Lifetime Assessment of an Operating Tailings Facility through Modelling of the Unconsolidated Tailings Layer

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Abstract

The following paper presents a case study in which the remaining lifetime of an operating kaolin tailings facility in Southeast United States was evaluated. Due to the characteristics of the tailings, an unconsolidated tailings layer occupies a portion of the lake's capacity. The turbidity and total suspended solids in this layer exceeded the discharge criteria. The characterization of this layer was improved to predict how it could affect discharge compliance throughout the remaining life of the facility. A typical water balance approach to model tailings solids input to the lake was insufficient to model the movement and progression of the unsettled tailings layer. A more detailed investigation was developed to understand solids in this unconsolidated layer.

Introduction

Operational tailings facilities need to quantify the remaining pond capacity to manage large inflow events and plan for future expansions. Tailings reservoirs are often modelled through a mass balance and water balance based on known inputs and outputs, including precipitation, tailings deposition, pumped flows, seepage, reclaim and evaporation. In some cases, there are additional constraints to the facilities which are more complex and difficult to model. The additional factor limiting capacity in this case study is characterizing suspended solids in the interface between the open water and consolidated tailings.

Vertical mixing of unsettled tailings is often studied in pit lakes, where a freshwater cap is designed to isolate deposited tailings from turbulent surface mixing. Turbidity in water covers over oil sands tailings in Canada have been studied over the last 20 years, as described by Lawrence (2015). In these studies, seasonal and diurnal wind induced turbulent mixing were evaluated, and a minimum cover thickness was estimated to protect the tailings layer.

In this case, tailings are actively deposited on the north edge of the lake, producing a beach, with a partial and shallow water cover. Near the tailings deposition point, water depths range from 0.5 to 2.0 m and increase to a maximum depth of 8 m on the southern end of the facility. Discharge from the lake to the receiving environment is through a decant structure on the south end. Colour gradation observed from aerial imagery suggests that there is a highly turbid unsettled solids layer above the consolidated tailings (white) and a thicker freshwater cover near the south outlet (dark green). The uncertainty of how this transition layer between consolidated tailings and the overlying water layer behaves confounds management decisions regarding tailings deposition and expansion plans.

This study highlights the conceptual model, developed using limiting parameters to examine current and projected capacity of the tailings lake.

Model Parameters

Four limiting factors to the facility were identified and evaluated in this assessment.

1. The impact of discharging additional tailings into the lake and the projection of the beach;
2. Thickness and characteristics of the turbid unconsolidated tailings layer;
3. Mixing as a result of wind and wave action; and
4. Horizontal settling distance required for re-suspended particles to settle below the inlet of the decant structure.

1. Projected Tailings Surface

The bathymetry was surveyed at six-month intervals over five years. A total of nine surveys, complete with aerial imagery were compiled and analysed to evaluate the change in the lake bed surface. In comparing sequential surveys, some trends were observed in the beach delta area, however changes were offset by the larger inconsistencies in the remaining lake area to the south.

Kriging was used in ArcGIS Spatial Analyst tool (Environmental Systems Research Institute (ESRI), 2016) to interpolate and smooth the bathymetric surveys. After smoothing was complete, the first survey from September 2011 was compared with the most recent survey in December 2016 to assess the change in volumetric capacity of the lake. Figure 1 presents a comparison of volumetric losses and gains between the 2011 and 2016 surfaces, with gains in red and losses in blue.

The gains suggest a growing tailings beach, with more prominent increase in volume around the deposition point. The measured volumetric changes were used as a target in a back-analysis model, using the software Muck3D (MineBridge Software).

The bathymetry measured in September 2011 was used as the base surface upon which tailings deposition was modelled for comparison with the measured December 2016 bathymetry. Parameters included input location (as this varied during the period of modelled history) input tonnage rate and beach geometry. Profiles across the lake from north to south and from east to west were used to compare modelled results with the December 2016 survey and results were reasonably consistent accounting for modelling limitations.

A mass balance was generated to validate the deposition model and bathymetric survey results. Historic plant losses were evaluated from the process plant discharge to the lake where the total mass added over the period between surveys amounted to approximately 90% of the calibrated tailings rate input to the model. This suggests that 10% of reported tailings deposited over this period remained in suspension within the turbid layer.

2. Turbidity Layer Thickness

To understand the unsettled tailings layer in the lake, thickness and characteristics of the layer were assessed in two lake surveys. The surveys were designed to capture turbidity levels throughout the water column at various locations across the lake. Each survey included:

- Bathymetric survey by boat to estimate the lake volume and depths at the time of the investigation.

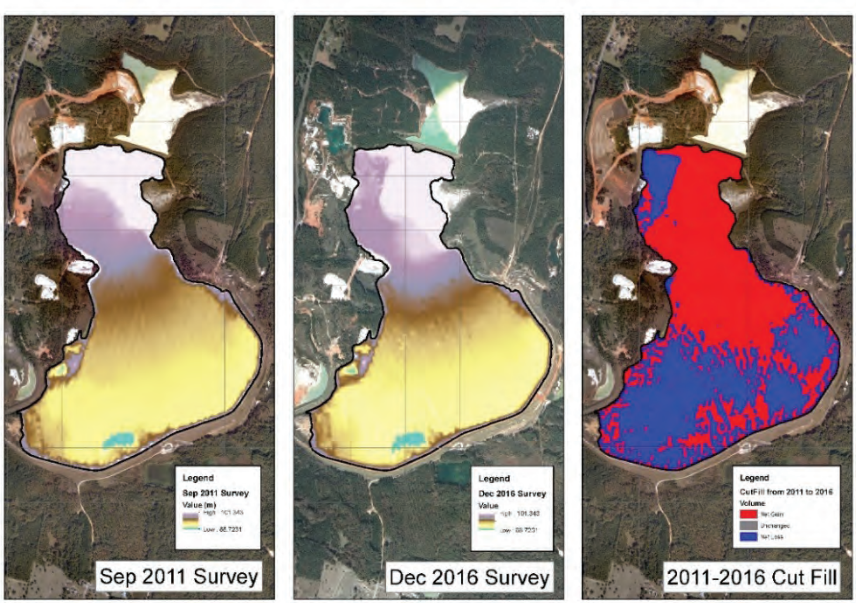

Figure 1: *Comparison of Historic Bathymetric Surveys in terms of Net Gains and Losses*

- Turbidity readings throughout the water column using a YSI DSS Probe. A total of 83 profiles were collected in February 2017 and 84 profiles in March 2017. Profiles of the water column up to the tailings surface were obtained at every 0.1 m.
- A total of 20 grab samples from random profile locations, taken from the turbid tailings layer and the non-turbid upper layer of the lake to analyse total suspended and dissolved solids concentrations.

The surveys were performed approximately 1 month apart and were intended to assess if there was any short-term variance in lake behaviour. Future surveys will be undertaken at less frequent increments. Both completed surveys attempted to cover a similar distribution across the lake. Upper lake samples presented turbidity levels between 5 and 25 FNU. The transition between the upper, clear water and the lower, turbid layer was identified where a sudden change in turbidity was measured from the continuous readings on the probe. Turbidity levels in the unsettled tailings layer increased abruptly from 50 FNU, to between 1000 to 10,000 FNU. A reading of 50 FNU was inferred as the transition zone interface between the freshwater cover and the turbid layer.

Based on the lake bottom reading at each location from the boat survey equipment, the thickness of the turbid layer from the lake bottom to the transition depth was calculated for each point. Figure 2 presents the results of all turbidity data through the water column. Profile data are presented in order of total lake depth, and colours reflect the turbidity reading. The blue and purple points are readings within the turbid layer, while green points reflect depth within the transition zone.

As the depth of the lake increases, the clear cover layer begins to form, and the turbidity layer maintains a relatively consistent thickness. Both turbidity survey results are as follows:

- Average turbid layer thickness over both surveys was 1.0 m
- 95th percentile thickness was 1.9 m and 1.6 m in February and March 2017, respectively
- Maximum thickness was 2.7 m and 1.9 m in February and March 2017, respectively.

An offset of 2.0 m was selected for the capacity assessment. This offset is reflected in Figure 2 as a red dashed line, which highlights that most of elevated turbidity readings are below 2.0 m depth.

Results from the lab testing were used to estimate volume of sediment within the turbid layer. The average total suspended solids

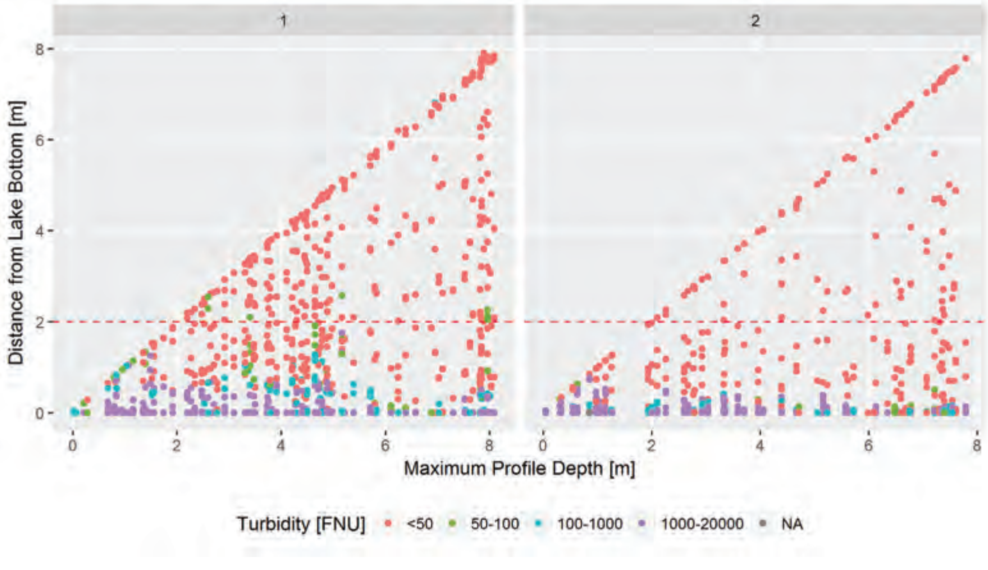

Figure 2: Turbidity Readings through Water Column over two Separate Lake Surveys, for February (1) and March (2).

concentration from the samples collected in the turbid layer was approximately 900 mg/L. The mass of total suspended sediment was calculated by multiplying concentration by the volume of the turbid layer. Without additional snapshots, there is insufficient data to assess whether the mass of solids will change over time, and if change occurs, whether it will impact the density of the layer or the volume of space it occupies.

3. Wind Mixing Cover

According to the MEND Design Guide for Subaqueous Disposal of Reactive Tailings (MEND, 1998), a water cover design is required to ensure the consolidated bed of tailings is not entrained or remobilized. The report identifies five processes which may impact solids entrainment. Based on the surface area, lake depth, and climate of the region, wind waves are the sole process to be considered.

Inputs to the water cover design include median grain size, wind speed, fetch length, sediment density and water density.

Grain Size and Density: Particle size distribution analysis was performed by the client on composite samples from solids in the northern extents of the lake. The average of two sample sets presented a median grain size equal to 4.2 microns. A particle density of 2300 kg/m^3 was used based on review of literature for kaolin clays.

Fetch Length: Both west to east and north to south fetch lengths were modelled. The maximum was north to south. The maximum fetch length was used for this assessment.

Wind Speed: Wind speed was evaluated from regional analysis of available meteorological stations within 100 km of the site. The longest record consisted of 56 years of wind speed, including mean daily wind speed, daily maximum sustained wind speed, and daily maximum wind gust. According to Lawrence (2015), design wind speed needs to be sustained for a minimum duration. For this purpose, the maximum wind gust measurements were not considered.

Frequency analyses were performed on the annual maximum values for both the daily average and daily maximum wind measurement. Selection of the appropriate design criteria and type of wind condition to be used for the water cover calculations is typically based on risk tolerance and engineering judgement. Two wind speeds modelled were:

- Daily wind speed expected to occur once every 20 years.
- Maximum daily sustained wind speed expected to occur once every average year.

Sensitivity analyses were performed on the median grain size, particle density and fetch length as well as wind speed, which identified wind speed and fetch length as the more critical parameters. Based on the sensitivity to wind speed, two wind covers were included in the capacity assessment based on the wind conditions described above:

- Wind cover of 2.0 m, based on the 20-year daily average wind speed.
- Wind cover of 3.0 m, based on the average year maximum sustained wind speed.

These cover depths were applied to the surface of the lake in conjunction with the turbidity offset on the projected tailings surface, where sediment re-suspension would be expected to occur at the intersection of both offsets. This case study shows results for the larger wind cover of 3.0 m.

4. Particle Settling Distance

Tailings particles will be in suspension near the active deposition zone and could be mobilized in the lake until sufficient freshwater cover is maintained. The offset distance from the decant structure to the suspended tailings particles was estimated based on Stokes Law for terminal settling velocity (British Columbia Ministry of Environment, 2015). Effective flow area in the lake enabled calculation of the settling length required from the decant structure. Additional inputs included median grain size, particle density, discharge rate from the lake, and water viscosity.

Discharge rate from the lake was regularly measured at the weir in the decant. An average discharge rate was used for the purpose of the settling calculations. The same grain size and particle density values were used as in the wind cover design calculations. The geometry of the lake suggested that flow may short-circuit the system, resulting in a reduced effective flow width towards the decant structure. Sensitivity analyses identified effective flow width and particle diameter as the most sensitive parameters to settling distance.

A factor of safety of 2 was applied to the minimum settling distance result from a potentially reduced effective flow width, producing a minimum settling distance of 300 m.

The application of Stokes Law for particle settling assumes that turbidity levels will reduce with particle settlement. There is often a trend with turbidity and suspended sediment concentrations, however additional factors can also increase turbidity. For the purpose of this study, it is assumed that turbidity levels will be reflected in the particle settlement in the lake.

Conceptual Model

In combining the turbidity layer offset, water cover, and the calibrated deposition results, a model was developed to capture the lake behaviour after continued deposition. The 5-year, 10-year, 15-year and 20-year tailings volumes were deposited onto the most recent bathymetric survey from December 2016 to generate the projected consolidated tailings surface. The turbid layer offset of 2.0 m was applied to the top of the consolidated tailings surface, and the wind cover depth of 3.0 m was applied to the water surface. The conceptual model and its limitations to capacity are presented on a north to south cross-section in Figure 3, illustrating the projected 10-year tailings solids surface.

The distance from the intersection point of the wind cover and the turbidity offset to the decant structure was calculated from the combined model to evaluate the effective settling distance under each projected tailings scenario. The offset distance based on 10 years of tailings deposition was found to be 387 m, which is greater than the required settling distance of 300 m. From these results, there is good confidence that the tailings lake can continue to operate for a minimum of 10 years. Based on the limited survey information at the time of the study, capacity beyond 10 years was not guaranteed, however, the number of deposition years remaining to produce a 300 m settling distance with a 3 m wind offset is approximately 16 years. Continued monitoring and confirmation of turbidity layer behaviour through repeated surveys will be performed in late 2018 to update the capacity assessment.

Conclusions

A conceptual tailings deposition model was generated based on four limiting factors to

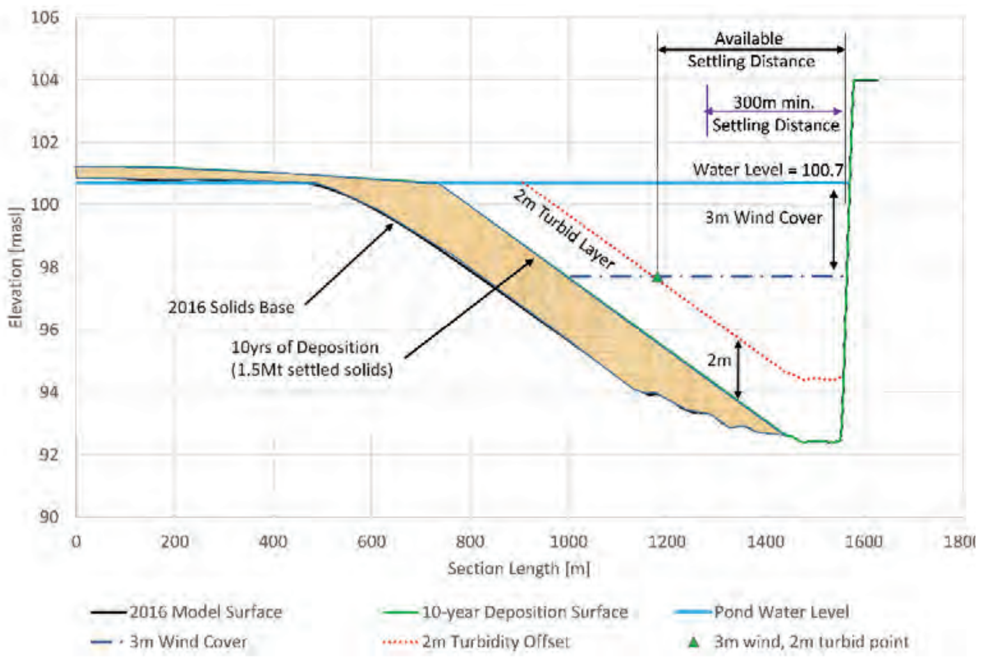

Figure 3: Conceptual Model along North-South Cross-Section of Tailings Lake

evaluate lake capacity. These include wave action, unsettled tailings, beach progression and settling distance. The model inputs were validated through two lake surveys to verify the lake was behaving in a predictable and consistent manner, as well as calibrated in a deposition software. Sensitivity analyses for model parameters, and the capacity of the structure in terms of remaining years of use, estimated there to be a minimum of 10 years based on currently available information.

The behaviour of the unsettled tailings layer was studied over a two-month period. These findings represent a snapshot of the tailings lake system, which does not capture potential seasonal variation. The projections assume that the system will continue to operate in a steady-state condition, with the underlying assumption that the unsettled tailings volume will not change over-time. Repeat surveys are required to confirm the turbidity layer thickness and total suspended solids concentrations to validate and model the tailings deposition over time.

Collection of particle size distributions for the material in suspension would provide greater confidence in the settling distance offset. A conservative factor of 2 was applied to account for this uncertainty, however in-situ testing, for example with tracer element monitoring, could be used to validate these calculations.

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