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Commercial Scale Novel Approaches to Water Treatment at Remote Sites in Extreme Cold Climates

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Abstract

Extreme cold climates and geographical isolation can present tremendous challenges for mine water treatment. These challenges include the requirement for meeting stringent discharge limits in near freezing water temperatures, treating large volumes of water produced during snow melt in a relatively short treatment season, high costs and restrictions imposed on water storage and waste disposal, complex logistics related to the delivery of supplies to remote sites, and staff turn-over associated with difficult working conditions. This paper will present two case studies of remote northern Canadian mine sites where the seasonal nature of water treatment combined with stringent regulatory requirements necessitate careful planning and management of water treatment. The first case study describes a novel approach to treating up to 10,500 m^3/day at an active nickel mine located in the sub-arctic permafrost of Nunavik, Québec. The treatment combines BioteQ's ChemSulphide® process with ion exchange. The ChemSulphide® plant was installed ten years ago and typically operates from May to November. This plant has consistently met discharge requirements for nickel and toxicity and produces no waste sludge for disposal. When recent regulatory changes required additional treatment capacity, site throughput was increased by 60% with a mobile Met-IX™ plant that runs in parallel of the existing plant. The second case study involves mine water treatment at an active copper mine in the Yukon. In this case a temporary in-pit treatment system was set up to address a sudden increase in water inventory at the mine. This was followed by the delivery of a modular treatment system. The modules were transported over an ice bridge to provide the mine with a permanent treatment plant capable of meeting an ultra-low site specific discharge limit of 10 parts per billion (ppb) for copper.

Introduction

Water quality standards are evolving and regulations are moving towards ultra-low discharge (ULD) limits. Discharge limits in the parts per billion (ppb) range for metals and metalloids and new regulations are being adopted for sulfate and nutrients. Site specific requirements are often more stringent than the end of pipe federal Metal Mining Effluent Regulations (MMER) in Canada and typically align with the Canadian Council of Ministers of the Environment (CCME) guidelines that are viewed as being broadly protective of aquatic environments across Canada.

For over a decade, metal sulfide precipitation and ion exchange (IX) water treatment solutions have been successfully applied at mine sites around the world including remote sites in the Canadian arctic and sub-arctic. Treatment systems involving sulfide precipitation and IX are capable of handling highly variable flows of cold water with fluctuating metals concentrations while reducing/eliminating waste sludge production and meeting ULD limits for the constituents of concern. In addition, the plant footprints and construction costs are minimized due to the modularity of ion exchange systems and the high specific gravity (SG) of metal sulfide solids compared to metal hydroxides generated in lime treatment. By applying these technologies to selectively treat constituents of concern, significant savings in the overall Life Cycle Cost (LCC) of water treatment for the mine operators can be realized.

This paper reviews active water treatment at remote sites with extreme cold (sub-arctic) climate and associated challenges. It also discusses the advantage of alternate business models applied to water treatment that aligns interests of service providers with customers and reduces overall project risks.

Active Water Treatment in Extreme Environments

Lime Treatment

Lime treatment can be used for simultaneous bulk removal of many metals as mixed metal hydroxides. Lime treatment is often conducted with ferric iron added to enhance removal by adsorption and co-precipitation. However, there are challenges facing lime treatment today, including:

1. The lack of capacity to meet new regulations for all constituents present in mine water including metals with widely different solubility, and/or selenium, and/or sulfate; and
2. High cost of disposal and/or long term management of waste sludge.

Metal sulfide precipitation

In contrast to lime treatment, metal sulfide precipitation offers the advantage of selectivity, typically targeting only one or two metals for removal to ULD limits or potential recovery. Selectivity can create value for customers and sites that generate mine impacted waters where only one or two metals require removal while the rest of constituents meet their respective discharge limits, or in situations where lime treatment removes the bulk of metals but polishing is required to meet discharge limits for one or two constituents. Over the past 14 years, metal sulfide precipitation has been developed and applied successfully worldwide at various mine sites.

In the ChemSulphide® process a chemical sulfide reagent such as sodium hydrosulfide (NaHS) is introduced to the metal-laden water in a contactor tank where conditions are controlled to selectively precipitate only targeted metals. The resultant metal sulfide precipitate reports to a clarifier where it settles as clean water overflows the clarifier weir to be either re-used or discharged. It is important to note that metal sulfide clarifiers are sized using solution rise rates ranging from 3 to 7 m/h. This contrasts with lime treatment clarifiers which typically operate with rise rates of 1.3 to 1.7 m/h. The increase of clarifier rise rate directly leads to smaller clarifiers, smaller plant footprints and decreased capital cost in the case of metal sulfidation. The metal sulfide precipitate is filtered to remove excess water, producing a high-grade marketable metal concentrate that can be sold to metal smelters or blended with concentrates produced at the mine site.

In the BioSulphide® process, the hydrogen sulfide reagent used for metal removal or recovery is produced biologically using sulfur-reducing bacteria in an anaerobic bioreactor. The production of hydrogen sulfide in this manner leads to a lower cost per unit sulfide than buying NaHS. As a result, this approach is used when the mass load of metal to be removed is high enough to warrant the economy of scale of the bioreactor. The bioreactor is isolated from the water treatment tanks, creating a controlled environment that produces hydrogen-sulfide gas on demand. Water to be treated does not come into contact with the bioreactor solution – it is a means to produce reagent at site cost effectively. The gaseous sulfide is then introduced to the metal-laden water in a contactor tank, where the conditions are adjusted to precipitate individual metals. Simplified schematics of the ChemSulphide® and BioSulphide® processes are shown in Figure 1 below.

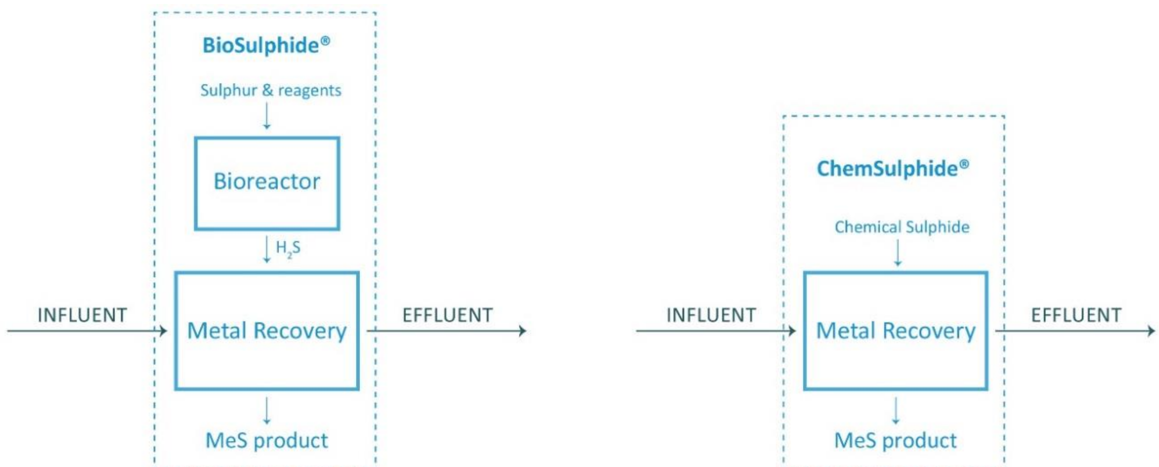

Figure 1: BioSulphide® and ChemSulphide® process flows

Ion Exchange for Metal Recovery

Similar to metal sulfide precipitation, ion exchange (IX) offers selectivity for the removal of dissolved metals. IX resins are available with a wide variety of functional groups, each of which bonds strongly to a range of metals. As a result, the IX resin must be chosen carefully depending on the constituent to be removed. The technology is particularly effective for high flows of cold water with already low metal concentrations that need to be further reduced in order to meet discharge limits. IX resins have finite capacity for metals and need to be regenerated prior to re-use. Consequently, IX systems operate using three-step cycles: loading, regeneration, and wash. During loading metals are selectively captured by the IX resin. During regeneration the loaded metals are stripped from the resin and concentrated into a regenerant solution. During wash the remnants of the regenerant solution are displaced with clean plant effluent water. IX systems are particularly cost-effective at treating mine water where they can produce solid by-products rich in the metals removed from water. One way of producing solid metal product using IX is to combine the IX system with metal sulfide precipitation that is applied on the small volume of liquid regenerant containing a high concentration of metals removed from mine water.

Case Study 1: Active Treatment at a Nickel Mine

The first case study involves water treatment at an active nickel mine in Québec situated in the Nunavik sub-arctic permafrost. The harsh climate limits the period of water treatment to 120 to 160 days per year. The source of mine impacted water fed to the treatment plant is surface run-off and water collected in open pits and underground workings. The water has a neutral pH but contains elevated levels of dissolved nickel that must be treated before it is discharged to the local receiving environment. Water treatment at the site consisted of a low-density sludge lime plant which suffered from low plant availability and high operating cost. The high operating cost was due to excessive lime and ferric salt additions followed by sulfuric acid addition to reach the nickel discharge standard of < 0.5 mg/L and pH suitable for discharge. The process also generated waste sludge that required disposal.

The ChemSulphide® plant was constructed in 2003, commissioned in 2004, and has been treating between 0.6 and 1.2 million m^3 of water in less than 150 days every year since it was commissioned. The plant removes and recovers nickel from the contaminated water and produces a high-grade nickel concentrate that is blended with the metal concentrate produced at site. The recovered nickel is owned by the mine operator and its value is used to offset the treatment cost. The treated water quality meets the water quality criteria set forth by Québec's "Directive 019 sur l'industrie minière" for discharge to local receiving waters and release into the pristine northern environment at site. It is important to note that the treated effluent consistently passes bioassay testing for toxicity using trout and daphnia magna prescribed by the regulations. Most importantly, the ChemSulphide® plant does not produce any metal-laden waste by-product that would create an ongoing waste disposal concern.

In 2011, in response to new regulatory requirement, water treatment capacity needed to be increased from 6,000 to 10,500 m^3/d in order to have the capacity to treat a one in one hundred year storm event. This was achieved at minimal incremental cost through the addition of a mobile ion exchange (Met-IX™) plant that treats water in parallel with the existing ChemSulphide® plant. Given the high construction costs at remote mine sites, the customer's main concern with the expansion of the treatment capacity by more than 60% was the cost associated with erecting a new plant housed in a new building. The solution was to expand the treatment capacity by adding a mobile IX plant housed in a modified tractor trailer, thereby eliminating the need for a new building. This approach also minimized site installation costs as all process equipment was already installed inside the mobile trailer. The overall site process flow diagram of the expanded water treatment system is shown in Figure 2 below. Note that the ChemSulphide® and Met-IX™ plants treat water in parallel, each meeting the effluent target before discharging to the environment; dilution is not used as a means to achieve Directive 019 effluent requirements. The small volume of concentrated nickel solution produced by the Met-IX™ is directed to the ChemSulphide® plant, thus ensuring that all nickel removed from water continues to be recovered in the solid concentrate form.

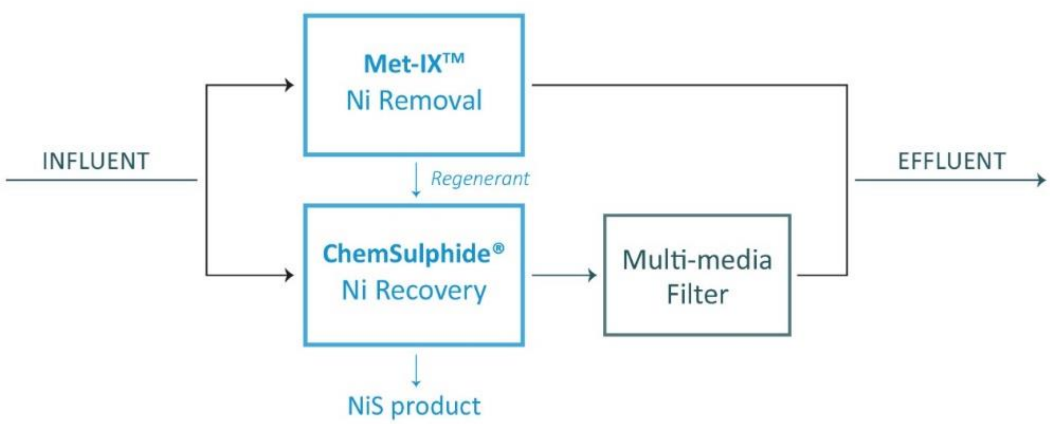

Figure 2: Combined process flow diagram

At this remote mine site all equipment and supplies are delivered via barge seven months of the year; workers and perishables are transported by plane year round. Due to winter shipping constraints, the last barge to reach the site before snowmelt leaves the port of Québec late January to early February. Sufficient reagents for the first four months of operation are ordered and delivered to site on this last barge. Shipping takes several weeks before the equipment arrives and is unloaded at site.

When the need for the expansion of the existing water treatment plant was announced in September 2011, the solution was required immediately in time for the following treatment season. This meant the plant needed to be ready for delivery in January, only a few months after the request was made. Due to this short window there was no time for erection of a building to house a permanent full scale water treatment plant; the client therefore opted for a mobile option. In order to deliver the selected Met-IX™ mobile plant in time for freshet, it was critical that the plant meet shipping deadlines – if not, the site would not meet its new regulatory requirement for treatment capacity. The project kick-off occurred in September and the mobile plant, housed in a tractor trailer, was delivered within five months to the port of Québec in late January, on time and on budget. The plant was commissioned during the same season.

Results

Table 1 includes the average feed and effluent water quality for the key site parameters. The plant exceeds the discharge objective set by the province in Directive 019 to produce clean water. The nickel sulfide product is transferred into 1,000 liter intermediate bulk container tanks and blended with the concentrate produced at site. As a result there is no waste sludge to manage.

Table 1: Results from water treatment for nickel removal 6,000 to 10,500 m^3/day

Parameter	Feed Chemistry	Discharge Limit	Actual Average Effluent Quality
pH	6.4 to 8.0	6.5 to 9.5	~ 7.9
Nickel	4 to 30 mg/L	0.50 mg/L	< 0.20 mg/L
Total Suspended Solids	variable	15.0 mg/L	< 1.0 mg/L

Figure 3 shows the progression of the feed nickel (in mg/L) over an entire season. As described previously, ChemSulphide® can handle a large variation of feed metal concentration and is insensitive to the cold water on site (water temperatures drop to < 1°C). Regardless of the slow increase in feed nickel (from 4 mg/L in the beginning of the season to 12 mg/L towards the end), the plant is capable of meeting the discharge limit for nickel.

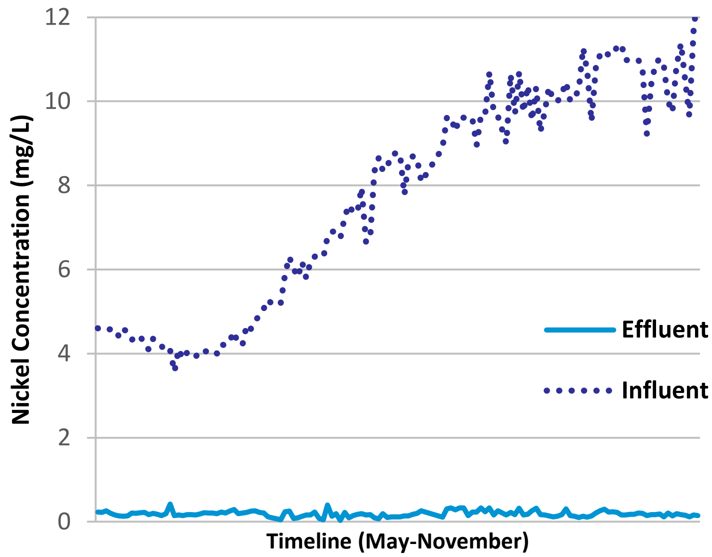

Figure 3: Results from treatment season

Toxicity has been raised as a potential issue for sulfide precipitation by service providers with limited or no expertise in this area. This ChemSulphide® plant proves that with proper controls and operating knowledge, sulfide precipitation meets toxicity test requirements. At this site toxicity tests using trout and daphnia are performed weekly.

Startup, Shutdown, Maintenance

The operation window is typically from June to the end of October. Large plant maintenance that requires a shutdown is typically performed at the beginning of the season to allow for an interruption free season and plant availability in excess of 98%. At the beginning of the season the pit is covered with several feet of ice. The water is pumped from below the ice cover through a feed pump housed in a small covered heated structure. The suction line to the pit has a heated wire to prevent the line from freezing during the startup. Once water starts circulating through the plant, discharge quality is achieved within four to five days.

Shutdown involves draining the plant and clarifier and shipping all nickel precipitate to the client. Shutdown typically occurs in November. By then, ice is once again formed over the pit. Water levels in the pit are monitored and the season ends when the pit contains sufficient water to begin pumping the following season and reach water quality before freshet starts. This ensures the plant is functioning and ready to discharge as soon as snow melt begins in the following season. During winterization of the plant, the feed pump and piping is carefully drained to ensure it will flow during the following year's startup.

Staff Management

Seasonal operation requires seasonal operators, which is a challenge to retain qualified personnel during the off season. To mitigate this, key staff are retained year-round to preserve the knowledge, expertise, and management practices. Return bonuses are also offered to operators who return for the next season.

Table 2 summarizes typical water challenges posed by a remote site with harsh cold climate, and how these issues are managed.

Table 2: Challenges with Water Treatment in Extreme Cold Environments and Solutions

Water Treatment Challenge	BioteQ's Solution
Ability to consistently meet very strict discharge limits for nickel, treating cold water and varying feed water chemistry	ChemSulphide® and Met-IX™ processes are less sensitive to temperature and chemistry than alternative technologies, consistently meeting strict discharge limits
Concerns regarding fish toxicity and environmental liability in fragile Arctic ecosystems	BioteQ's technology systems produce: • Clean, discharge quality water that consistently passes toxicity tests for fish and daphnia • Metal recovered as a saleable nickel product instead of waste for disposal
Short treatment season	BioteQ's processes can: • Operate effectively in cold environments, extending the available treatment season • Increase plant availability and treatment capacity by eliminating the need to stop operation to allow for settling (significant issue with LDS) • System can be mobilized quickly, producing discharge quality water within 5 days of start-up
Staff turn-over due to seasonal operation	Retain permanent staff year-round who return to site each year, providing an experienced, trained team
Limited accommodation on site	Provide an integrated team of operators for the ChemSulphide® and Met-IX™ increasing operational efficiency and reducing the number of staff required for water treatment operations

Cost

This project was delivered under a Build-Own-Operate (BOO) business model. Under this model BioteQ invested the upfront capital required to build the plant, charging the mine owner a monthly capital re-payment fee that ended after three years when the capital was re-paid and a treatment fee based on the cubic meter of water treated meeting the discharge criteria under an ongoing operating contract. Included in the contract was a guaranteed minimum volume of water to be treated. The treatment fee includes all labor required to operate the treatment plant, perform preventative maintenance, health and safety training, supervision, management, and reporting. Depending on the volume of water treated and whether water is treated through the ChemSulphide® plant or the Met-IX™ plant, the treatment fee varies between $0.60 and $1.20/m^3 and provides the customer with the cost certainty which is important to any remote site mine operator. In addition, since there is no waste sludge produced by the treatment, the disposal cost of sludge is eliminated. Finally, the value of nickel recovered from wastewater reduces the cost of treatment by approximately $0.20/m^3, assuming a nickel price of $6.00/lb.

Case Study 2: Active Treatment at a Copper Mine

The second case study involves active water treatment at a copper mine located in the Yukon. The cold climate limits the period of water treatment to five to six months of the year. The mine impacted water that is collected at the site contains copper levels between 0.050 and 0.250 mg/L. However, due to the fact that the aquatic environment downstream of the mine include a salmon spawning habitat, a site specific end of pipe discharge limit for copper of 0.010 mg/L was adopted by the local authorities with variances of up to 0.020 mg/L in certain circumstances.

In-Situ Temporary Sulfide Treatment

BioteQ was initially involved in providing emergency relief water treatment services following an extreme wet event in early spring that filled the open pit with water and prevented mining activities from continuing as scheduled. A temporary in-situ treatment system was installed within five weeks of an initial site visit. The temporary system treated 700,000 m^3 of water in a three-month period, emptied the open pit which allowed mining activities to resume, and reduced the concentrations of dissolved copper that ranged from 0.150 to 0.250 mg/L to less than 0.020 mg/L, meeting regulatory requirements.

The in-situ treatment consisted of a floating clarifier installed in the open pit. This novel clarifier design accelerated the overall schedule significantly by eliminating the need for pouring concrete foundations and the long lead times associated with equipment procurement.

Figure 4: In-situ treatment floating clarifier

Table 3 shows the average results of treatment during the in-situ campaign.

Table 3: Results from the in-situ sulfide treatment

Parameter	Feed Chemistry	Discharge Limit	Actual Average Effluent Quality
pH	7.0 to 8.0	6.5 to 9.0	7.0 to 8.0
Copper	0.05 to 0.25 mg/L	0.05 mg/L	< 0.02 mg/L
Total Suspended Solids	4 to 90 mg/L	15.0 mg/L	< 2 mg/L

The cost for the in-situ treatment was in the range of \$0.65 to 0.85/m^3 discharged, including mobilization and demobilization.

The temporary solution was acceptable as a short term approach. However, in the long term a permanent treatment had to be installed outside the pit to manage and treat mine impacted water to maintain an overall site water balance.

Permanent ChemSulphide® Water Treatment Plant

In response to the need for a permanent treatment system, a 4,000 m^3/day ChemSulphide® plant, was commissioned the year after the in-pit treatment. This system targeted copper as the constituent of concern. Figure 5 shows a simplified block diagram of the plant. In this plant multi-media filters are used downstream of the precipitation stage to reach the ppb level for copper.

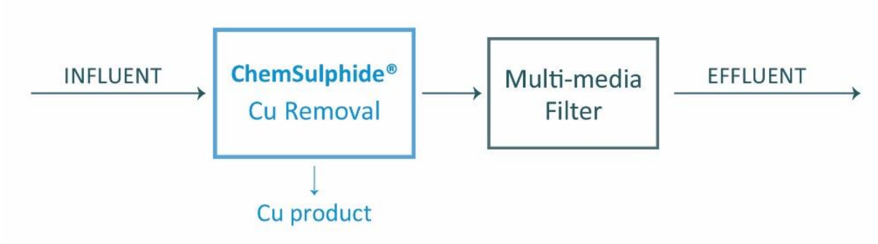

Figure 5: Full scale ChemSulphide® process diagram

BioteQ supplied the turn-key plant within a period of five months following the receipt of the order. The overall project schedule was very aggressive and revolved around the necessity to transport pre-fabricated equipment modules across the "ice bridge" over the nearby river before the beginning of spring thaw.

Results

The products from this process are clean water for discharge and stable sludge that was blended with the tailings at site. The effluent, objective, and treatment results are summarized in Table 4 below.

Table 4: Results for copper removal water treatment 4,000 m^3/day

Parameter	Feed Chemistry	Discharge Limit	Actual Average Effluent Quality
pH	7.0 to 8.0	6.5 to 9.0	7.0 to 8.0
Copper	0.05 to 0.25 mg/L	0.01 mg/L	≤ 0.01 mg/L
Total Suspended Solids	4 to 90 mg/L	15.0 mg/L	< 2 mg/L

Treatment Costs

The turn-key plant was delivered under a Design-Operate-Transfer (DOT) business model. Under this model the customer purchased the plant from BioteQ. After the plant was commissioned, BioteQ provided operating services for a three-year period prior to transferring the plant operation responsibility to the customer. However, since it was difficult for the mine owner to establish a guaranteed minimum volume of water to be treated annually, the fee structure was slightly different from the one applied at the nickel mine. In this case the fee consisted of a fixed monthly labor component to operate the plant, perform preventative maintenance, health and safety training, management, and reporting, that was paid regardless of the plant throughput as well as a variable component that had a sliding scale linked to the residual copper concentration in the plant discharge as measured in daily composite samples, and the hydraulic throughput. The treatment fee over the three-year term ranged between \$1 and \$1.25/m^3.

Summary

The two commercial case studies described in this paper demonstrate that sulfide precipitation and ion exchange represent active water treatment technologies that are well suited to handle the challenges associated with water treatment at remote sites. These challenges include extreme northern climates, short operating seasons during which large volumes of water need to be processed and discharged, ultra-low discharge limits, and high staff turn-over due to the difficult site conditions. These are robust process technologies that start-up quickly and can handle high variability in feed flow, metal loading, and water temperature. They are also mechanically reliable systems requiring minimum maintenance. Operating facilities applying these technologies typically achieve discharge water quality within days of mobilizing, maintain high plant availability during the treatment season, and can be winterized just as quickly at the end of the treatment season.

The selective nature of the technologies minimizes or eliminates the production of waste sludge, minimizes reagent costs, and offers the potential to recover metals as a valuable by-product of treatment to offset the overall treatment cost. Capital costs are reduced by minimizing site construction requirements through the reduction in plant footprint, pre-fabrication of equipment modules off site, and reduction in the cost of plant tie-ins / infrastructure associated with flow equalization ponds and waste sludge ponds or repositories.

The two commercial case studies also demonstrate how overall project risks can be mitigated and minimized by the business model applied to water treatment at remotes sites and difficult climates. Remote site operators are often concerned about the escalation in treatment cost and about developing and maintaining the expertise to operate water treatment plants reliably on a seasonal basis. BioteQ addresses these concerns by operating plants under fixed fee contracts that link fees to the plant performance, providing cost certainty to mine owners.