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Bloom Lake Mine Water Treatment Plant

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ABSTRACT

Cliffs Natural Resources, Bloom Lake Mine forms part of the south western corner of the Labrador Trough iron range and is located in close proximity to a number of producing mines near Fermont, Québec. In 2011, the site had two systems for removing suspended solids using settling ponds. These systems often had difficulty treating sufficient water for discharge and operating costs were high. Due to planned expansion, and higher volumes of water to be treated in the future, a new treatment plant was planned. The intention was to build a treatment plant to properly handle all the site runoff for discharge in compliance with environmental regulations. The parameters of concern for the mine water at Bloom Lake were the total suspended solids and total iron concentration.

AMEC was retained by Cliffs to conduct a three-week pilot campaign at the Bloom Lake Mine in October 2011. This pilot program served to verify different alternatives for reagents and process options. Different coagulants were fed, two types of alkalis, several flocculants, two different types of clarifiers were used, and sludge recirculation was also tested. The results showed that ferric sulphate with lime and an anionic flocculant, in a process with a lamella-type clarifier and sludge recycle, could most economically meet the process requirements.

Based on these results, a full-scale treatment plant was then designed. AMEC and Beaudoin Hurens completed the detailed engineering and start-up of the treatment plant, which was commissioned in July of 2013. The plant can successfully treat more than 75,000 m^3/day of mine drainage to a discharge quality that easily surpasses provincial and federal regulations.

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INTRODUCTION

Cliffs Natural Resources Inc. is an international mining and natural resources company. Cliffs' Bloom Lake operation is located in Fermont, Quebec and was in an expansion phase to double the iron production. Part of the long-term plan includes expansion of the tailings and water management infrastructure. This includes the water treatment facilities required to treat all the site runoff for discharge in compliance with environmental regulations. There were two previously existing systems for removing suspended solids – one for the mine area and another for the tailings areas. These were already undersized before planning began for an expansion. Operating costs were also high due to 24-hour operation, high reagent dosages, and frequent need to remove sludge. It was determined that an automated plant would greatly reduce operating costs and increase reliability.

With the objective of designing and building a full-scale treatment plant, the process and reagents required for treatment must be optimised. Cliffs retained AMEC to operate a pilot plant designed to evaluate different potential treatment options to consistently meet the Canadian Metal Mining Effluent Regulations (MMER – Canada, 2012) and the Québec effluent regulations, Directive 019 (Québec, 2012). The two potential issues for the site are total suspended solids and iron. The specific objective for a successful test in this pilot campaign was defined as steady-state operation with a total suspended solids content of 4 mg/L or less in the final effluent. As the iron is in particulate form, a low solids content would ensure that the total Fe limit of 3 mg/L would also be met.

PILOT PLANT

Cliffs retained AMEC to operate a pilot plant on-site in the fall of 2011. The project was completed with the assistance of CANMET Mining for use of their pilot equipment, mobile laboratory and experienced operators to cover half the shifts. AMEC led the pilot operations, planned the tests, and completed the interpretation and report writing.

The process applied during piloting is displayed in Figure 1. The pilot plant campaign was designed to evaluate different potential treatment options to consistently meet discharge criteria from the mine site. The pilot tests included trials with ferric sulphate, gypsum, or limestone for coagulation, and lime or caustic for pH adjustment. A flocculant was also used in almost all tests as it proved to be necessary in attaining the low suspended solids contents required. The reactor received the raw water feed, the coagulant, the alkali, and the sludge recycle when applicable. The raw water feed rate for all tests was 1 L/min. The Reactor had a retention time of 5 minutes (5 L volume). The Floc Tank received only the flocculant and Reactor overflow. The first Floc Tank used was small, with a retention time of only 3 minutes. After bench tests showed improved results with increased floc mixing, the tank was changed over to one with a 10-L volume, for a 10-minute retention time.

The pilot was run in two phases, nine scoping tests and two detail tests, for a total of 11 tests. The two detail tests included recirculation and significant optimisation. These are discussed in the following sections.

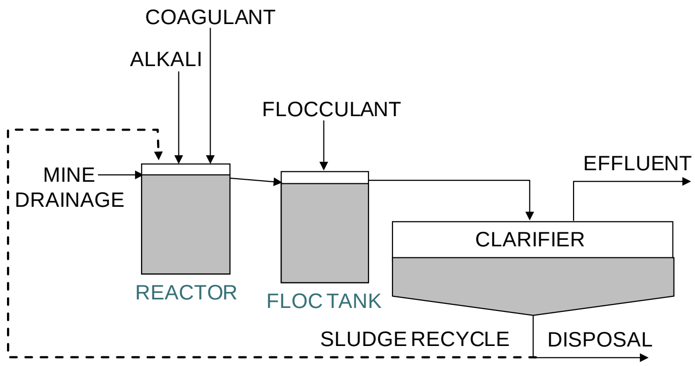

Figure 1 Process applied during piloting

Raw Water Quality

Figure 2 shows the raw water variability during the 11 tests, which were conducted from October 7th to October 30th, 2011. The raw water suspended solids concentrations were not controlled and the representativity of this raw water compared to that expected in the future was not known. As shown in Figure 2, there was significant variability in total suspended solids during the first 3 tests, but the raw water quality then stabilised near 120 mg/L.

Scoping Tests

In the 9 scoping trials, there was no recirculation and a lamellar tube-type clarifier was used. All of the different coagulants were tested at varying dosages and pH setpoints. The average duration of the scoping tests was 25 hours. The alkali agents used in the pH control system were caustic (NaOH) or hydrated lime ($Ca(OH)_2$), added to an adjusted pH of 7.5 or 9.0. The coagulants used were ferric sulphate (at 11.4 or 5.7 ppm), gypsum (at 1 g/L) or calcite (limestone, at 1 g/L), and the optimal flocculant identified in bench testing was Flomin 920MC fed at 2 to 5 ppm.

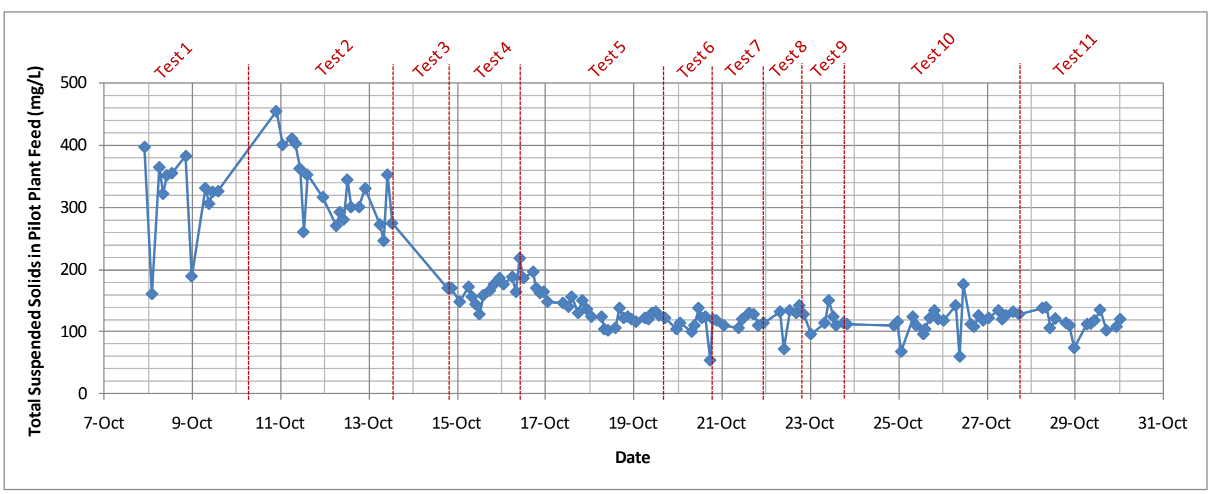

Figure 2 Raw water total suspended solids during piloting

Scoping trials showed that all the coagulants showed promise, but the very high dosages required for gypsum or calcite resulted in reagent costs that would be five times higher with either of these reagents as compared to ferric sulphate. Both alkalis, caustic and lime, were successful with ferric sulphate. It was therefore decided to retain only ferric sulphate as the coagulant, with lime or caustic as the alkali for the detail tests. Sludge recirculation was also planned to help improve treatment efficiency and sludge density (Aubé, 2004).

Detailed Pilot Tests

Following scoping trials, two options were tried with sludge recirculation: lime with ferric sulphate (Test 10) and caustic with ferric sulphate (Test 11). The lamella clarifier used in the scoping tests did not have a rake mechanism installed. For the detail tests with recirculation, a conventional clarifier was used which had a rake to push the solids toward the center cone. Optimisation was required to ensure that the sludge flowed well. This included adjusting the speed of the rake drive and reducing the flocculant dosage from 3 to 2 ppm.

The recycle efficiency was then monitored by measuring the solids concentration in the reactor. With the feed TSS near 120 mg/L and the fresh precipitates from the added iron representing 10 to 20 mg/L, all additional solids in the reactor slurry are from recycled sludge. In both tests, the best effluent quality was obtained with reactor solids contents of about 3 g/L (3,000 mg/L) or more. The highest solids content measured was near 6 g/L with excellent resulting effluent quality. This sludge recycle also allows for a robust process, as TSS variations from less than 100 mg/L to more than 400 mg/L in the raw water will not significantly affect the treatment efficiency if there are more 6,000 mg/L in the reactor.

Both process options were able to successfully treat the raw water to meet the objective: an average concentration of less than 4 mg/L total suspended solids over 24 hours of operation. The best results with lime were obtained with a ferric sulphate addition of 5.7 mg Fe/L, lime addition to a pH of 9.0, and 2 ppm flocculant dosage. The sludge recycle rate was operated at 100 mL/min, or 10% or the feed rate, volumetrically. After the sludge recycle system was optimised, the sludge density increased to 12% solids by weight.

The best results obtained with caustic were with identical settings, apart from the choice of alkali: 5.7 mg/L Fe dosage, caustic addition to a pH of 9.0, and 2 ppm flocculant addition, with 100 mL/min sludge recycle. The maximum sludge density attained with caustic was 5% solids content.

Final Effluent Compliance

To ensure that the proposed process met the discharge criteria, some samples were sent for analysis and for toxicity testing. A full scan of metals was completed on the filtered raw water, total effluent and filtered effluent. The total concentrations in the final effluent are the regulated parameter, but the other two were submitted for analysis to verify changes in dissolved concentrations in the process. The effluent metals concentrations were well within regulated limits for all parameters in both the Directive 019 and MMER. There were no mortalities in either the *daphnia magna* or the rainbow trout (100% survival) thereby confirming that this process produces a non-toxic effluent.

Costs

Both processes clearly showed that they could efficiently treat the raw water, meaning that the choice between the two alkalis will be made based on the cost. Capital costs would be similar for both process options as the most significant item, the solid/liquid separation equipment, is not dependent on the type of alkali. The ferric sulphate, the sludge recirculation, the flocculant, and the automation systems are all essentially the same. The only difference in capital is a caustic system versus a lime system, which would be similar even though the systems are quite different.

The operating costs would be the same for power, labour, management, sampling, and maintenance. The determining factor falls to reagent and sludge costs (MEND, 2013), which are summarised in Table 1. Reagent unit costs were obtained from local suppliers in 2011. The sludge costs were assumed to be approximately $2 per cubic meter, which should cover pumping plus storage or management costs. A representative total annual treated water rate of 20 million cubic meters is used to evaluate the potential annual costs of treatment.

Table 1 Comparative cost of successful tests (2011 C $)

		Ferric Sulphate and Lime				**Ferric Sulphate and Caustic**			
Reagent	**Unit Cost**	**Consumption**		**Cost**		**Consumption**		**Cost**	
	($/t)		**Unit**	**($/m³)**	**($/20 Mm³)**		**Unit**	**($/m³)**	**($/20Mm³)**
Lime	$400	0.020	g/L	$0.0082	$163,218	-	g/L	-	-
Caustic	$1,250	-	mL/L	-	-	0.024	mL/L	$0.0445	$889,583
Ferric sulphate	$350	0.03	mL/L	$0.0160	$319,200	0.03	mL/L	$0.0160	$319,200
Flocculant	$4,750	2	mg/L	$0.0095	$190,000	2	mg/L	$0.0095	$190,000
Sludge	$2 per m³	0.79	mL/L	$0.0016	$31,746	1.64	mL/L	$0.0033	$65,574
Total				$0.0352	$704,164			$0.0732	$1,464,358

Because lime forms a much denser sludge (12% solids for Test 10 vs. 5% solids for Test 11), sludge pumping and disposal costs are lower, making lime the cheapest option for sludge management. The greatest cost difference between the two process options is due to the cost of alkali addition, as caustic is much more expensive than lime as shown in Table 1: $889,583 vs. $163,218 for lime. The combination of these two benefits of lime makes it the much cheaper option for alkali addition.

It was therefore recommended that the full-scale design of a water treatment plant (WTP) for Bloom Lake mine apply the process as shown in Figure 1, with ferric sulphate, lime, and an anionic flocculant, with a sludge recycle designed to feed up to 10% volumetrically.

BLOOM LAKE WATER TREATMENT PLANT

The design of the Bloom Lake water treatment plant was based on a two-phase implementation. The first phase of the process was to be capable of treating all runoff from the site for the current footprint in a 1 in 1000-year recurrent wet year. As the expected expansion of the mine would significantly increase the affected surface area and catchment basin, the plant size was planned to eventually double in capacity. The initial phase was to have a design flowrate of 75,000 m^3/d and the second phase would increase to 150,000 m^3/d. The first phase was designed with a hydraulic capacity of 100,000 m^3/d. Because the plant could be installed at the base of the primary feed water basin, the raw water is fed by gravity through a decant tower. There are provisions for raw water also being fed by pump from other parts of the mine, but the main feed point is from the decant tower.

Process System

The Densadeg process system (Dauthuille, 1992) by Degrémont was selected for the Bloom Lake WTP and is shown in Figure 3. This system includes a reactor and Floc Tank integrated as part of the design. AMEC made some modifications on the standard Degrémont design, including a larger reactor (5-minute retention time), modified clarifier, and modified sludge recirculation. As shown in Figure 3, the ferric sulphate solution and lime are combined with the feed water in the reactor. The mixed slurry then flows though a buried pipe to the centre bottom of the Floc Tank where mixing with the flocculant is completed via a draft tube. The flocculated solids are then settled in the clarifier to form a sludge. This sludge is constantly recycled and partially purged from the system to maintain a steady inventory. The clarified effluent overflows to a launder where the pH, turbidity and flowrate are measured prior to final effluent release.

There were two major modifications to the clarifier, both of which were designed to improve sludge handling as the pilot project showed that the sludge could be viscous. The first modification was to increase the slope of the clarifier cone bottom to 9°. A greater slope helps the sludge to flow towards the centre cone. The second modification to the clarifier was the rake mechanism. For such an application, Degrémont typically installs four full-length arms on the rake. To minimise the risk of entraining the sludge with the rakes, AMEC requested to remove every second blade on each rake arm. This design still ensures that the sludge flows towards the centre, but minimises the direct push against the sludge bed which could cause the entire sludge bed to turn with the rakes.

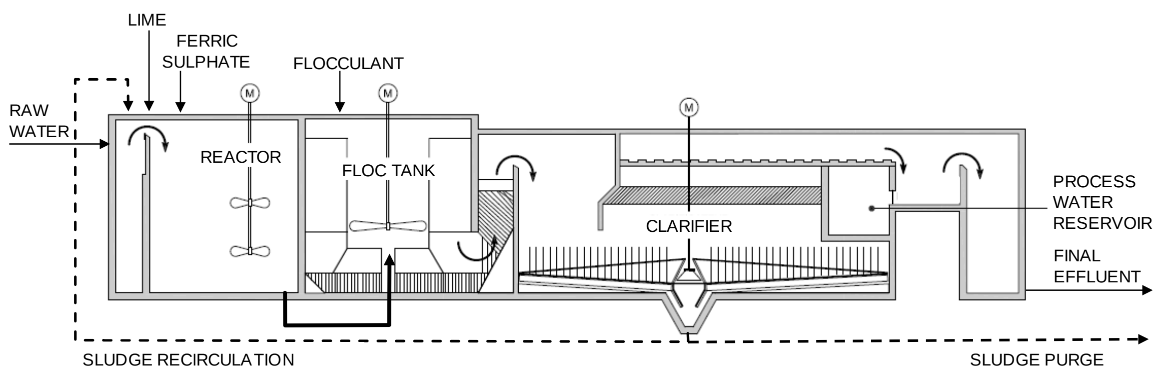

Figure 3 Process system at the Bloom Lake WTP

Another modification to the standard Densadeg design was the location of the sludge recycle. In the standard Densadeg design, the sludge is recycled to the intake of the Floc Tank. AMEC modified this so that the sludge is sent to the Reactor. This was done because the fresh ferric hydroxides and raw water TSS are expected to agglomerate best with the existing sludge if they are combined prior to flocculation.

Plant Overview

Figure 4 shows a three-dimensional view of the plant as built and Figure 5 is a photo of the plant exterior during commissioning. The reagent systems and control room were located in a prefabricated building. The Densadeg was installed under a dome structure, sufficiently large for both phases of the project. All of the major reagent and process systems are identified in Figure 4 and discussed in the next section. Most of the electrical requirements for the plant are not shown as they are external in a portable electrical building. Also not shown are the feed decant tower, the exterior piping (feed, effluent, effluent recycle, and sludge), and the emergency generator.

Reagent Systems

All of the reagent storage and preparation systems were designed for the total flowrate of 150,000 m^3/d. Due to the remoteness of the mine site, Cliffs requested that the reagent systems be designed to store sufficient material for 5 to 7 days of autonomy. The reagent dosage pumps are duplicated to ensure continuous treatment. One of the construction objectives was to minimise local labour due to high costs and low availability of employee lodging in the region. For this reason, all pump systems were ordered with skids which simply needed to be assembled, connected, and wired on-site. To account for the two phases of the project, each skid was delivered with two installed pumps and room for a third on the same skid. The systems below are described as currently installed.

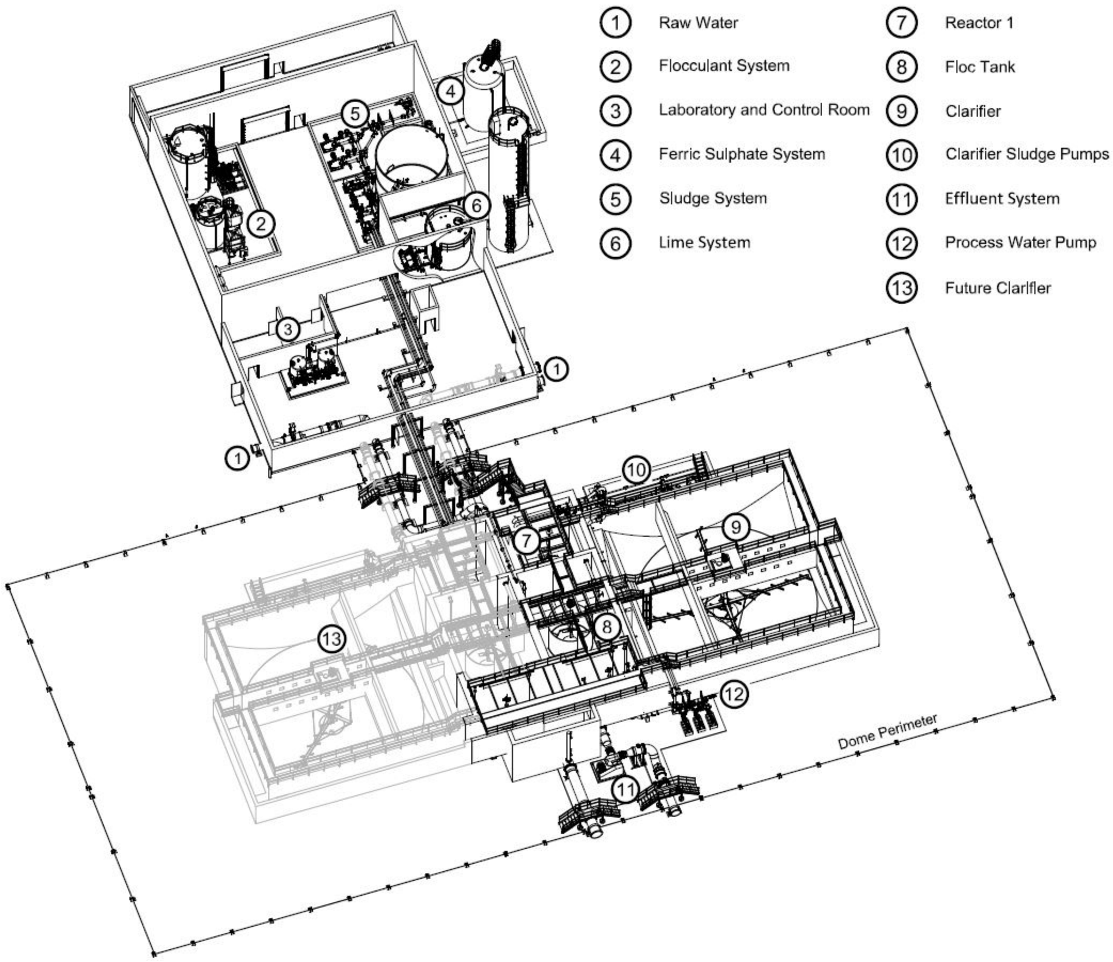

Figure 4 Graphical view of the Bloom Lake WTP

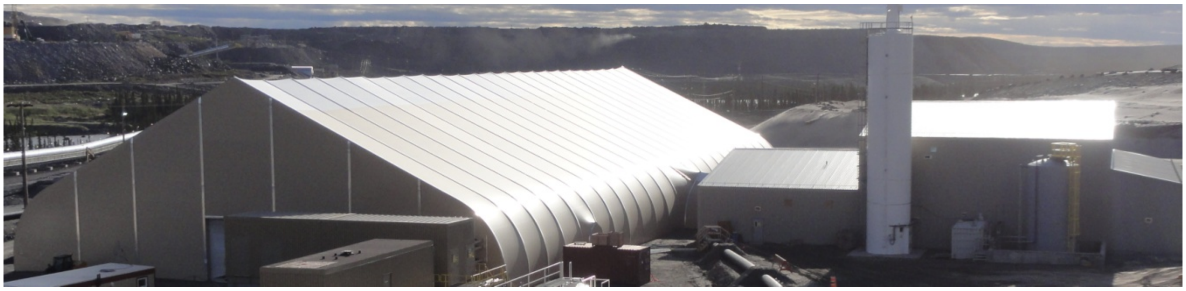

Figure 5 Bloom Lake WTP during commissioning

The ferric sulphate is received in tanker trucks and stored in a 77 m^3 storage tank. As the ferric sulphate solution can be very viscous at cold temperatures, the storage tank is heat-traced and insulated to prevent pumping problems during winter operation. The ferric sulphate is fed to the reactor via one of two variable-speed peristaltic pumps. The dosage rate is automatically controlled based on an operator-selected dosage rate and the flowrate of raw water fed to the plant.

The lime system includes a 75-tonne silo, 0.6 tonne/hour screw feeder, and a 41 m^3 lime slurry storage tank. The lime is dosed to the reactor on a pH control loop via one of two variable-speed peristaltic pumps. Two separate flexible lines are installed, to ensure constant operation. Automatic valves on the dosage systems allow for remote changing of the lime dosage pumps. These include pump isolation valves, flush water, and drain valves.

The anionic flocculant powder is delivered in big-bags which are placed on a hopper and screw conveyor feeding a venturi system for wetting the polymer. The flocculant solution is prepared in a 20 m^3 mixing and aging tank, before being transferred to a 65 m^3 storage tank. One of two progressive-cavity pumps is used to feed the flocculant to the Floc Tank, where it is dispersed through a ring in the draft tube.

Sludge Management

One of two progressive cavity pumps is used to recycle sludge to the Reactor. Each of these pumps can provide up to 7,500 m^3/d, or 10% of the feed flowrate. Sludge is bled (or purged) from the system via a single progressive cavity to a sludge storage tank. To prevent settling in the sludge stock tank, recirculating pumps drawing from a low point in the tank return the pumped sludge through two jets, forcing a circular motion (Siemens, 2011). This jet-mixing system allows the sludge to be drawn to very low levels in the tank without affecting mixing and mechanical integrity of the system.

When a high level is attained in the sludge stock tank, the sludge is pumped via two large peristaltic pumps to the tailings pond, at a distance of 600 m. These two pumps operate concurrently to ensure a sufficient velocity in the 15 cm sludge pipe.

Effluent System

The clear water from the clarifier overflows into a launder where the turbidity, pH, and flowrate are constantly monitored. Turbidity is an excellent indicator of clarification efficiency and has been correlated with the total suspended solids concentration. If either turbidity or pH exceeds pre-set limits, an emergency recycle pump will engage and return the plant effluent to the raw water storage basin. During normal operation, the treated water will flow by gravity to the discharge point 425 m away.

The treated effluent is also used as process water for the plant. A large basin near the final effluent section is used to maintain a minimum inventory of water which is used directly for hoses, flushing lines, flocculant dilution, and lime slurry preparation. A sand filtration system is also fed with this treated effluent to provide service water where just a few milligrams per litre of solids could have an effect. This includes the flocculant preparation system, laboratory sink, lavatory, and safety showers. For the safety showers and eyewash stations, the water is also heated and passed through an ultraviolet disinfection system before the point of use.

PLANT CONSTRUCTION AND START-UP

The water treatment plant construction started in August of 2012 with site civil preparation. In order to continue construction activities during the winter, the building and dome structure were the first priority. The dome had significant temporary heating installed to allow for proper curing of the concrete with exterior temperatures reaching well below -30 degrees C. Although many challenges were faced during construction, overall, the plant was successfully completed within 11 months.

The plant start-up was delayed due a province-wide construction strike in the summer of 2013. Upon completion, the start-up was very efficient, with treated water sent out to the environment within 3 days of commissioning.

The second phase of the Bloom Lake water treatment plant, to a total flowrate of 150,000 m^3/d, will be required when the mine footprint increases to a point where the current system would be insufficient. Determining exactly when the Phase 2 implementation will occur is currently under study.

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