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Leading practice in tailings planning for high-throughput mining operations

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ABSTRACT

Tailings planning requires integration of managerial, geotechnical, hydrological, hydrogeological, mining, and process engineering disciplines. It is an important activity for all mineral processing operations but is critically important to high-throughput mining operations that produce large tailings volumes. The large volumes mean that deposition and water management conditions can change rapidly over short durations and lead to adverse production outcomes or failure.

Both the Canadian oil sands and Chilean copper mining industries contain multiple examples of high-throughput mining operations. They provide useful case studies to identify leading practices in tailings planning and management. Copper and oil sands mining differ in their history, labor costs, tailings composition, regulatory requirements, risk tolerance, and climate. However, there remain opportunities for both industries to learn from each other.

Different approaches to design, operation, water management and regulation provide opportunities to develop a leading practice approach to tailings planning. Examples of these practices include the separation of long and short-range planning activities, the use of probabilistic as opposed to deterministic mass balance models, a focus on the management of slimes (or fluid tailings) as a distinct tailings stream, and the integration of consolidation into volumetric tailings planning.

1 INTRODUCTION

Oil sands mines have been operating commercially and producing tailings in Canada since the late 1960s. As of 2013, there were approximately 976 million cubic meters of fluid tailings contained within oil sands tailings ponds (AESRD, 2015). By comparison, copper mines in Chile have been operating at a commercial scale since the beginning of the 20th century. The industry produces approximately 1.4 million tonnes of copper tailings per day (Ministry of Mining, 2015). They are the largest source of the 183 identified tailings deposits in the country (Ministry of Mining, 2014). For both countries, the large volume of tailings and large number of tailings storage facilities make the sustainable management of tailings an important issue for government and for the social license of operators.

Tailings planning is a complex, multi-disciplinary field that requires integration of managerial, geotechnical, hydrological, hydrogeological, mining, and process engineering components. It is an important activity for all mineral processing operations; inextricably linked to regulatory compliance and the ability to continue production activities at the mine.

Effective tailings plans are critically important to high-throughput mining operations that produce large tailings volumes. Large areas and high rates of rise mean that the poor management of deposition or water can rapidly lead to adverse production outcomes (with implications for cost) or the loss of containment. In the Canadian oil sands, this has been evidenced by the inability of operators to achieve Directive 074 fines capture targets, in part because of the large areas, large volumes and complexity of managing fines drying activities (Healing, 2014). A loss of containment can occur for multiple reasons, including failure to adequately manage tailings and impounded water during operations (Azam, 2010). Arguably, the risks associated with the mismanagement of tailings and water increase for larger dams or operations with a high rate of rise.

2 INDUSTRY COMPARISON

Table 1 provides a comparison of tailings production rates and containment structure construction methods and materials for high-throughput mining operations in the Canadian minable oil sands and Chilean copper industry.

Table 1: Industry Comparison of High-Throughput Mining Operations

Example Project	Primary Resource	Tailings Production Rate	Containment Structure Construction Method and Materials	Reference
Collahuasi Mine	Copper	165,000 tpd	Downstream Construction Rockfill Dam	
Horizon Mine	Oil Sands	100,000 tpd	Downstream Construction Overburden Dam	Canadian Natural, 2012
Mildred Lake Mine	Oil Sands	330,000 tpd	Upstream Construction Coarse Sand Cells	Syncrude, 2012
Millennium Mine	Oil Sands	330,000 tpd	Upstream Construction Coarse Sand Cells	Suncor, 2012
Minera Escondida	Copper	200,000 tpd	Downstream Construction Earthfill Dam	BHP Billiton, 2014
Minera Los Pelambres	Copper	205,000 tpd	Downstream Construction Cyclone Tailings Sand Dam	Antofagasta Minerals, 2015
Muskeg River Mine	Oil Sands	200,000 tpd	Upstream Construction Coarse Sand Cells	Shell, 2012

Table 2 summarizes some key site and tailings planning characteristics comparing the Canadian minable oil sands with Chilean copper mines. The summary is not intended to be a comprehensive summary of all sites and it is expected that there will be some exceptions within both industries. Rather, the comparison is based on the authors' industry experience, coupled with interviews and published references, where available.

Table 2: Industry Comparison of Current Key Tailings Planning Trends

Characteristic	Canadian Oil Sands	Chilean Copper
Climate	Humid continental climate with severe winters, no dry season, warm summers and strong seasonality; boreal moist forest biome (ClimaTemps, 2015B).	Mid-latitude desert/ arid cool climate; warm, temperate desert biome (ClimaTemps, 2015A).
Key regulatory drivers	Focus on the management of fluid tailings volumes and reclamation of fluid fine tailings (AER, 2009 and AESRD, 2015)	Previously focused on satisfying seismic stability requirements. DS No. 248 provides a more holistic focus on general requirements for approval of design, construction, operation, and closure of tailings deposits (Ministry of Mining, 2006).
Management structure	Mining, processing, dyke design (geotechnical), tailings planning, surface and ground water managed by separate functional group/departments within operators	Mining, processing, dam design (geotechnical), tailings planning and water management managed as separate functions by operators
Typical tailings	Whole tailings (WT), coarse sand	Whole tailings and slimes (which

streams	tailings (CST), froth treatment tailings (FTT), flotation tailings (FT), thickened tailings (TT), composite tailings (CT), non-segregating tailings (NST), and fluid fine tailings (FFT) (Oil Sands Tailings Roadmap, 2012)	segregates during deposition), Coarse cyclone sand tailings used in dam construction
Tailings planning resources	Largely in-house with limited assistance from consultants	Largely contract work to consultants
Tailings planning software	Muck3D is industry leading software utilized by almost all mining operations (Minebridge, 2015)	Consultant and operator specific. Includes GoldTail, Muck3D, Rift, and Civil3D. (Cooper, 2015)
Approach to short-term planning	Developed and executed by in-house planners, engineers, and site personnel, usually carried out on site.	Periodically updated by consultants
Approach to long-term planning	Developed by in-house engineers, with support from consultants. Can be carried out as part of or independent of dyke/facility design.	Primarily developed by consultants, coupled with facility design
Planning operational interface	Short-range planners develop plans to fit into long-range plan, provide direction to operators with regards to discharge locations and durations	Operators work from plans provided by consultants who make periodic visits and provide operational support at some sites
Mass balance modelling	Typically deterministic using Excel spreadsheets. Probabilistic models currently being considered by some operators.	Typically deterministic using Excel spreadsheets.
Water balance modelling	Varies between operators, both deterministic and probabilistic	Varies between operators, both deterministic and probabilistic
Consideration of consolidation in tailings planning	Measured and modelled separate to planning activities (COSIA, 2012). Often simplified using spreadsheets for volumetric inputs to tailings planning.	GoldTail tailings modeling software incorporates consolidation (Eldridge, 2007). Also incorporated separately as part of facility design.

3 DISCUSSION

Some of the key differences and similarities between the two industries are discussed in the following sections.

3.1 Separation of long-range and short-range tailings planning activities

In the oil sands industry, long-range tailings planning is largely performed in-house by experienced engineers and planners working in coordination with short-range planners. Consultants tend to be used to supplement in-house resources on a project or as required basis. The recent downturn in the oil price has reduced expansion projects within the oil sands, reducing the reliance on external resources. The use of in-house personnel aids in maintaining confidentiality and retaining the internal knowledge base of companies.

Short-range tailings planning in the oil sands is almost exclusively performed by in-house personnel. Short-range planners are located on-site to monitor pond levels and beach lengths and prepare and execute weekly, monthly, and quarterly deposition plans.

Oil sands operators must demonstrate that sufficient monitoring, measurement, and sampling are performed to accurately measure and report on fines from the oil sands feed. On an annual basis, operators perform beach surveys (using LiDAR), pond surveys (using SONAR and CT-09) to measure pond and mudline elevations, and CPT programs to measure strength of tailings deposits. These annual measurements are performed to meet regulatory requirements, reconcile tailings mass balance models, and confirm that current beach and pond elevations and locations are in compliance with long-range tailings plans (AER, 2009).

Similarly, in the copper industry, operators are required to submit quarterly reports that summarize instrumentation and testing data such as pore pressure measurements from piezometers, tailings dam and beach surveys, and compaction results from sand dam construction. In addition, operators are required to submit monthly production rates and report any general dam safety issues.

In the copper mining industry, long-range tailings plans are typically developed by external consultants based on the long-range mine plan produced by the operator. The use of external consultants to prepare and review long-term plans means that the methods and software used are likely to reflect leading practices from multiple industries.

The short-range tailings operations are performed by on-site personnel, and consultants visit, as required by the site, to confirm that the tailings operations are adhering to the long-range tailings plan. Short-range tailings plans are not typically developed in the same way as the oil sands. The lack of in-house tailings planning personnel provides potential cost savings over training and maintaining a dedicated planning team.

There is little indication that the lack of short-range planners in the copper mining industry increases the likelihood of operations deviating from the long-range plan. However, operations do deviate from the long-range plan for reasons such as plant and pipeline maintenance, deviation from construction schedule, change in ore and resulting tailings used for construction, and weather. Short-range planners used in the oil sands are beneficial in making adjustments to operations to re-align with long-range plans.

The rigorous approach to short-range planning in the oil sands may be a reflection of the way the oil and gas industry views risk. Tailings management practices in the oil sands are often more rigorous than the broader mining industry, evidenced by staffing levels, tailings research and development expenditure, and operational freeboard that accommodates the probable maximum precipitation (Anstey, 2014). It is possible that this approach to risk management is influenced by the close relationship between oil sands miners and the downstream consumer (conventional mining companies do not typically sell directly to the consumer) as well as incidents such as the Piper Alpha accident (Pate-Cornell, 1993).

3.2 Management of Water and Fluid Tailings (Slimes)

In the Canadian oil sands, planning activities distinguish between different tailings streams. This is particularly the case for fluid tailings streams, driven by the low density and long settlement time of this material as well as the regulatory requirements to monitor and reduce the volume of fluid fine tailings (FFT). Dredging FFT and mature fine tailings (MFT) to spike in other tailings streams, add to thickeners, or apply atmospheric drying techniques are all common technologies utilized to reduce the volume of FFT and move towards reclamation. Tailings planners calculate the capture of fines in tailings beaches, measure beach length and slope, and perform periodic surveys to identify pond and mudline elevation to monitor FFT volume and satisfy regulatory requirements.

Muck3D, a volumetric planning software code used extensively in the oil sands, allows for the division of tailings ponds into fluid tailings and “clear water zones”, tracking and reporting these volumes separately.

In Chile, there are no regulatory controls for the reduction of fines. There are no specific tailings deposit trafficability strength requirements for tailings storage facilities, as in the oil sands. However, due to the scarcity of water in the arid climate of northern Chile and because water is crucial to the long-term sustainability of the copper mining industry, tailings treatment technologies that maximize water recovery without increasing power consumption benefit both capital and operating costs.

GoldTail, a volumetric planning software code developed by Golder Associates in South America, allows users to plan the location and volume of the pond and adjusts tailings deposition automatically to achieve these pond outcomes. The focus of the software is around the management of water for tailings storage facilities. This reflects the importance of water resources to mines in the arid climates of South America.

It is apparent that the material properties, climate and regulatory framework are key drivers in the development and use of tailings planning tools.

3.3 Use of probabilistic as opposed to deterministic mass balance models

A deterministic model is a mathematical model in which every variable has an assumed value such that, given the same initial conditions, the output will be the same. In a probabilistic or stochastic model, variables are not represented by unique values but probability distributions. There is uncertainty associated with several of the parameters that influence tailings planning including tailings production rates, material behavior (slurry density, beach slope, and consolidation) and climate (for oil sands). A probabilistic tailings mass balance model allows users to input a probabilistic distribution or stochastic data set for key parameters that will influence the outcome of the model. The model produces an output that reflects the probability of the input parameters.

Probabilistic water balance models are commonly used in both the oil sands and Chilean copper mining industries, implemented using software such as GoldSim (GoldSim, 2007). The use of probabilistic models for water balance reflects the high degree of importance of water to both industries and the uncertainty associated with some of the key parameters influencing its management.

By comparison, probabilistic mass balance models are far less common. A tailings probabilistic mass balance model seeks to incorporate all of the mass balance inputs (mineral, bitumen and water in the case of the oil sands). The model can reflect the uncertainty associated with key inputs that may otherwise be treated deterministically, such as production rate, bitumen recovery, fines capture, and consolidation.

Water and tailings are typically managed by separate groups within oil sands operators. This results in the need to transfer data between the models maintained by the two groups. Deterministic modelling is an attractive option as it simplifies the transfer of key inputs between groups. In the author's experience in developing and reviewing tailings mass balance models for three oil sands operations since 2011, deterministic mass balance models are preferred by operators.

The Tailings Management Framework for the Mineable Athabasca Oil Sands (AESRD, 2015) requires operators to define and maintain fluid tailings volumes within an approved operating envelope. Given the uncertainties associated with fluid tailings performance, a probabilistic mass balance model would assist operators to define and justify an achievable FFT volume profile. Indeed, the author is aware of at least one oil sands operator that is considering the implementation of a probabilistic mass balance model.

Probabilistic mass balance modelling may also be useful in the Chilean copper mining context when assessing the sand to slimes split. Insufficient sand can compromise the containment freeboard and impact the stability due to steeper dam slopes. High fines content in the sand dam can reduce wall density and increase moisture content in the dam with consequent risks for stability and liquefaction.

3.4 Integration of consolidation into volumetric tailings planning

Consolidation of tailings can have a substantial impact on tailings deposition planning and tailings storage facility (TSF) closure design (Errazuriz, 2014). The consolidation of a tailings deposit can influence stored densities, construction scheduling and surface drainage. Tailings planning is used to direct operations towards the creation of a landform that satisfies the ultimate storage requirements and minimizes the amount of material re-handling required at closure. Failure to adequately account for consolidation can substantially increase closure costs or result in an ultimate landform that does not satisfy the closure criteria.

Incorporating consolidation into tailings deposition modelling enables the user to more accurately predict the pond and mudline elevations and water and fluid tailings volumes. In the author's experience, deterministic tailings mass balance models sometimes incorporate simplified consolidation inputs by assuming that the tailings achieves a particular density within a given period of time. These calculations may or may not be supported by more sophisticated consolidation models. The simplified consolidation inputs are used to predict the volume of tailings, which is then used as an input to deposition modelling. The validity of tailings plans produced using this method is limited by the ability to calculate consolidation at discrete time increments and assign different stored densities to different elements within the tailings planning model.

Although more commonly used in the Chilean copper mining industry, GoldTail allows the integration of consolidation directly into the tailings planning model (Eldridge, 2007). Densities are tracked within the deposit as deposition progress. The performance and planning of fine oil sands tailings deposits are particularly sensitive to consolidation, water release and the consequent change in stored density. There exists an opportunity to incorporate consolidation directly into the tailings planning software used in the oil sands.

4 CONCLUSIONS

The conclusions made from the comparison of the two industries are presented below:

- The material properties, climate, and regulatory framework are key drivers in the development and use of tailings planning tools and mass balance models.
- The approach to long-range and short-range tailings planning differs significantly between oil sands and copper mining. Currently, this includes differences in software, the use of consultants as opposed to in-house resources and the integration of short-range planning with operations. There are strengths to the approaches used by both industries that may be worthy of broader consideration or application. In particular, the use of short-range planners to keep operations in line with the long-range plan and adjust to changes in conditions on site may have benefits for mines with high tailings throughputs. Similarly, the use of consultants for tailings planning may have cost advantages and allow companies to adjust to fluctuations in workload.
- The current regulatory framework in Alberta emphasizes the importance of fluid tailings management. Adopting a probabilistic tailings mass balance model may provide benefits to oil sands operators in defining and justifying a realistic FFT volume profile to satisfy the regulations.
- There exists an opportunity to incorporate consolidation modelling directly into the tailings planning software used in the oil sands as is currently done in copper mining. Accurate prediction of consolidation and implementation into tailings plans

would allow for more reliable prediction of pond and mudline volumes and elevations and improve confidence in closure planning.

Leading practices in tailings planning are expected to change as technology and computing power advance. Ultimately, it is possible that future tailings planning software will integrate both consolidation modelling and probabilistic water and mass balance inputs and outputs.

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