Tailings Facility Expansion & Operation Plan "Overcoming Weak Foundation Challenges"

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Abstract. To accommodate an increased mine life, Seabee Mine required an expansion to their tailings storage capacity. This meant an increase in containment for their existing East Lake and Triangle Lake tailings management facilities (TMFs). Due to regulatory, operational, and space limitations, innovative solutions were necessary. Specifically for the East Lake TMF, staged construction of a waste rock containment dike directly over historically deposited tailings was required.

A foundation characterization program was undertaken prior to completing the TMF expansion design. This characterization confirmed the presence of unconsolidated tailings zones with variable thickness overlying more competent ground. The impact of this variability was examined through rigorous sensitivity analysis in the initial design analysis of the structure; followed by construction of a full-scale test section within the existing facility footprint. Test section monitoring data was used to reassess and confirm the design analysis such that full-scale construction could commence. Stage 1 construction was completed in May 2016 with tailings placement immediately after in accordance with a detailed operations plan that includes a comprehensive tailings deposition plan and associated water balance.

This paper presents an overview of the findings from the test section monitoring, details of the operations plan, and a discussion of Stage 1 operation during the summer of 2016. The information presented demonstrates how rigorous numerical analysis coupled with sound experiential judgement can be used to overcome challenging operational issues continuously faced by mining companies.

Keywords: expansion of tailing storage capacity, full-scale test section, confirm the design analysis, operations plan

1 Introduction

FIG. 1. Project location.

The Seabee Mine is located about 120 km northeast of La Ronge, Saskatchewan, Canada *(see FIG. 1.)*. Seabee has been in operation since 1991. Additional reserves at Seabee Mine and Santoy deposits were discovered and as a result, the life of mine is projected to continue past 2020.

Ore is processed at the Seabee mill and tailings are deposited into the East Lake and Triangle Lake TMFs *(see FIG. 2.)*. The capacity of the combined TMFs was not sufficient to handle the increased mine life and thus expansion of the facilities was required. Triangle Lake TMF has been periodically raised in accordance with its staged expansion design plan, and Stage 1 expansion of the East Lake TMF was completed in 2016. Expansion of the East Lake TMF consisted of constructing a waste rock containment dike directly on top of existing tailings in the TMF. To reduce the risks associated with uncertainty related to the strength characteristics of the tailings and how that might affect the proposed dike, the initial phase of construction served as a test section allowing for field data collection on actual performance of the foundation.

The East and Triangle Lakes were natural lakes converted to TMFs when Seabee Mine was developed. Prior to tailings deposition, the lakes were partially dewatered to provide the necessary capacity. Over the years as new reserves were found, a series of earthen and concrete containment structures were constructed along the TMFs low lying edges to increase their capacity. In 2003, a final series of raises brought the East Lake TMF containment structures to their final crest elevation of 460 m, which includes 0.5 m freeboard. Tailings were hydraulically deposited in the East Lake TMF via single pipe discharge from 1991 to 2003. Following that, tailings were deposited in Triangle Lake TMF. As of spring 2016, the Triangle Lake TMF was constructed to its final permitted crest elevation at 460 m, and Stage 1 Expansion of the East Lake TMF was completed to a crest elevation at 463 m.

FIG. 2. Site plan and general arrangement of tailings management facilities.

2 East Lake TMF Expansion Design History

Several design concepts to expand the existing East Lake TMF were evaluated, which consisted of utilizing and/or raising the existing retaining structures, constructing a series of internal waste rock containment cells, and various waste rock dike alignments for internal tailings storage. The chosen design consisted of a continuous waste rock dike, approximately 900 m in length that would be constructed on top of tailings within the footprint of the existing TMF (*see FIG.2.*).

Following preliminary design work, a field investigation was carried out that consisted of 16 cone penetration tests along the alignment of the proposed dike. This data was coupled with limit equilibrium and bearing capacity calculations to optimize the design. Staged construction of the expansion dike was subsequently undertaken. The first step being a test section that would allow for collection of actual performance data to alleviate some of the uncertainty associated with the weak tailings foundation properties. The test section data was then used in a back analysis to determine suitable tailings properties for finalization of the expansion dike design. Lastly, an operations plan was developed to provide mine staff with procedures for safe operation of the East Lake TMF.

3 Test Section

The test section was constructed over the weakest foundation zone as identified through the field investigation. Construction of the test section commenced early October 2012 and was largely completed by late April 2013. The target crest elevation of the test section was 460 m and the base width was the full final design width of about 50 m.

A total 47 fixed survey monuments were placed near the upstream and downstream crests of the test section to assess deformation after construction. The location of these monuments *(see FIG. 3.)* had to accommodate ongoing construction traffic over the test section. An as-built survey of the dike test section was completed, which enabled generation of a waste rock isopach showing fill thickness.

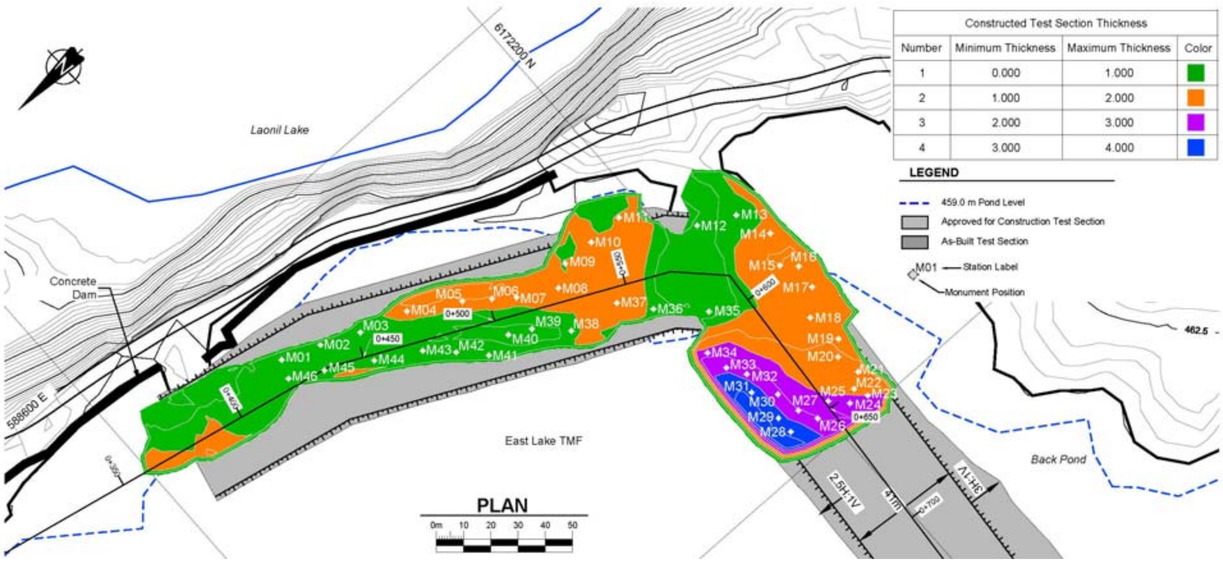

FIG. 3. Test section as-built, settlement monuments and isopach of waste rock thickness.

Primary data collection was stopped in August 2013, four months after completion of the test section, as the deformation and primary settlement data showed an attenuation of movement towards steady state.

Vertical displacements ranged from 0.03 to 0.93 m, while horizontal displacements ranged from around 0 to 0.38 m *(see FIG. 4)*. The bulk of the displacements occurred within the first two and a half months of monitoring up to the end of June 2013. Displacements after this time were noticeably smaller and by August 2013 primary settlement appears to have stopped.

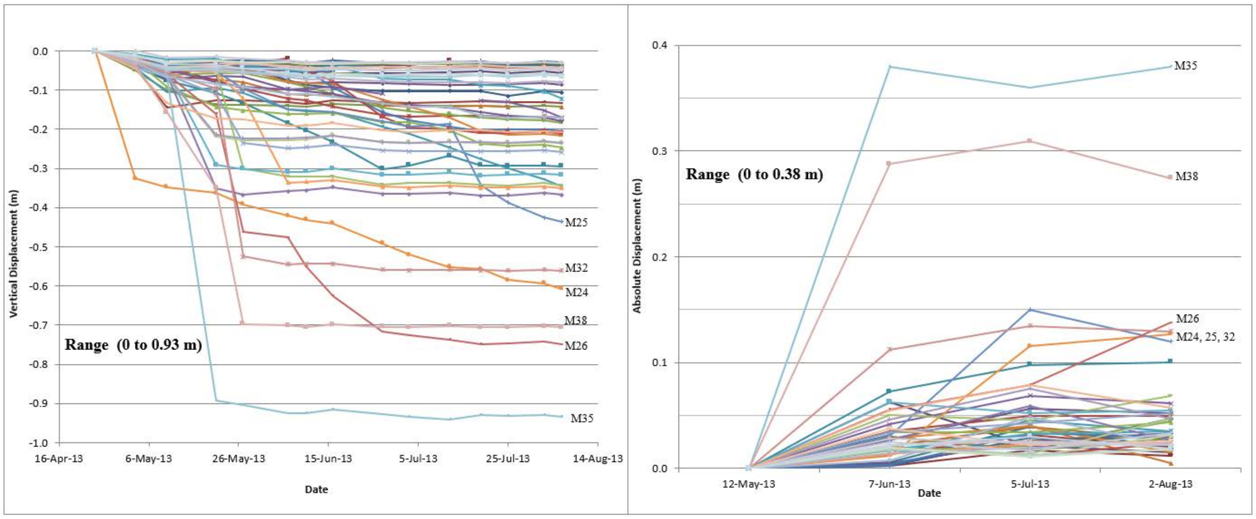

FIG. 4. Vertical and horizontal displacements of test section survey monuments.

Select survey monuments M24, 25, 26, 32, 35, and 38 *(see FIG. 4)* were placed very close to the edges of the test section crest. Some slumping/relaxing of the waste rock was observed at these locations due to over steepened slopes. Therefore, some of the ongoing changes in these locations were attributed not only to primary settlement, but also from deformations as a result of the monuments moving as the slope relaxed. This was taken into consideration during the back analysis to ensure the results were not skewed unnecessarily. Figure 5 presents an isopach of how the settlement data varied spatially across the test section at the end of the monitoring period.

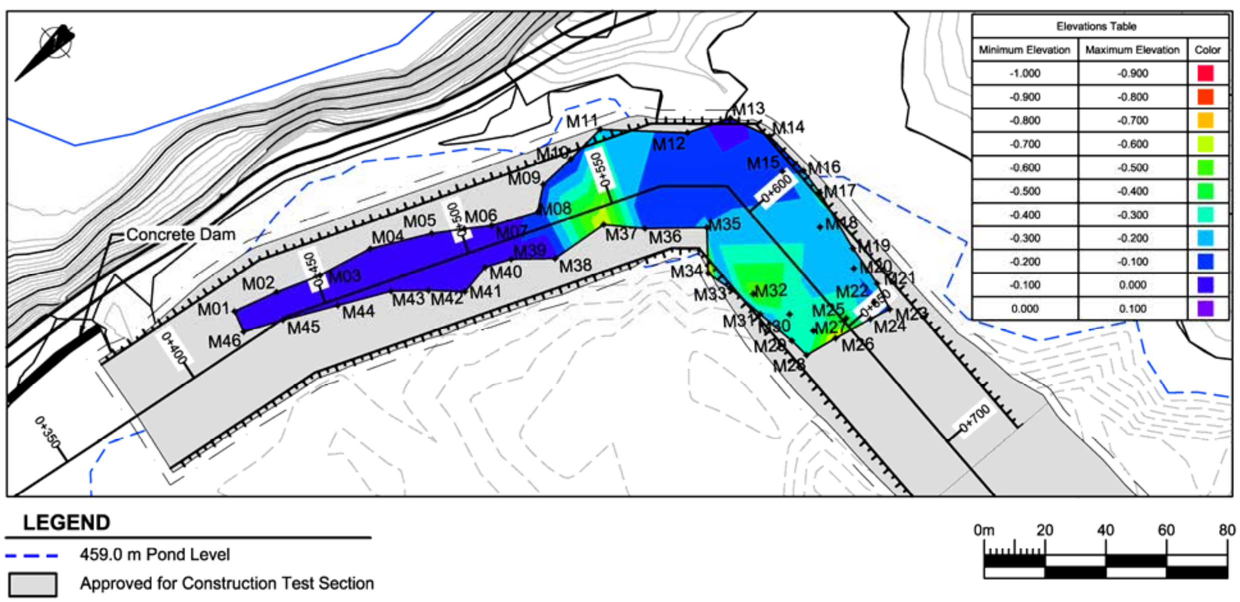

FIG. 5. Settlement isopach based on vertical settlements at test section survey monuments.

4 Back Analysis of Test Section Data

For the final expansion dike configuration at crest elevation 466 m, the test section monitoring data was used to complete empirical settlement calculations using Terzaghi's one-dimensional theory of consolidation (Terzaghi, 1996 [1]). The data was then incorporated into finite element deformation and shear strength reduction models to determine "safety factors" for each of the dike construction stages.

4.1 One-dimensional Consolidation Analysis

Given the variability in dike geometry and foundation conditions, consolidation calculations were completed at several key locations across the dike section and about every 50 m along the dike centerline. Calculations were also completed for interim dike heights at elevations 460 and 463 m. These were done to assess the potential benefits of staged construction and to determine the maximum expected settlement during construction. For these calculations, the foundation material was assumed to consist entirely of tailings with variable thickness and consolidation index values (C_c) from 0.3 to 0.4.

Figure 6 illustrates the predicted maximum settlement based on these one-dimensional settlement calculations that ranged from 0.3 to 2.1 m. These settlement values assume instantaneous construction of the expansion dike to its maximum crest elevation of 466 m.

Elevations Table			
Number	Minimum Elevation	Maximum Elevation	Color
1	0.000	0.200	
2	0.200	0.400	
3	0.400	0.600	
4	0.600	0.800	
5	0.800	1.000	
6	1.000	1.200	
7	1.200	1.400	
8	1.400	1.600	
9	1.600	1.800	
10	1.800	2.000	
11	2.000	2.200	

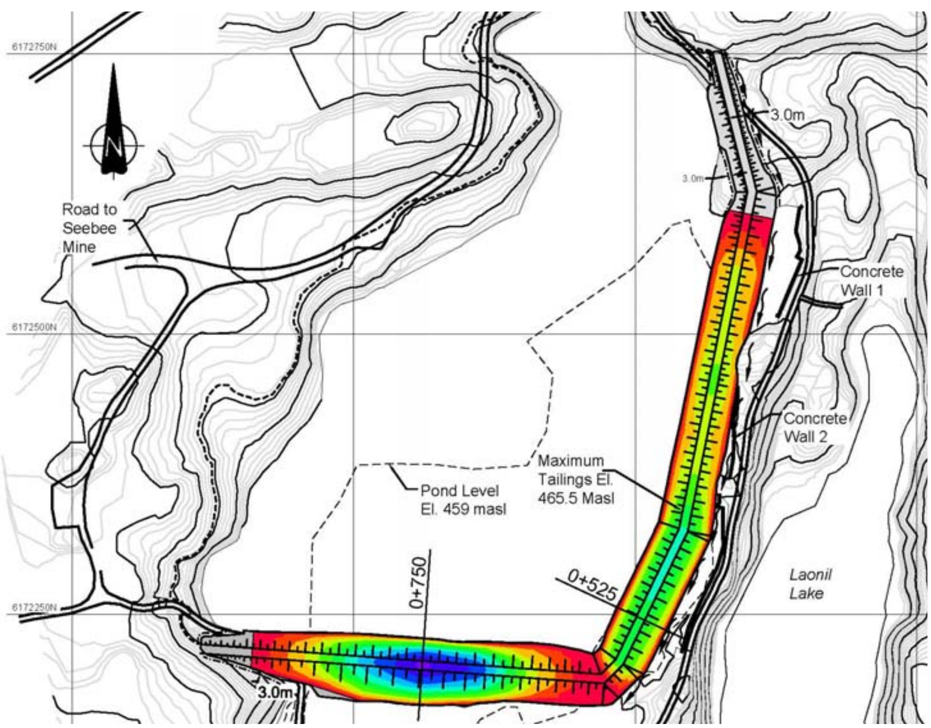

FIG. 6. Predicted settlements based on one-dimensional consolidation calculations.

4.2 Finite Element Analysis

Deformation analyses were carried out using PLAXIS 2D Anniversary Edition two-dimensional finite element software (Plaxis, 2014 [2]). The analyses included pore water pressures induced by compression and consolidation of the foundation tailings, solved simultaneously with the soil, and rock mass stress field. The results were also coupled with the computation of a strength factor via strength reduction techniques.

Two Plaxis calibration models were set up to allow for comparison to the monitoring data as follows: (1) Uniform 5 m thick waste rock dike with a tailings foundation that increased in thickness from 0 to 5 m and (2) Uniform 5 m thick tailings foundation that had an overlying waste rock dike thickness that increased from 1 to 6 m.

Using the initial Plaxis calibration model results, the tailings material properties were adjusted until the results best fit the collected monitoring data. The primary values that were adjusted included void ratio, compression index, recompression index, and internal friction angle. These values, along with engineering judgement and published benchmark values, were used to calculate some of the secondary material properties for the tailings (EPRI, 1990 [3], Santos *et al*., 2001 [4]). These back analyzed tailings material properties were then adopted and used in the subsequent deformation models for two critical design sections.

Two critical dike sections were modelled *(see FIG. 6.)*: (1) Station 0+750 situated in area of maximum observed displacements, and (2) Station 0+525 situated in an area of maximum dike thickness overlying a thick tailings foundation.

Dike displacements due primarily to consolidation were less than 2.1 m for the worst case deformation model and were typically less than 1.6 m. The analysis suggests that the majority of primary consolidation for a given raise occurs over a period of approximately 7 to 12 months, which correlates well with the test section data. As the dike is raised, further primary consolidation is triggered resulting in an increased total settlement over the life of the structure.

Finite element modeling of horizontal sections across the dike indicated differential settlements may range from 0.8 to 1.2 m. These differential settlements lead to some strain development within the dike; however, these strains do not appear to result in the development of a large failure plane in the waste rock itself.

Based on the settlement, deformation and stability analysis, safety factors were found to be above 1.4 for all modelled cases under static conditions and “without consideration of staged construction”. With staged construction (i.e. the proposed method to construct the expansion dike), the finite element models yielded minimum safety factors of 1.6 or greater. These results were used to confirm that the expansion dike design, as proposed, would function appropriately.

5 East Lake TMF Expansion Design

The initial design work and the subsequent back analysis revealed that the failure mode for the East Lake TMF expansion dike would likely be complete foundation failure governed by the low strength tailings or failure of a portion of the dike as a result of the poor mechanical response of the underlying tailings foundation.

The analysis also confirmed that the dike should be constructed in stages as it allowed for increases in the shear strength properties in the tailings foundation tailings over time and assisted in dissipation of foundation pore pressures. The final expansion dike design entailed a 6 m high, 900 m long waste rock dike, constructed in 1.5 m high raises *(see Fig. 7)*.

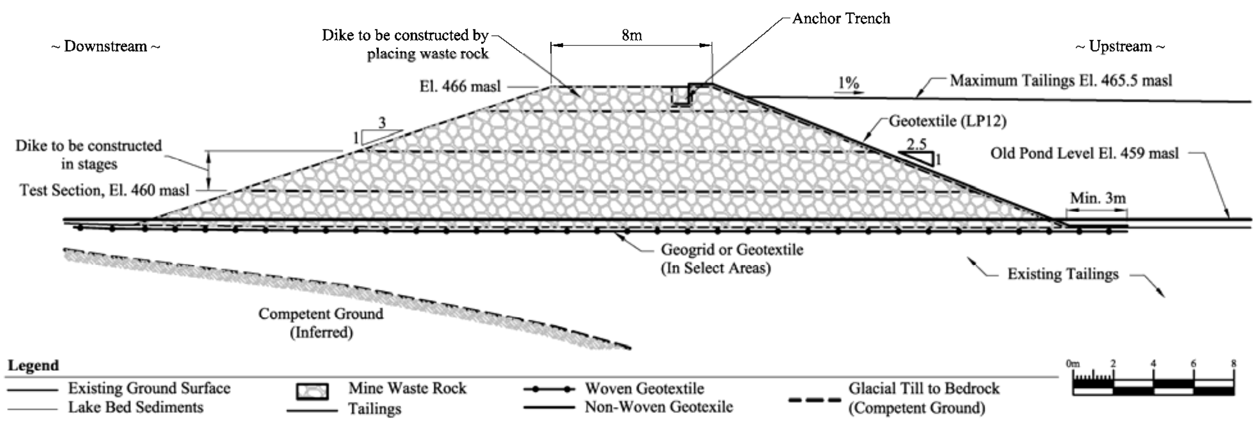

FIG. 7. Typical East Lake TMF expansion dike design section.

6 Operations Plan

6.1 Water Management

The East Lake TMF expansion dike was designed to impound tailings but not water; thus, a robust water management plan became an integral component for successful operation of the East Lake TMF.

All supernatant water and precipitation within the East Lake TMF is pumped to and managed within the Triangle Lake TMF. To do this, a floating reclaim pump is situated within the basin of the East Lake TMF along with two seepage collection pumps situated along the east flank of the facility between concrete Dams 1 and 2 and the downstream toe of the expansion dike *(see FIG. 8.)*. The proposed floating reclaim pump was sized to maintain a pond level as low as practicable within the TMF. The East and Triangle Lake TMFs are utilized for tailings deposition where the East Lake TMF is operated only during the summer months (May to October). Figure 8 shows the proposed water management plan for the TMFs. A live water balance was developed based on the proposed water management plan such that mine staff can manage and predict the water within each of the TMF’s through to closure.

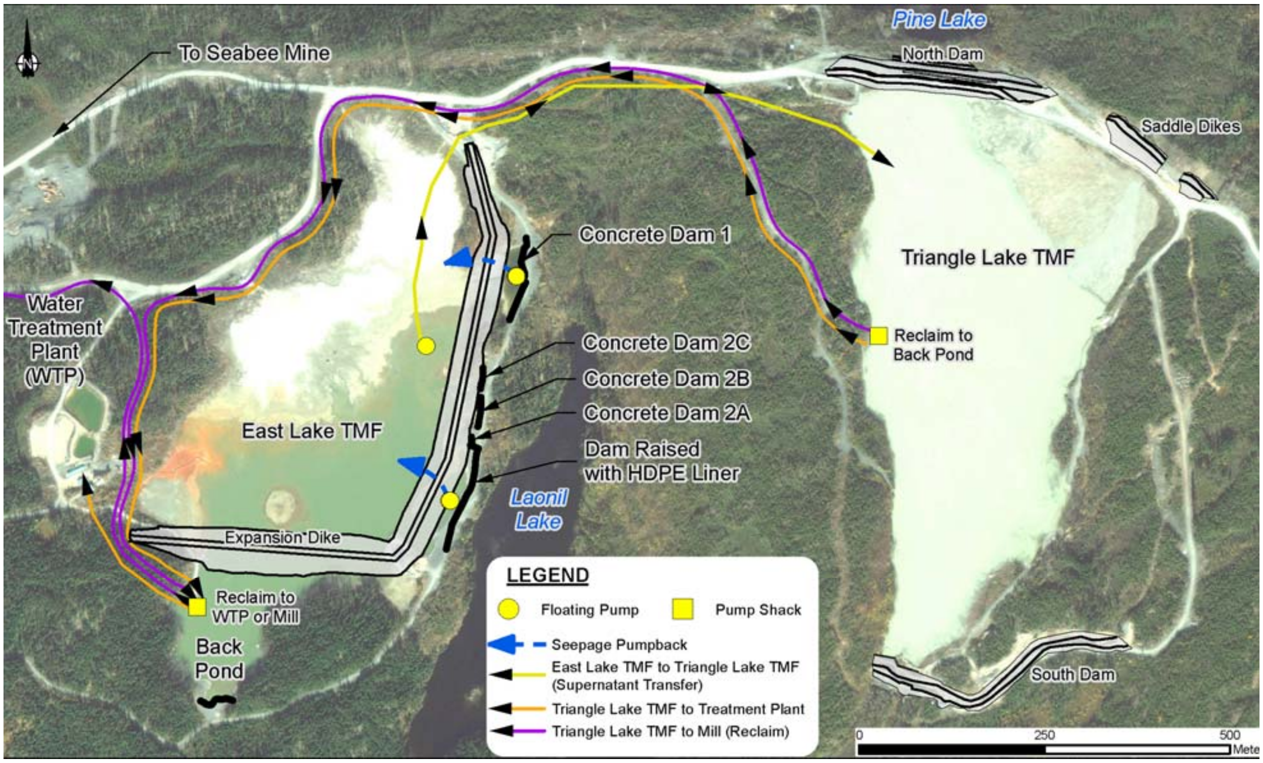

FIG. 8. Water management system for East and Triangle Lake TMFs.

6.2 Tailings Deposition Plan

To ensure adequate performance of the design, it was important that a uniform tailings beach be developed immediately upstream of the expansion dike. This beach reduces seepage rates through the dike and facilitates dike stability by moving the supernatant pond as far from the dike as practical. A detailed tailings deposition plan was completed that included proposed embankment construction schedules, spigot locations and elevations, tailings discharge durations for each spigot, the annual tailings depositional surface, annual water treatment requirements, and annual pumping requirements. A simplified example of the combined tailings and water management plan for the East Lake TMF is shown in Figure 9.

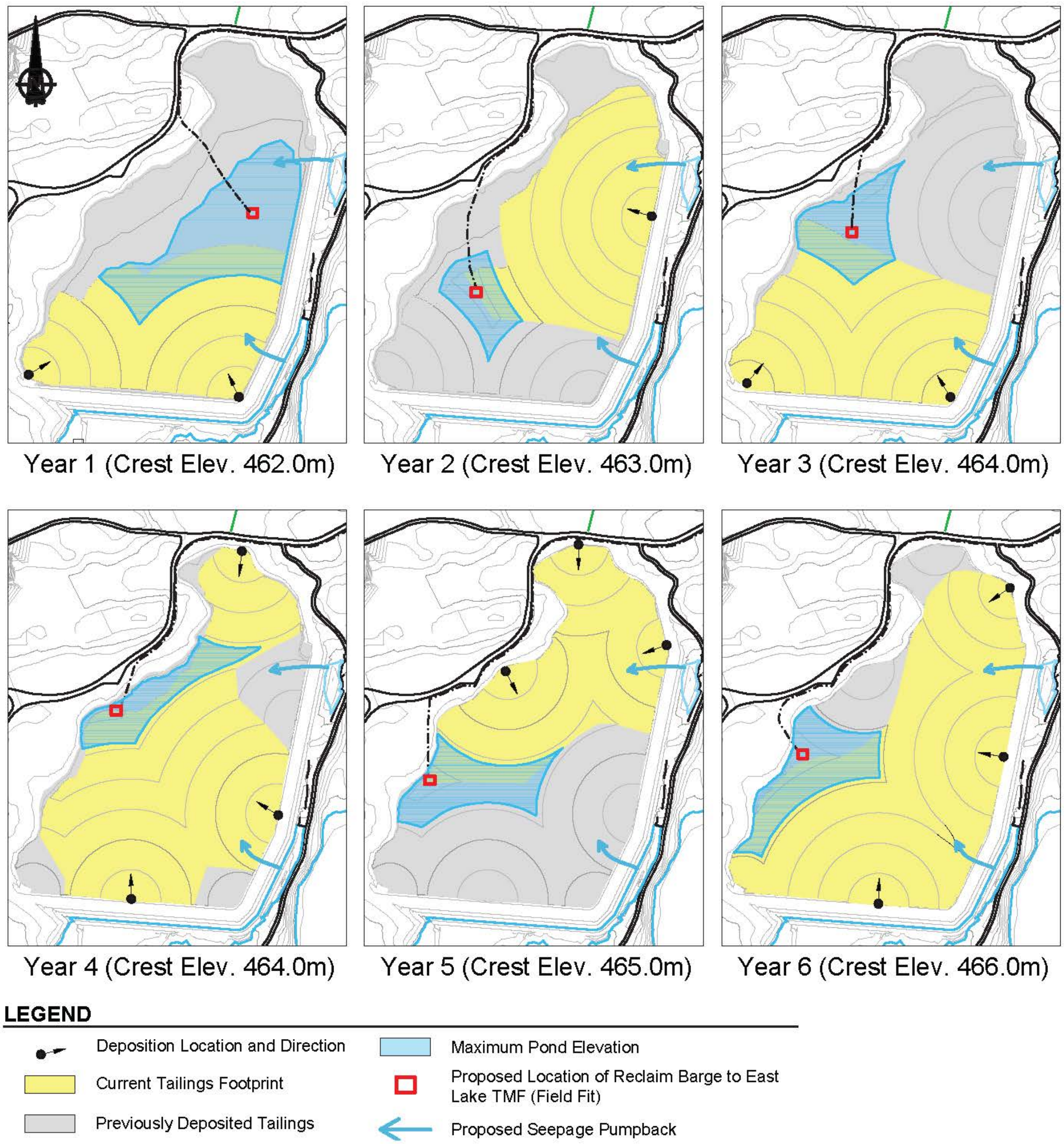

FIG. 9. East Lake TMF tailings and water management plan.

6.3 Inspection and Monitoring

An inspection and monitoring procedures check list was developed for assessment of pond levels, tailings deposition, seepage, containment structures, and instrumentation (settlement monuments and piezometers). The procedures included specific instructions on how to inspect each of these items as well as action plans that were based on the severity of the inspection (i.e. low, intermediate, or critical). In summary, the operations plan became part of the mine sites operations maintenance and surveillance plan for the TMFs.

7 Performance and Conclusion

The East Lake TMF Stage 1 expansion has been in operation since May 2016 and as of September 2016 has performed in accordance with the design. A uniform tailings beach was developed along the southern extent of the Dike and water levels within the East Lake TMF are managed well below freeboard *(see FIG. 10.)*.

FIG. 10. Status of East Lake TMF September 2016.

8 Acknowledgements

The authors are grateful to Silver Standard Inc. for permission to publish this material. The authors also wish to acknowledge their colleagues John Kurylo, Murray McGregor, and Arcesio Lizcano who have provided design support throughout this project. Finally, the authors could not have presented this material were it not for the efforts of their other colleagues at SRK Consulting (Canada) Inc. and Seabee Mine site staff.

9 References

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