ore; beneficiation and processing of ore; and the contact of natural water resources (groundwater, meteoric) with the extraction area and processing plant.

While there are numerous examples of mine sites with zero waste discharge and excellent environmental stewardship, there are many others where poor planning has led to large-scale problems. The cost of managing waste water after a non-scheduled environmental release is usually very high financially, ecologically and socially. As a result, mining firms worldwide are focused on the early planning and implementation of water-management plans.

Water conservation and reuse are important issues for mining operations, increasingly so in regions where it is scarce, such as Australasia, South America, Africa and parts of the US.

Umit Turunc, product applications engineer at GE Power & Water, says: "In arid regions, such as the copper-mining regions of Latin America, there is a higher level of emphasis given to recycling and reusing water within the production process. Recycle rates range from 70-88%, which is consistently higher than copper mines in areas where water is more abundant."

Arid areas tend to suffer from water supply and conservation issues, while wetter regions typically encounter challenges in maintaining mine-water discharge quality.

Rob Bowell, principal geochemist and corporate consultant at SRK Consulting, explains: "Water itself is a commodity with a high value. As society increases in number, the demands placed on our resources are also increasing rapidly. A smart approach to water management is essential. In arid regions, such as Arizona, many operations collect and treat mine waste water before selling it to be used in crop irrigation and similar applications. Even water that isn't suitable for drinking still has a value."

Over the past decade, water management has also become a key consideration for greenfield operations looking to attain environmental approval permits and construct mineral-processing plants. Without access to fresh water of an appropriate quality or a feasible point of discharge, the viability of a mining operation is seriously compromised.

WASTE WATER PRODUCTION

Primary sources of waste water on mine sites include: dewatering operations to lower groundwater levels and prevent the flooding of open pits or underground workings; water pumped from open pits or underground workings that comes into contact with exposed surfaces; seepage and run-off from waste rock facilities; seepage and run-off from ore stockpiles and ore in transit; seepage or uncontrolled run-off from heap-leach facilities; excess water or seepage from tailings and storage facilities; and excess water from mineral-recovery facilities.

Acid mine drainage occurs naturally at about 70% of base metal mines

All mining operations, both open pit and underground, will produce at least one of these waste-water streams. Geographical location can reduce or eliminate some of the sources; for example, in arid climates there may be a net negative water balance for tailings facilities, so excess tailings water is not created, while wet climates can have the opposite effect, resulting in excess waste water, requiring treatment.

Locations with significant snowfall, particularly periglacial regions, can present an extra challenge during the spring freshet as the volume of waste water can increase by an order of magnitude during a relatively short time. Similar issues can arise for projects in ►

Mine dewatering
Photo: Hatch

A BioteQ BioSulphide treatment tank

"Water quality issues are mainly related to whether the mineral is recovered through physical (flotation) or chemical processes"

areas susceptible to monsoon rains; these require a balance of storage facilities and waste water-treatment capacity, such that the latter is no larger than it needs to be.

Ambient temperatures at mine sites must be considered as this affects the rate of evaporation. Heat can act as a catalyst for oxidative reactions and, in the presence of water, mineral oxidation will be much higher at warm than cold sites.

The mining method used, along with the geochemical compositions of the ore extracted and the host rock, as well as the metallurgical processes used to recover the mineral of value will all have a significant impact on the quality and characteristics of waste water generated – and the potential effects if output is not controlled carefully.

The mining cycle can be broken into three main phases – mining, mineral recovery and waste-material storage.

MINING

The main geochemical property of ore that effects water quality is the presence of sulphide minerals that have a tendency to produce acid rock drainage (ARD) or acid mine drainage (AMD).

In the presence of water, sulphide-type ores will oxidise, creating sulphuric acid, which produces waste water with a low pH and the ability to liberate toxic metals such as cadmium, antimony, arsenic and iron, as well as dissolved solids, including calcium and sulphates, from the rocks it comes into contact with. Water that is either extremely alkaline or acidic also has the potential to be very corrosive.

These characteristics are typical of water that comes into contact with exposed surfaces in open-pit or underground mines, and run-off/seepage from ore stockpiles. ARD is a naturally occurring process that affects an estimated 70% of the world's base-metal mine sites, and is also prevalent at many precious metal and coal mines. Low-sulphide ores will generally produce neutral drainage with much lower concentrations of contaminants.

Waste-water streams from mines can also contain elevated levels of suspended solids, such as ammonia or nitrates from blast residues. Blasting and excavation (and eventual beneficiation or processing) can generate huge volumes of fine solids, which, if not managed properly, can damage aquatic life or clog natural wetlands. Radioactive particles can also find their way into waste-water streams at uranium mines and facilities that extract rare earth elements (REEs) from minerals such as monazite.

Operations that extract sulphide-bearing ores require a specific ARD/AMD management plan to suit the mining method, local climate and site topography. Accurate predictions can be made as to the mobilisation of certain ions and metals at different pH levels, helping mines to plan suitable treatments in advance.

MINERAL RECOVERY

Metallurgical processes, and their specific application, have a large influence on the quality of waste water produced from the mineral-recovery facilities at precious and base-metal operations. Water quality issues are mainly related to whether the mineral is recovered through physical (flotation) or chemical-type processes (acid leaching, cyanide leaching).

Kevin Conroy, principal and water-treatment practice leader at Golder Associates, explains: "Different issues are created if heap leaching is used for mineral recovery. This can be used for both precious and base metals, and is either facilitated using cyanide or strong acid solutions. Any release of pregnant leach solutions would be a significant water quality concern. Uncontrolled releases of run-off water and seepage water from heap-leach facilities would have similar concerns."

WASTE MATERIAL STORAGE

Waste materials produced during mining and mineral-recovery processes include waste rock (all types of mining) and tailings (precious and base metals). Similar to the mining process itself, waste water from these sources is strongly influenced by the geochemical properties of the ore. Metallurgical processes used for mineral recovery can also influence water quality in tailings and result in elevated levels of cyanide, ammonia or nitrate.

TREATMENT

Three main methods are used to treat mine waste water. Chemical treatment is primarily used to remove metals; the most widely used process being neutralisation and chemical precipitation with sodium hydroxide (caustic soda) or calcium hydroxide (lime) to remove metals as metal hydroxides.

Bioteq Environmental Technologies CEO Brad Marchant explains: "Lime, $Ca(OH)_2$, is added to contaminated water. The dissolved metals precipitate into solids, forming a metal-laden sludge. The treated water is separated from the sludge, which is then stored in ponds. Although very common in the mining industry, the disadvantage of this treatment method is that the sludge can create a waste-disposal problem, and possibly an ongoing environmental liability.

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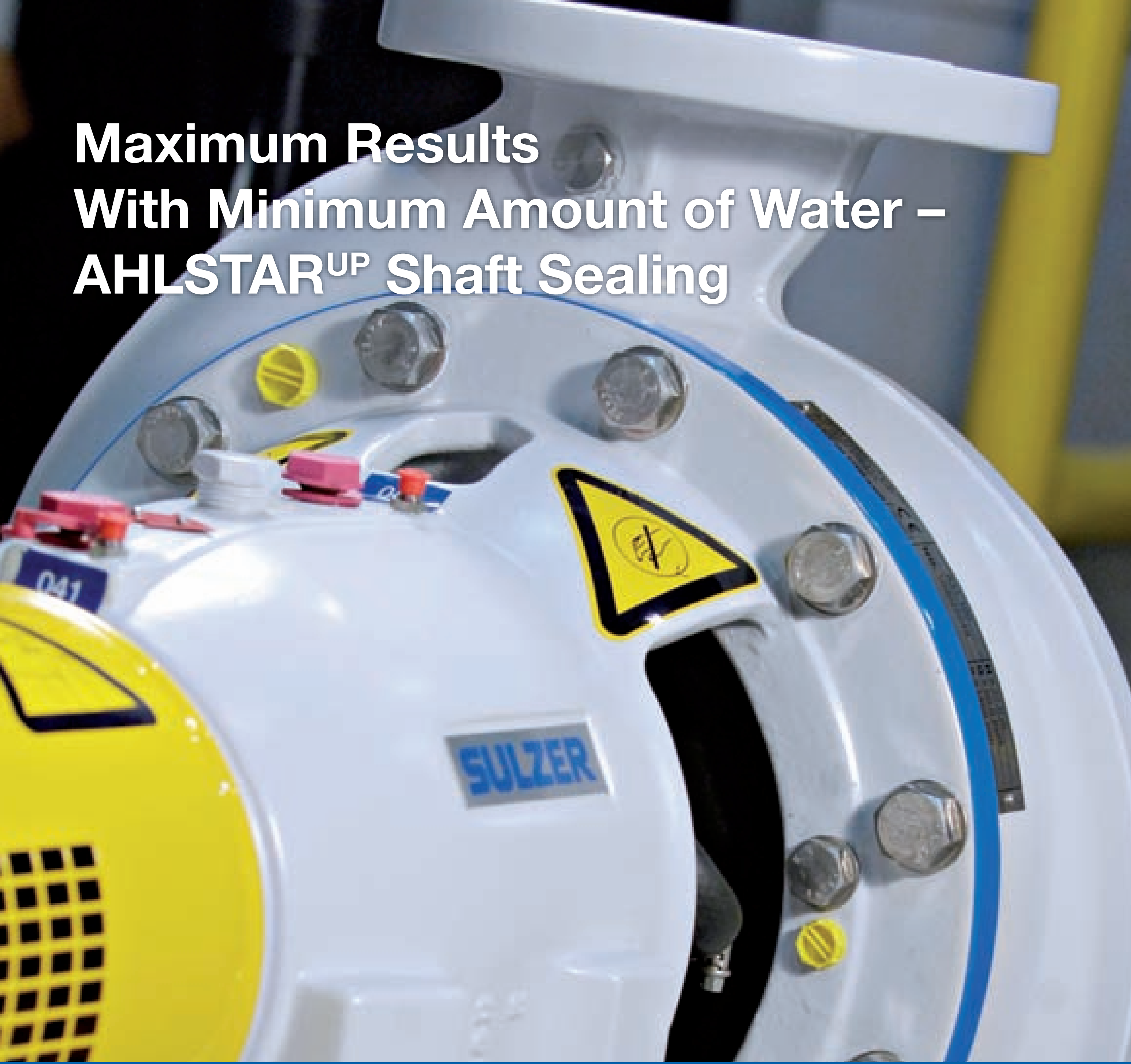

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Vale's Onça Puma nickel mine, Brazil. Hatch undertook the design and construction management for stormwater drainage systems

"Because the sludge contains the residual metals from the water, it requires careful storage and management to prevent the metals from re-dissolving and entering the environment. This method is most suited for waters that contain high levels of iron or aluminium as these metals are relatively benign and do not usually pose a threat to human health."

Although not as widely applied as caustic soda or lime, chemical treatment with sulphide has been used to remove metals as insoluble metal sulphides. Mr Marchant says: "In sulphide precipitation, sulphide in the form of H_2S or NaHS is added to contaminated water, and the conditions are adjusted so that individual metals can be selectively precipitated, forming high-grade, solid metal sulphides.

"The treated water is separated from the metal solids, and can be released directly to the environment or reused in the mining process. The solid metal sulphides can be refined and sold to generate a revenue stream that offsets treatment costs. This method is suited for high volumes of water that contain relatively low concentrations of dissolved metals."

"Physical treatments use membranes or other media to separate particles from the water"

The chemical oxidation or reduction of some metals can be accomplished by adding hydrogen/hypochlorite or bisulphite, respectively. Aeration can also be used for

oxidation. For process streams with high metal concentrations, solvent-extraction and electro-winning processes (SX-EW) can be used to remove metals from solutions. Due to the higher costs associated with this method, it is best suited to low volumes of water with high amounts of metal.

Physical treatments use membranes or other media to separate particles from the water. Membrane treatments include ultrafiltration, microfiltration, nanofiltration, reverse osmosis and nanofiltration. For media filtration, the most commonly used methods are filter presses, multimedia filters, sand filters, greensand filters, activated carbon filters, walnut shell filters, gravity and pressure filtration.

Neil Beckingham, business development manager at Hatch, says: "Membrane systems are being increasingly applied at mining projects to facilitate zero-liquid discharge or in component recovery applications."

Physical treatments can be used if dissolved solids need to be reduced, and are usually applied after a metals removal process such as chemical treatment. In some cases, membranes can be used as the primary process for removing metals and dissolved solids, followed by the chemical treatment of the concentrated brine from the membrane system.

Biological treatment can be applied in three cases. The first is the biological production of sulphide to chemically remove metals as metal sulphides. This is generally only applicable if metals are at concentrations that have economic value.

The second is active biological treatment for the removal of selenium (anaerobic treatment) or nitrogen-containing compounds such as cyanide, ammonia or nitrates (combination of aerobic and anaerobic treatment).

The third case is passive biological treatments, which use facilities such as wetlands to allow particles to settle out of solution naturally. This is suitable for very low volumes of water with low metal concentrations.

Mr Conroy says: "These systems are generally applicable to relatively small seepage-type flows that can continue to be produced after a mine is closed. They can be used with a wide range of metals. Configurations include anaerobic biochemical reactors and aerobic wetlands."

A number of hybrid methods and specific procedures patented by certain consultancies can also be used to treat mine waste water. For example, Golder is the exclusive licensee in the US and Canada for the Immobilised Cell Bioreactor (ICB) technology. This active biological treatment has been used successfully for the removal of selenium from mine waste water.

BioteQ has patented three process technologies for sulphide precipitation – BioSulphide, ChemSulphide and ion-exchange Sulf-IX.

Mr Marchant tells *Mining Magazine*: "Over the past decade, we have built ten sulphide-precipitation plants that treat water and recover metals at mine sites in Canada, the US, Mexico, Australia and China for international mining customers and regulators including Xstrata, Jiangxi Copper Co, Aditya Birla, Capstone Mining, Breakwater and the US Environmental Protection Agency. We have extensively piloted the Sulf-IX process to remove sulphate from water at sites in Canada, the US and Chile. The first commercial-scale Sulf-IX plant is slated for construction this year in the US."

The level of treatment required before water can be fed back into the processing line is highly dependent on the metallurgical processes used for mineral recovery.

Barrick Gold's Eskay Creek project: Hatch provided sulphide flotation, pressure filter and tailings pressure filters for wastewater treatment

A contaminant that can 'poison' mineral recovery in one process may have no effect in another. It also depends on the sensitivity of the equipment, the materials being processed and the reactive nature of any additives.

Mr Bowell explains: "Heap leach can tolerate quite high levels of metals and salinity whereas flotation can tolerate high metal levels, but requires a low salinity and solids content. Autoclaves are particularly sensitive, and require solutions with very low levels of carbonates and salinity. High levels of salt can lead to corrosion, and high levels of CO_2 can lead to failure in couplings and even cause fires. Refineries require ultra-clean water of a higher standard even than drinking water."

Mr Turunc echoes this: "The quality of water that can be reused depends on the application. One example is GE's experience of treating tailing dams at iron mines in North America where there is a high concentration of sulphate in the water. This interferes with the concentrator operations and causes scaling. In addition to removing the suspended solids, it is necessary to reduce the sulphate levels, both to reuse water and discharge it back into the environment. Other applications, such as coal-mine water-discharge systems in Australia, require ultrafiltration and reverse-osmosis membrane technology to treat the water before it is reused."

Build-up of dissolved solids in recycle streams can also be an issue. Some metallurgical processes can be affected by a build-up of cyanide if it is used in metal recovery, so it is important to monitor the water chemistry frequently.

TAILINGS FACILITIES & STORAGE

Strict regulations dictate how contaminated water is stored and managed. Water is usually collected in a series of storage ponds prior to treatment. Globally, there is a trend to increase the safeguards for storage facilities and tailings ponds (although these are technically part of the treatment process), which are often double-lined and fitted with leak-detection devices. ►

"Strict regulations dictate how contaminated water is stored and managed"

Operations in arid regions, such as BHP's Escondida copper mine, suffer water supply and conservation issues

In some regions regulatory policies also require that tailings and evaporation ponds be as small as possible.

In environments that are conducive to high levels of evaporation, mining firms either need to take measures to minimise it, if the water is designated for reuse, or to enhance it, depending on the available storage facilities for liquid and solid waste.

Evaporation can be used to minimise waste water, leaving just solids and salts that need to be stored, which, in some scenarios, can be of economical and environmental benefit to mining firms. Sometimes snowmakers are used to enhance evaporative conditions and speed up this process.

For mines in arid climates, SRK has designed heap-leach operations where feeder pipes are buried within the heap material to minimise evaporative loss of process solutions. This includes uranium heaps in Namibia, and on copper heaps in the middle east and south west US.

The design of facilities with the potential to release contaminated waste water will include measures to help prevent it: surface water diversions and control systems can be added to minimise the contact of clean run-off water with waste materials on site; waste rock and tailings facilities are lined, or double-lined, with materials such as clay or geosynthetics, which have a low permeability; seepage collection and control systems can be included in the design of pond and tailings facilities to capture waste water; and cover systems can be used to limit infiltration and evaporation.

> "Evaporation can be used to minimise waste water, leaving just solids and salts that need to be stored"

It is important to consider the types of contaminants involved when designing waste-water storage and channelling facilities. Some chemicals and solutions with a high or low pH can be highly corrosive, as can waste waters with a high salinity. Salt corrodes steel, from which most pipes and structures are built. The chemistry of the water also has the potential to react with the bedrock substrate, which can cause leaching or seep into groundwater flows, reinforcing the need for proper lining.

Mr Beckingham at Hatch illustrates this: "In the vanadium industry, for example, waste waters and tailings need to be stored to minimise the opportunity for leaching of residual vanadium and other contaminants into the environment. This requires ponds with specific linings, possibly capped, with leachate-collection systems. Another example is cyanide-rich waste from gold mining, which must be managed carefully to avoid accidental environmental contamination. The catastrophic failure of a tailings dam into a river system in the Baia Mare area, Romania, in 2000, is an example of what can happen if facilities are not properly designed and maintained."

CONSULTANCIES & TREATMENT COMPANIES

The sustainable management of waste water generated by mining must begin with the early development and execution of a plan, for which most mining companies employ an external consultancy.

Involving a third-party that specialises in water-treatment procedures, and has a lot of knowledge and experience in the field, can prove invaluable, particularly if the mine is located in an environmentally sensitive or highly populated region.

Some of the main global players include: Hatch; Golder Associates; BioteQ Environmental Technologies; GHD; GE Power & Water; Schlumberger; SRK Consulting; Veolia and SGS, to name a few. However, there are also many independent consultancies specialising in certain geographical areas and particular facets of waste-water management, such as tailings disposal or mine closure.

The most effective way to prevent untreated waste water from entering the environment is to minimise the amount that is generated. Consultancies will often help to implement company-wide strategies for effective water management. This is particularly important for firms working in at least two geographical jurisdictions that must standardise practices across all of their mine sites in order to maintain a good reputation, and keep their shareholders happy.

Consultancies can act as ambassadors for mining companies by: liaising with government bodies for approvals and permits; contacting public and private utilities over water-resource supply; consulting with indigenous peoples and community stakeholders; giving objective advice; and preparing site and resource-specific water balances, based on their findings.

Consultancies can also help with a number of on-site activities, including: securing and managing water supplies; water collection and distribution; water treatment for use, reuse and discharge; monitoring water chemistry, including acid rock drainage; environmental baseline establishment and ongoing monitoring (surface and sub-surface); water audits; process and equipment design/selection to optimise water usage; tailings management and closure; and remediation planning, implementation and monitoring.

Graham Sim, director of global mining at GE Power & Water, says: "In addition to our range of permanent water-treatment solutions, GE operates the world's largest mobile water-treatment fleet. The breadth of our fleet size and range of treatment technologies allows us to provide customers with short-term water-treatment solutions. This is a key issue when seasonal weather patterns create excess water that needs to be treated at the mine site prior to disposal."

REGULATION & POLICY

In addition to the global guidelines for water-management best practice, as specified by the World Health Organisation (WHO), and regional or local regulations imposed on mining firms by individual governments, there has been a shift over the last 20 years towards self-regulation and standardisation in the industry.

All mining operations are subject to acquiring abstraction and discharge licences for water prior to commencing operations. Before granting licences, the issuers will look at the general practices of each company, as well as any potential stresses placed on local resources. As water is such a critical resource in many parts of the world, social responsibility concepts dictate that it be used and managed in a responsible manner, so those companies that demonstrate a good ethos towards water management and conservation are more likely to obtain licences quickly and easily.

"Water treatment is not typically a large up-front cost for a mining operation in relative terms," points out Mr Marchant. "However, because the need for water treatment can extend well beyond the life of a mine, and because ARD can be generated for many years after mine closure, the overall 'life-cycle cost' for water treatment can be significant over time. Increasingly, mining firms are

"Companies that demonstrate a good ethos to water management are more likely to obtain licences"

Golder at Summitville mine

In 2003, Golder was contracted by the Colorado Department of Health to design and install a water-treatment plant at Summitville mine, Colorado, as part of site-remediation activities. The new plant will replace an existing, but ageing facility that is costly to operate and maintain.

Summitville is an abandoned gold mine, located at an elevation of 3,400m. The site receives a high level of snowfall each year and requires water treatment at a flow rate of up to 6m^3/min. Primary contaminants of concern include copper and aluminum.

The facility was designed with the local climatic conditions in mind, and precast-concrete panels were used, rather than the usual, pre-engineered metal sheets, to support drifting snow.

Snow and ice accumulation also required that the large clarifier, located outside the plant, be covered with a geodesic dome for protection from the weather. The facility has an expected 50-year lifespan under extreme climatic conditions.

During the conceptual design report phase of the project, Golder developed and implemented a multiple-step process-development programme. This included: a review of historical water quantity and quality data; the collection of additional water-quality data; analysis of site flow data; and completion of bench and pilot plant studies. As a result, a lime-precipitation system with sludge recycle was recommended for wastewater treatment.

The new treatment plant is currently being built, with completion scheduled for 2011. Golder is providing a full-time, resident engineer for administration services throughout the construction phase. Golder also holds the operations and maintenance contract for the existing treatment plant, and 13 full-time members of staff will operate the new facility once built.

BioteQ recently commissioned a new water-treatment plant at the Minto mine in Canada

"As water becomes scarcer there is a greater emphasis on ensuring waste-water discharge meets the guidelines for all industrial facilities"

evaluating the overall life-cycle costs of their water-treatment alternatives; taking into account not only capital and operating costs, but also long-term costs such as sludge management and disposal, environmental liability and the value of clean water."

Mr Sim explains: "Larger companies tend to adopt long-term, sustainable water-management practices. However, we are increasingly seeing smaller mining companies become more willing to adopt and trial innovative, breakthrough technologies for solving water-treatment challenges."

SRK has found that large companies that work in many jurisdictions worldwide have greater exposure to the public and media, and have reputations that they must protect to ensure competitiveness, so they are very stringent on waste-water treatment practices. Larger companies tend to standardise practices across their operations to ensure high standards are maintained internationally, while juniors that only operate in one jurisdiction will be more focused on meeting local policies and standards.

Larger mining companies also have their shareholders and dividends to consider. For example, the Government Pension Fund of Norway only invests in blue-chip firms that operate to high environmental standards. In March 2009, Barrick Gold became the third mining company to have its shares dropped by the fund in two years because of its involvement with the Porgera gold mine in Papua New Guinea. The fund said it had sold its shares following recommendations from the Council of Ethics, stating that Barrick's practice of disposing of waste material into a river was a "breach of international norms".

Environmental regulations are becoming more stringent in both developing and developed regions, with more regulation for key contaminants – chlorides, sulphates and heavy metals – on a global basis.

There is increasing scrutiny on the composition of waste-water streams; surface-water discharge limits vary depending on whether the receiving stream is regulated on its use for aquatic life, irrigation, agriculture or drinking water. Discharges to groundwater can have varying limits, depending on site-specific conditions.

Changes in the regulatory framework have been driven by the requirement to maintain groundwater or drinking-water quality. As water becomes scarcer there is a greater emphasis on ensuring the quality of waste-water discharge meets the guidelines for all industrial facilities.

As environmental regulations have matured, the main impacts have been felt in developing countries. Generic standards imposed by the WHO and lending organisations such as the World Bank have forced companies to consider waste-water quality, and the regulatory authorities of many mineral-rich countries have been catching up with the standards seen in places like the US, Canada and Europe.

Regional and local regulations for mine waste water vary, depending on where the site is located. Mr Beckingham explains: "In our experience, worldwide, the mining industry has become very cognisant of the value of water and the need to minimise production of waste water. This is consistent between small and large companies operating in both developed and underdeveloped regions.

"The main difference is the type of discharge standards in place for the companies to work with. Occasionally, Hatch works in areas where internal regulations are not well developed, and in these instances we work with the mining company and local governing bodies to achieve acceptable criteria such as World Bank standards."

In arid regions, the cost of wasting or not fully recycling water can be enormous. For example, at mine sites in Peru and Chile, desalinated water sometimes has to be pumped for hundreds of miles through significant changes in altitude, with the result that the cost of water is many times that for other regions, so it is utilised as efficiently as possible. Some processes may also be converted to 'dry processing' rather than the wet processing used in other regions.

BioteQ at Minto mine

BioteQ is providing an integrated package of water-management services for Minto copper mine in Yukon, Canada. This is a design-supply-operate project.

BioteQ will provide process design, plant equipment and installation, commissioning services, and fee-based water-treatment operations at the site for the next three operating seasons.

Plant commissioning was completed in early June, and continuous operations are expected to begin in the next few months.

The plant treats run-off, generated by rainfall and snow melt, to meet the strict water quality regulations for dissolved solids and metals set by the Yukon government.

The plant is designed to treat up to 600,000m^3 of water per season and remove copper concentrations to below 50ppb.

Minto is the first of the two new plants that Bioteq will commission in 2010; the second will be in China, subject to final review and approval of the design report, which is in progress.