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Mexican iron ore mine – surface paste tailings system development: a case study

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Abstract

The mine site is a historic location with operations dating back to 1828. The community and the mine have grown side by side, with the city, including critical infrastructure, almost surrounding the mine. As a water conservation measure, the mine currently treats sewage from the community, with reclaimed water used in ore processing. The available land for tailings disposal is competing with the growth of the population, agricultural uses and other industries in the area.

The mine currently produces approximately 1 M t per year. The site recently opened a new tailings pond (TSF-2), adjacent to the main pond (TSF-1) and mine, and is temporally depositing the slurry tailings stream in TSF-2. Supernatant water from TSF-2 is recycled back to the process plant for reuse.

To optimise the storage capacity of TSF-2, and to maximise water reclaim, a surface stack system was selected. A paste team of WesTech, Clifton, and Paterson and Cooke was assembled to provide a design for the system (Johnson & Slottee 2004). The paste system plan is to transition TSF-2 to a surface stack and open a new site (TSF-3) approximately 1.5 km to the north. Both sites are adjacent to the current workings and bordering the neighbouring farm lands and residential areas of the city.

This paper provides the selection of the deposition design, the paste thickener to produce the non-Newtonian tailings stream, transportation to the sites and placement strategy in the facilities.

Keywords: *surface stack, site management, paste and thickened tailings*

1 Introduction – current operation

The mine site is a historic location with operations dating back to 1828. The local community and the mine have grown side by side, with the city, including critical infrastructure, almost surrounding the mine. The site currently includes the open pit mine, waste rock piles, process plant, and two tailings storage facilities (TSFs), referenced here as TSF-1 and TSF-2. In addition, rail transportation infrastructure exists to allow shipment of ore concentrate from the site.

The topography of the site can be described as an area of rolling hills ranging in elevation from approximately 1,900 m above sea level (masl) to 2,200 masl. The site is located in an area of low seismic hazard (peak ground acceleration with a 10% probability of exceedance in 50 years, 475 year return period of less than 0.04 g). The site is in a region of Mexico with an arid climate with an annual rainfall of approximately 460 mm which is exceeded by the average evaporation of 2,250 mm annually. As a water conservation measure, the mine installed and is currently operating a treatment plant that treats a portion of the sewage from the community, which, along with reclaimed water from the TSF, is used in ore processing.

Ore processing includes grinding, gravity separation, magnetic separation, flotation and dewatering with thickeners and filtration of the concentrate. Concentrate is loaded on trains for transport to market. The mine currently produces approximately 1 M t per year of tailings.

The general site layout is presented in Figure 1. The original TSF (TSF-1) has been closed, having reached its capacity and the city electing to not allow any additional dam raises. The requirement for additional tailings disposal capacity is competing with the growth of the population, agricultural uses and other industries in the area. The mine recently commissioned a new TSF (TSF-2), adjacent to TSF-1 and the open pit mine, and is temporarily depositing the slurry tailings stream in the pond. Supernatant water from TSF-2 is recycled back to the process plant for reuse.

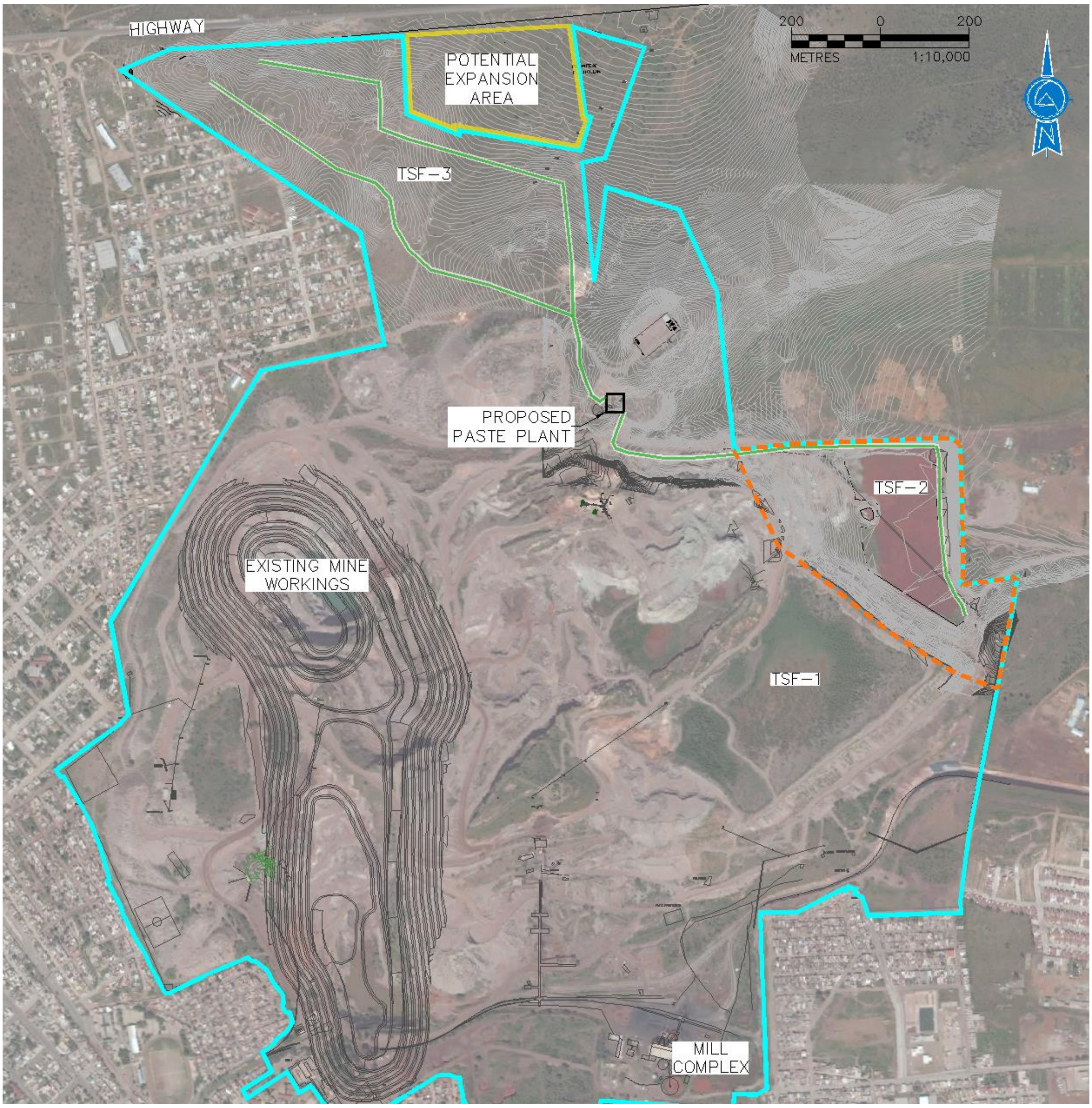

Figure 1 Site map of Mexican iron mine

The small size of TSF-2 does not permit the development of a water collection area of the necessary depth; therefore, a barrier to screen the solids is required. The mine has constructed a supernatant water collection area with a perimeter dyke constructed of rock to provide filtration for the water to remove suspended solids. A significant driving head is required to permit water flow through the filtration berm. Evaporation, water retained in the pore spaces of the deposited fine solids, and seepage consumes a majority of the water sent to TSF-2. The return water collection pond is shown in Figure 2, with TSF-2 in the background. As can be seen in Figure 2, a very flat beach surface is developed on tailings deposition due to the fine gradation of the tailings.

Figure 2 Iron tailings water collection from current new slurry pond

The water balance for the new operating plan was calculated for TSF-2 and TSF-3. The increase in water recovery for the tailings stream is shown in Table 1. The feed to the paste thickener is a high-rate thickener underflow. This feed comes from the treatment plant 1–2 km from the paste thickener location. The paste thickener will produce 60–65 wt% solids underflow and recovers an additional 132 m^3/hr resulting in an overall 94 % water recovery.

Table 1 Improved water balance around the two stage thickening circuit at Mexico iron mine

Stage	Water in feed (m^3/hr)	Water in overflow (m^3/hr)	Water in underflow (m^3/hr)	Overall recovery
High-rate thickener	976 (estimated)	764	212	80.2%
WesTech paste thickener (projected)	212	132	80	94.0%

2 Thickener design and selection

The current tailings dewatering is accomplished with a high-rate type thickener (~35 m diameter) located at the concentrator plant. The underflow (35–38 wt% solids) feeds the TSF-2 at about 250–300 m^3/hr. The tailings are deposited in one corner of TSF-2, creating a flat planar beach sloping towards the supernatant water collection pond. The plan to convert the system to paste and thickened tailings (P&TT) requires selection of the type and size of paste thickener to meet project requirements.

Sizing of paste thickeners are basically the same as high-rate thickeners in that the hydraulic and solids loading to the unit must be considered. The hydraulic loading criterion for a paste thickener is similar to high-rate thickeners. The site criteria is identified by bench-scale settling tests which included flocculant screening, feed solids concentration effect, flocculant dosage and static settling tests. Based on the optimum selected flocculating conditions, the initial settling rate is determined. The hydraulic criterion provides the minimum thickener diameter that could be considered for this application.

Next, the solids loading criteria is determined for the material. In the case of paste type thickeners, the solids loading criteria is based on the yield stress curve. Based on the intended use of the paste thickener underflow, the target yield stress range is selected. For this application, surface stacking of tails generally targets a yield stress of about 30–80 Pa. The bench-scale rheology study resulted in the yield stress curve shown in Figure 3. The rheology study also included a form-only vacuum filter cake. This form-only cake has interstitial water between the closely packed particles. The weight percent of this cake is used to estimate the boundary between where a suspension will flow like a paste and a higher wt% that is not a paste and will crack like a cake. The material tested showed that the target underflow wt% solids would be about 60 to 65 wt%.

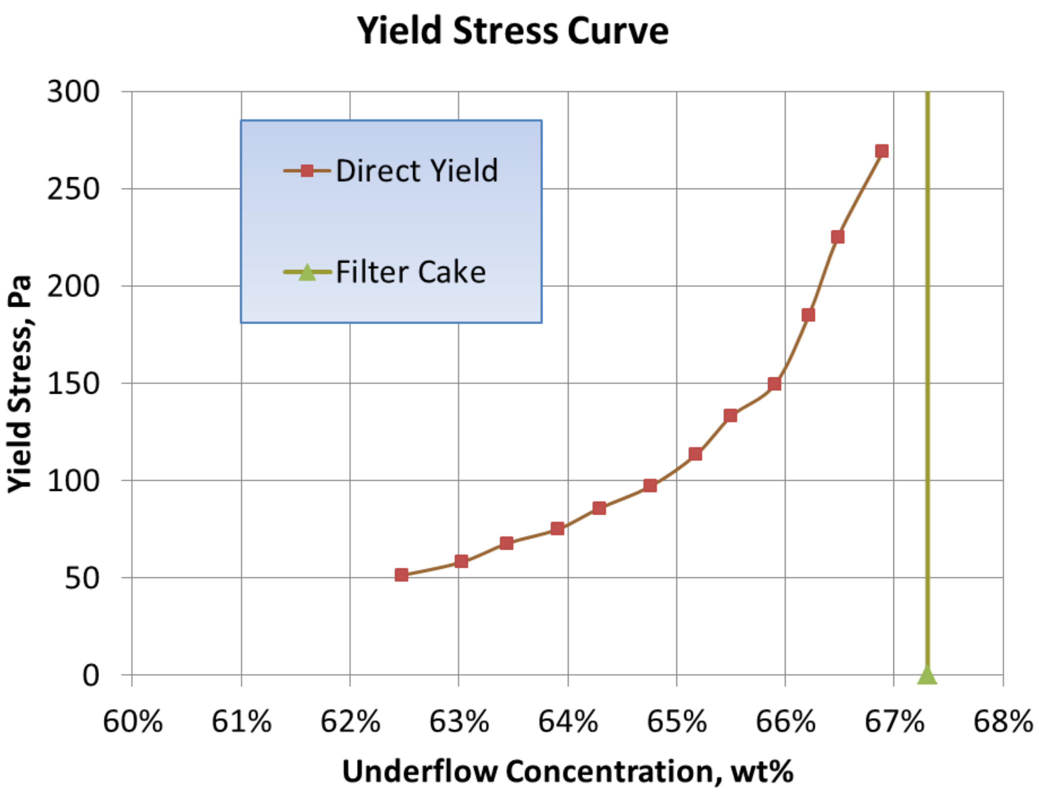

Figure 3 Bench-scale rheology test result (Haake™ Viscotester™ 550)

The recommended paste type thickener for this application is the WesTech HiDenisty™ and the general dimensions of 15 m diameter, an 8 m vertical sidewall and a 14° floor slope. The underflow will be non-Newtonian.

3 Conceptual deposition and pumping study

The capacity of TSF-2 is minimal and is constrained by the available land area currently owned by the mine. Current plans for continued operation of the mine require that a third TSF (TSF-3) be developed approximately 1.5 km to the north of TSF-2, on the northern perimeter of the mine. TSF-3 will be bounded by the active mine to the south, residential neighbourhoods to the west, and a major four-lane highway to the north. As with TSF-2, TSF-3 will be constrained by the available land area for the development. The combined operation is being designed to provide capacity for approximately 10 years of operation at current production rates.

To optimise the storage capacity of these two sites, and to maximise water reclaim, a P&TT surface stack system was selected. WesTech met with the mine to present the P&TT system and assembled a paste team of WesTech, Clifton, and Paterson and Cooke to provide a conceptual design for the system. It is currently planned to convert TSF-2 and to develop TSF-3 for P&TT deposition.

The goal of the design is to provide a facility that will provide for safe and effective disposal of the tailings while improving the overall physical characteristics of the deposits and to maximise water recovery to the process plant (Brackebusch & Shillaber 1998; Fourie 2015).

The conceptual study evaluated the two sites using a phased approach to the design as follows:

1. Site data collection and review.
2. Site visit.
   a. Site inspection.
   b. Process review.
3. Options evaluation.
   a. Operating criteria.
   b. Option identification and evaluation.
4. Conceptual and basic engineering.
   a. Selection of the paste thickener and prediction of underflow rheology.
   b. Conceptual design of containment structures.
   c. Conceptual operating plan.
   d. Preliminary transportation of P&TT for pumping design.
   e. Conceptual water management.
5. Transportation conceptual review.
   a. Selection of pumping and pipeline specification for purchasing.
6. Engineering report of findings.

This study provided the required information needed for sourcing of the thickener, the pumps and the pipeline. In addition, a preliminary management plan for the surface stack was developed which includes requirements for containment dam construction, tailings deposition plan and water management.

3.1 Site information

Site-specific data required for the design studies was collected from the mine engineering department. A site visit was conducted to identify any specific site constraints for TSF design and construction, and to gain an understanding of the plant process. The data which was collected and reviewed, included:

- Tailings properties – tailings gradation, chemistry and specific gravity.
- Climate data – long-term and average temperature, precipitation, evaporation, wind and relative humidity and storm events.
- Topography and geology – topographic mapping, geotechnical, hydrogeological and geophysical reports.
- Design and construction – design, construction and operation reports for the current TSF.

3.2 TSF option evaluation

Based on current land ownership, the mine has limited options for development of TSF-3. Discussion with the mine revealed the only undeveloped land area currently owned by the mine, that is large enough for significant tailings storage, is located north of the existing open pit as shown on Figure 1. This site has undulating topography sloping to the north and is bound by a highway and privately owned land. The mine is currently working to acquire additional land (‘Potential expansion area’ shown in Figure 1) which could significantly increase the storage capacity of TSF-3.

The preliminary design for TSF-3 considers thickened tailings deposition with containment provided through the construction of earthfill dams. The preliminary TSF-3 site layout at the start of operation, along with the proposed layout of the tailings distribution system, is shown in Figure 4. The containment dams will be constructed in stages to reduce upfront capital costs for TSF-3.

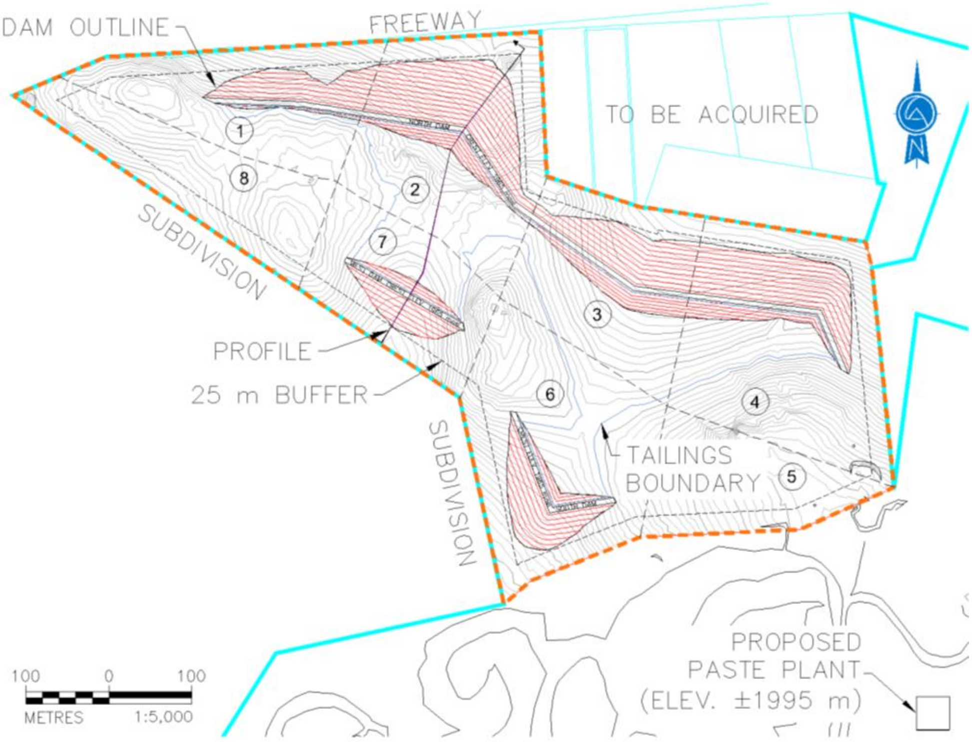

Figure 4 Preliminary site layout – TSF-3

3.3 Conceptual and basic engineering

The conceptual design for the TSF-3 earthfill dams provides a minimum 25 m buffer between the property boundary and the ultimate toe of the containment dams to permit construction of seepage and runoff water collection and control, TSF monitoring and slope maintenance. The conceptual design calls for the dam raises to be constructed using upstream construction methods.

The starter dam will be constructed of locally available borrow materials. The dam cross-section will have a 6 m crest width to permit vehicle access for inspection, and upstream and downstream slopes at two horizontal to one vertical (2H:1V) and 3H:1V, respectively. A vertical chimney drain connected to a horizontal blanket drain under the downstream slope of the dam will be included to control seepage through the dams.

Starter dam construction will be carried out with locally available materials excavated from within the footprint of TSF-3 to maximise available tailings disposal capacity. It is assumed that site preparation will include removal of existing vegetation and relic structures within the TSF-3 area. Foundation preparation will require excavation to intact bedrock or competent soils below the dam footprint.

Subsequent dam raises will be constructed using upstream construction methods. Fill material will be placed over a prepared tailings surface. Additional analysis will be required to evaluate the potential to utilise dried tailings materials for embankment fill in the dam raises. A typical cross-section through TSF-3 at the end of operation is presented in Figure 5.

As discussed in more detail in Section 3.5, the tailings will be deposited in thin layers and allowed to dry prior to placement of subsequent layers, with the intent of improving the physical (strength) properties of the tailings. Prior to raising the dams, the tailings surface will be compacted to provide a stable foundation for subsequent lifts.

Due to the low seismic hazard, relatively flat dam slopes and improvement in tailings properties from drying and foundation preparation, the stability of the dam slopes is not expected to be an issue. In addition, the volume of ponded water will be maintained near zero at all times. However, further analysis will be required at the detailed design stage to confirm the assumptions.

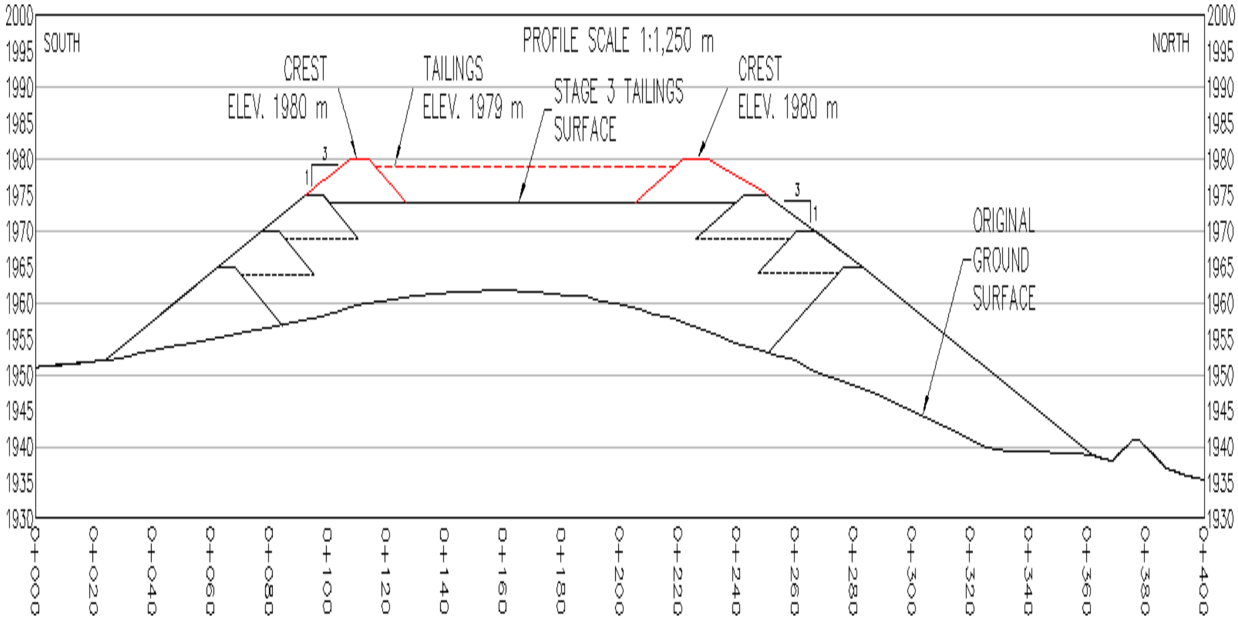

Figure 5 Typical cross-section through TSF-3 at the end of operation

3.4 Pumping and pipeline sizing

Peripheral spigots were selected as the preferred method of deposition. Spigots will be provided at approximately 50 m spacing along the distribution pipelines as shown in Figure 6. The pipeline plan for both TSF-2 and TSF-3 were determined. A central location between the TSF-2 and TSF-3 sites was selected for the paste thickener. The site is located near the top of the hill with easy routes to either site. The profiles for initial pipeline runs and final pipelines were determined to base the selection of the pump and pipeline design. The pipeline profiles selected for each condition and site are shown in Figure 6.

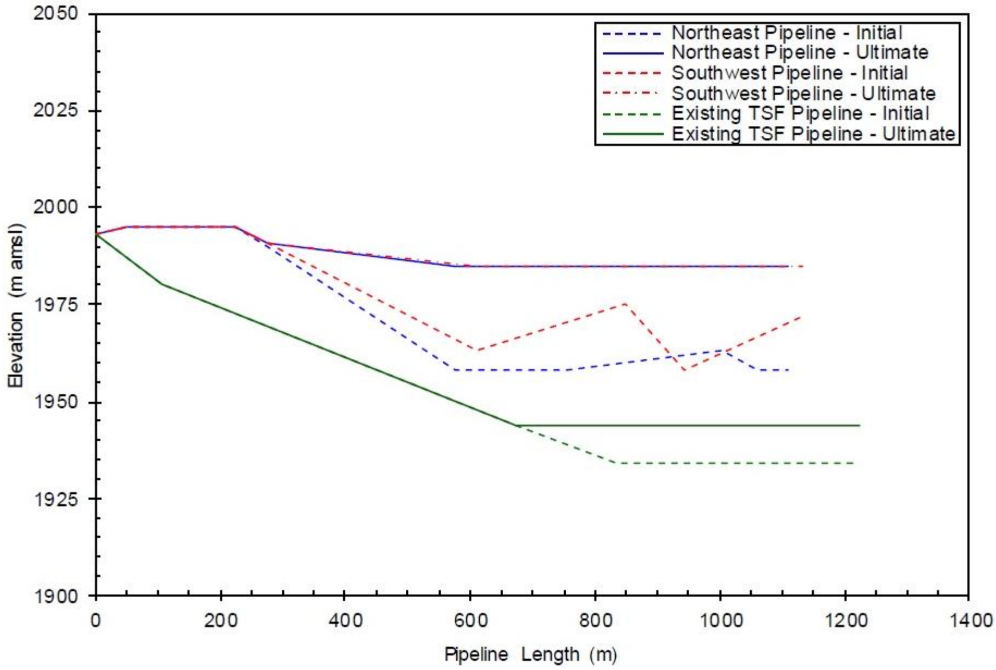

Figure 6 Pipeline profile to TSF-2 (existing) and TSF-3 (northeast and southwest pipelines)

The pipeline was designed to operate in laminar flow. Due to the relatively high yield stress of the tailings at the design solid concentrations, pipeline velocities are below the estimated laminar to turbulent transition velocity.

A pump station consisting of two pump trains (one operating and one standby) each with three centrifugal pumps in series was selected. The pump size of 4/3 horizontal centrifugal slurry pumps are recommended with 110 kW motors. The two pump trains can deliver paste tailings to any of the three pipelines (one operating at a time). The pipeline selection is shown in Table 2.

Table 2 Pipeline selection for the paste distribution to TSF-2 and TSF-3

Pipe location	Pipe length, type
Southwest perimeter of TSF-3	600 m, 6 in. schedule 40 steel A53 grade B, class 300. 530 m, 8 in. SDR 7 PE4710HDPE.
Northeast perimeter of TSF-3	600 m, 6 in. schedule 40 steel A53 grade B, class 300. 530 m, 8 in. SDR 7 PE4710HDPE.
Current TSF-2	675 m, 6 in. schedule 40 steel A53 grade B, class 300. 550 m, 8 in. SDR 7 PE4710HDPE.

3.5 Conceptual operating plan

Best practice requires that every TSF have an operating plan that is regularly updated to include changes in TSF design and construction, changes in operating philosophy, and changes in corporate structure and responsibility for safe operation of the TSF. The operating plan will also provide guidance on inspection and maintenance of the facility over the operating, closure and post closure periods.

As part of the study, a conceptual operating plan was developed. The operating plan was used to provide inputs to the pipeline and pump selection. It also provides guidance on the future operation of TSF-2 and TSF-3, including construction scheduling for dam raises and water management.

The goal of the conceptual operating plan was to maximise water recovery and allow deposition to occur in such a way that tailings will be allowed to dry between deposition cycles, resulting in improved geotechnical properties for the deposited tailings. To achieve these results, each TSF has been broken into zones where deposition will occur in cycles.

Tailings will be deposited as a P&TT, distributed by the pumps and pipelines. A series of spigots along each pipeline will be used to direct the tailings to the different zones of the TSF. The tailings will flow into areas near each spigot with the goal of developing a layer of less than 150 mm in thickness. Following deposition within a zone to achieve the desired tailings layer thickness, the active spigots will be flushed and discharge will be initiated in a new zone. The cycles of deposition will be sequenced to allow drying of the deposited tailings between subsequent deposition cycles. Deposition will be cycled between TSF-3 and TSF-2, particularly during the initial period of operation to provide sufficient drying time between deposition cycles. The preliminary operating plan calls for approximately 8 to 10 deposition cycles per year over the entire facility.

This thin layer provides for relatively quick drying and enhanced consolidation of the tailings under climatic conditions at the site. Initial estimates indicate that a drying cycle should be at least two weeks. Following the drying cycle, the tailings flow can be returned for the next layer. Trials will be carried out during the initial operating period to confirm the drying cycle times and to optimise operation of the facility.

During operation, the deposition and construction will be scheduled to maintain a minimum of 1 m of freeboard along the dam crest at all times. Careful planning will be required to ensure that freeboard is maintained, construction of dam raises can be completed, and that adequate discharge zones are always available throughout the operating period.

A water management plan/water balance has been developed for each TSF. For safe operation, sufficient capacity should be available in the TSF for any water that could report to the TSF, including slurry water, direct precipitation and runoff, and any other emergency discharges that may occur. At the same time, the pond volume will be minimised to reduce potential evaporation losses.

4 Conclusion

The mine discussed in this study is located in an arid climate with limited water resources available. Maximising water recovery, while also improving the physical characteristics of the deposited tailings, was a key driver for the mine to convert the current slurry tailings system to a P&TT system.

Improved water recovery and physical stability of the deposited tailings can be achieved at this site through conversion of the existing system. Water losses from the tailings stream (evaporation, seepage, and water trapped with the solids) can be reduced, improving the overall site water balance, and reducing costs to the mine.

P&TT permits more water to be recovered at the thickener while producing a non-Newtonian suspension underflow that achieves a higher final density of the tailings.

Converting the current TSF to a surface stack, and design and operation of the new TSF site requires knowledgeable experts to produce a plan for the site. The integrated team compiled for this project was able to develop a design concept which includes paste production (thickener design), tailings transport (pumping and pipeline design) and final disposal (geotechnical and operational planning), that extends the life of the existing TSF-2 while providing additional disposal capacity through the development of TSF-3.

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