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Integrating Site Conditions and Deposition Sequence to Beach Slope Estimations for High Thickened Tailings

Tomás Errázuriz and Alexis Gonzalez*
Wood, Chile

ABSTRACT

The application of highly thickened tailings technologies is rapidly increasing due to the perceived benefits with respect to reduction of environmental impacts, water savings and potential reductions in dam size and footprint impoundment. Evaluation of this potential benefits requires that during early design stages an understanding is developed for the range of feasible beach slopes to be achieved during deposition. A comprehensive evaluation of the whole range of factors that influence the beach formation process is paramount to ensure that expected performance during design stages is met throughout operations.

This paper presents an integral approach for beach slope estimation, considering a broader range of aspects affecting the beach formation process than those commonly used in current models (rheology and discharge rate of the deposited tailings). The additional aspects considered by this approach are site conditions (site morphology and climate), the rate of rise of the tailings impounded (the relationship between the tailings production rate and the available area for tailings spreading) and the deposition sequence (the configuration of the deposition system and its operation, e.g. thin layer deposition with drying cycles).

The approach is supported by a beach slope model based on a dimensionless parameter for non-Newtonian flows, associated with sheet flows on an inclined plane, which directly relates to the tailings beach slope expected to be formed due to sub-aerial disposal. This dimensionless parameter provides a closed expression for estimating tailings beach slopes based on rheological properties and discharge rates, but with the integration of site conditions, rate of rise and deposition sequence.

High thickened tailings management facility (TMF) design is well supported by this approach, providing key input as the configuration of the distribution system and the minimum area required to achieve expected performance with respect to desired beach slope, density, degree of saturation and strength.

INTRODUCTION

This paper presents an integrated approach for beach slope estimation, adding the effect of climate, site morphology, tailings throughput per unit area (i.e. the rate of rise) and tailings deposition sequence (sectorized discharges and drying cycles), to the common rheological (level of thickening) and discharge rate considerations (number of multiple spigots). The sheet flow formulation for tailings and beach slope estimation model presented by Errazuriz (2018) along with a mass balance allow to develop a basic model for estimating proper TMF area, number of sectors, discharge time per sector and maximum rate of rise to implement a thin layer deposition scheme with drying cycles, promoting enough desiccation of tailings as a tool for managing the occurrence of sheet flows.

BEACH SLOPE ESTIMATIONS – THE FLOW SHAPE ASSUMPTION

There is a basic energy concept behind a tailings beach slope: The greater the energy loss in the flow, the greater the beach slope. If the energy required to keep the solid particles suspended within the tailings flow is lost near to the discharge, the particles will settle at a short distance. Higher beach slopes mean settling particles nearest the discharge. Lower beach slopes mean the opposite, where smaller losses in the flow path allow to transport particles farther.

The water content in tailings can be reduced (i.e. thickening) so the energy loss will be increased due to the higher contact between particles. The discharge rate can be reduced (i.e. dividing the total flow with multiple spigots) so the energy loss will be increased due to the higher contact surface between the flow and its own channel. Both mechanisms induce frictional energy losses, representing the basis of most beach slope estimation models. These models provide how much thickening and how many spigots the project should have according with the target design range of beach slopes.

There is a common assumption in beach slope models, which is the shape type of the self-formed tailings channels. This can be called the flow shape assumption.

McPhail (2008) and Fitton (2007) consider a self-formed channel shape associated with an steady state condition, in which the tailings flow converges to an optimal channel shape that minimize the energy losses, following the well-known nature principle of energy minimization in its processes. These shapes are semi-circular for McPhail (2008), the optimum mathematical shape for maximizing the hydraulic radius for a given flow cross-section area, and parabolic for Fitton (2007), following the same principle, but considering that the stability of lateral walls of the self-formed channels promotes parabolic shapes. Each model works properly with their own assumptions, presenting consistent validation with experimental data.

Li (2011) and Errazuriz (2018) assume that given a thin layer deposition scheme with drying cycles (i.e. multiple sectors for discharge), a layer by layer flow can be developed, where self-formed channel is almost plane, so called sheet flow[1].

This assumption provides further insights about complementary mechanisms available for increasing energy losses along the flow path. For a given tailings flow, if a sheet flow is developed, the wet perimeter will be larger (so the friction losses could be higher) and this implies a lower hydraulic radius (R_H) respect to a narrow channel flow.

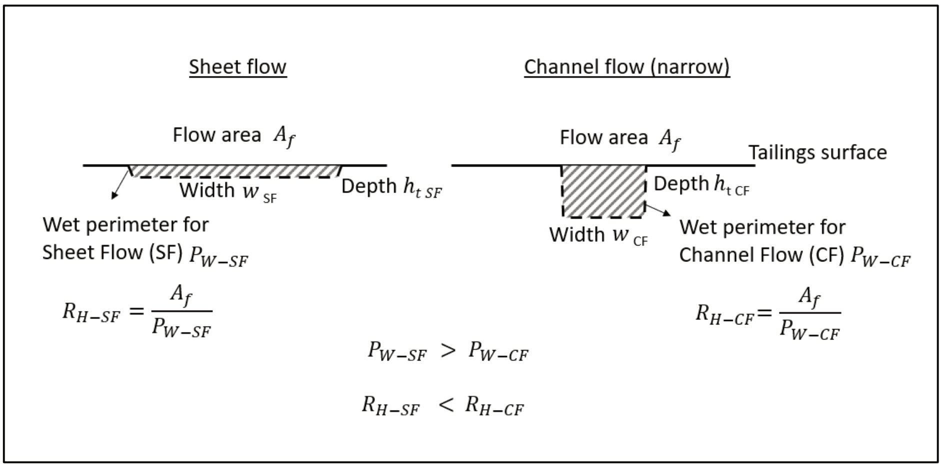

Figure 1: Scheme of the flow shape assumption

The question is: how does this aspect could be managed to provide an additional tool for steeper beach slopes? The development of a sheet flow requires, at least:

- A previous dried tailings surface (provided by drying cycles), forming a less erodible surface.
- Low discharge rate (provided by multiple spigots), develops a flow with lower erosion potential.
- Yield stress and viscosity (provided by high thickening) develops laminar flow with lower erosion potential.
- A short period of discharge. Limited time to erode narrow channels until the end of the beach.

If these features cannot be reached, the tailings flow will be prone to become semi-circular and parabolic narrow channels nearly to the McPhail (2008) and Fitton (2007) assumptions, instead of sheet flows.

[1] Sheet flow approach is not equal to lubrication theory (i.e. includes explicitly the effect of the discharge rate). The sheet flow approach by Errazuriz (2018) was verified using the data from two TMF operation (full scale) where the principle of thin layer deposition scheme with drying cycles were applied. One of them being a large production tailings operation ~100 ktpd.

Promoting the features mentioned for sheet flows, smaller hydraulic radius, becomes an additional tool to reach steeper slopes. Site evaporation (i.e. further dewatering and shrinkage of tailings) and restricted operational times can be used to inhibit the natural tendency of tailings flow to develop narrow channels. First layer deposition above dried tailings, as sheet flows instead narrow channels, are well documented as shown in Figure 2.

Figure 2: Tailings Beach Slope Prediction for a sheet flow (Jewell, 2010)

The distinguish feature of a sheet flow is shown in equation 1, considering, for simplicity, a flat rectangular channel shape (Figure 1).

$$R_H = \frac{w \cdot h_t}{w + 2h_t} \rightarrow h_t \quad when \quad w >> h_t. \; So \; R_H \approx h_t \; for \; sheet \; flows \rightarrow \frac{h_t}{R_H} \approx 1 \qquad (1)$$

Exploring the effect of flow shape assumption in a simple way, it is possible to analyze the basic equation for initial beach slope (S_0) used by Fitton and Slatter (2013) eq. 2.

$$S_0 = \frac{v^2 f}{8 g R_H} \qquad (2)$$

Where

v = velocity of the flow, f = friction coefficient, g = gravity acceleration

$f = 64/Re$, Re = Reynolds number.

It is evident from equation 2 that the lower the R_H, the greater the initial beach slope. But, in fact, v and f are also affected by R_H. So, a brief example can be made to show the general effect of R_H in beach slope estimation (tailings production 95,000 tpd, Cw=65% Gs=2.7, tailings flow as a Bingham Plastic with yield stress 30 Pa and viscosity of 0.1 Pa*s).

Following the step by step Fitton and Slatter (2013) methodology, *f* and *v* are estimated, for a given flow shape, R_H (a simplified one, as Figure 1). This procedure allows to obtain the initial beach slope in function of the aspect ratio h_t/ R_H, that tends to 1 for a sheet flow (equation 1). Figure 3 shows this result. As h_t/ R_H tends to 1, the estimated beach slope increase. As h_t/ R_H tends to 1, the Fitton and Slatter (2013) estimation tends to the Errazuriz (2018) estimation for the same example, which considers explicitly a sheet flow (R_H ~h_t).

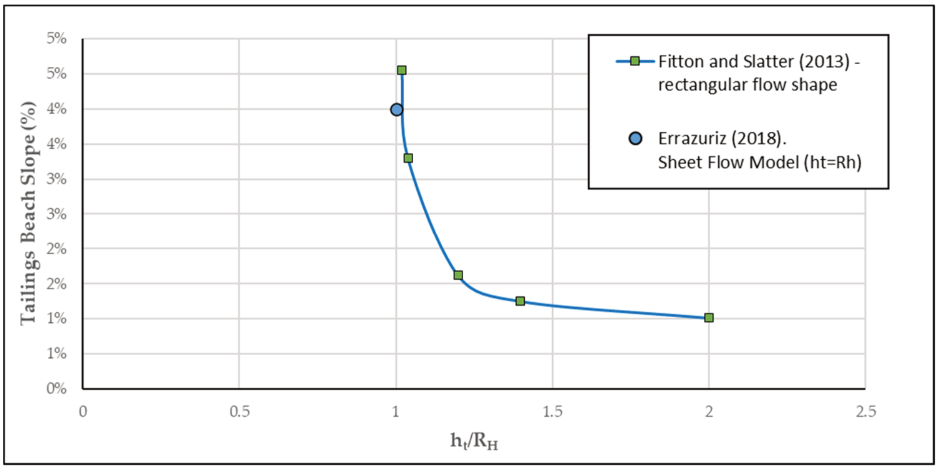

Figure 3: Conceptual initial tailings Beach Slope Prediction for different hydraulic radius (R_H)

This example shows how the general principle of the flow shape assumption influences the estimations of beach slope models; the general tendency of their equations that clearly shows that the lower the R_H, the higher the beach slope (McPhail, 2008, Fitton, 2007, among other well documented models, had similar equations for S_0).

MANAGEMENT OF THE FLOW SHAPE: AN INTEGRATED APPROACH

Promoting sheet flows as an additional tool to reach steeper beach slopes, for a given rheology (thickening) and discharge rate (number of spigots), are associated with a management of the flow shape. This management requires an integrated approach.

Fundamental part of this integrated approach is the well-known concept of thin layer deposition scheme with drying cycles. "Drying cycles" implies arid climate (drying) and multiple sectors (cycles). "Thin layer" implies limiting the active deposition time per sector.

So, this fundamental concept imply an integrated approach: How many sectors, how much area per sector and how much time should be the active deposition time to reach substantial drying, depend on the tailings production rate, the climate (site evaporation), the site morphology (enough wide plane area), the tailings thickening (i.e. how much water have to be evaporated), the tailings properties and associated behavior (such deposition density, shrinkage limit, water retention curve, etc.).

Multiple spigots system contributes to thin layer deposition and sheet flows. Figure 2 presents a conceptual scheme for a TMF developing an integrated approach. The idealization shown in Figure 2 is the basis for the basic model developed in the next chapter for design purposes. The active discharge zone is operated while the rest of the zones are drying, and this active zone discharges until it reaches the area ξA. When this area is reached, the current active operation stops and moves to the next zone (cycles).

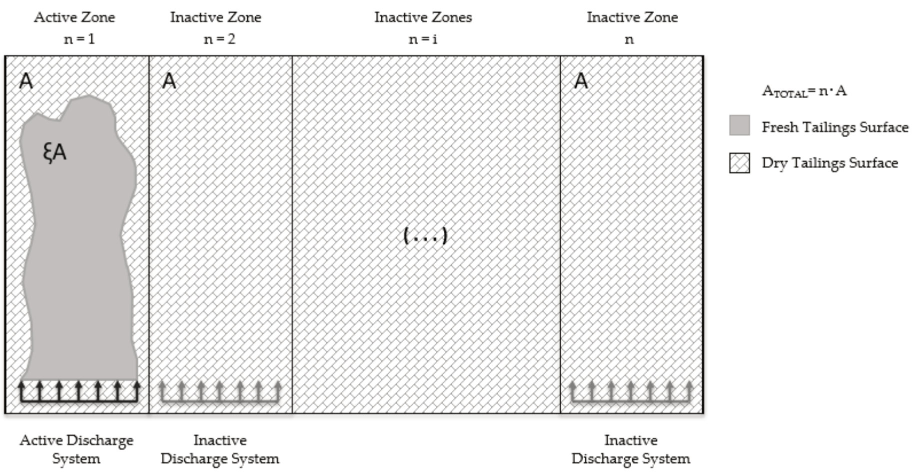

Figure 4: Total area (A_{Total}) divided in *n* zones

The operational time T_{op} is key for promoting sheet flows and avoid narrow channel flows ruling the final beach slope. As narrow channel slope is lower than the sheet flow slope for the same thickened tailings (due to the greater Rh), the channels can travel through the sheet flow spread, but when it reaches a dried tailings can become sheet flow again. When T_{op} is adopted, the resulting beach slope will be ruled by the sheets flows beach slope and then move to another sector. Figure 4 shows this concept to promote beach slopes ruled by sheet flows. The T_{op} time can be adjusted during operation with drone monitoring using the Observational Method: D'Apollonia (1990), Peck (1969).

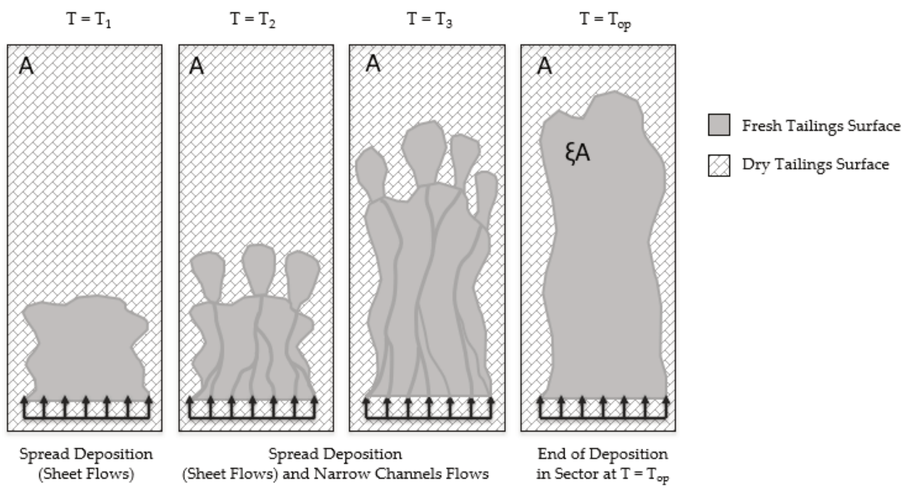

Figure 5: Active zone sequence in the same sector

This idealization also requires gentle site morphology, a regular area. For example, the desert in the north of Chile, generally provides this regular area with arid climate.

The final question is about multiple spigots discharge system configuration.

McPhail (2015) recommend keeping a minimum separation between spigots to avoid two or more narrow channels became one. So, this separation and the number of spigots required determine the total system width. Fitton (2007) suggest multiple spigots in conical configurations, also to avoid channel coalescing. Nevertheless, this recommendation is in the context of narrow channels are being developed, where the sum of two channels implies increasing the hydraulic radius. In case of sheet flow ruling the tailings beach formation, it is possible to evaluate having more spigots with less separation (it is convenient having more sectors in less area, when available area for the TMF is restricted), because sheet flows should not be sensitive to coalescing processes, as the hydraulic radius is the flow height, that only needs a truly plane surface, i.e. less erodible dried tailings facing gentle tailings flow only during T_{op} (Errazuriz, 2018, also providing equations for flow width estimation).

Finally, an active research subject is the concavity of tailings beach profiles, where initial beach slopes starts near the discharge and tends to decrease along the distance. A note of caution is recommended for long beach slope estimation (>1500 m) where well documented precedents do not exist up to date and concavity effects should dominate the average beach slope (estimations of initial beach slope becomes less relevant, and the change of slopes with distance become the real issue).

BASIC MODEL FOR AN INTEGRATED APPROACH

This basic model describes requirements for a thin layer deposition scheme with drying cycles. The results provide the minimum number of sectors (n), the minimum area (A) per sector and the maximum operational time (T_{op}) required to promote sheet flows as an additional tool for generating steeper beach slopes.

The estimation is derived from basic parameters related to project features, tailings properties[2] and site conditions as:

- Production rate (P)
- Solid Content by weight (C_W)
- Specific gravity of solid (S_G)
- Initial surficial dry density (γ_{dryi})
- Shrinkage limit (SL)
- Initial water content (w_i)
- Initial surficial dry density (γ_{drySL})
- Potential evaporation (v_{PE}) from site

[2] An example of laboratory determination of the parameter related with tailings behaviour could be found in Fisseha et. al. (2010), including laboratory settling tests, drying box tests, shrinkage limit, soil water characteristic curve, rewetting, etc.

- Velocity of evaporation from tailings (v_{evap})
- Velocity of infiltration during rewetting (v_{inf})
- Morphology (slope and shapes) and available area

The model considers a one-dimension scheme for a tailings sheet flow (layer). Figure 5 shows this scheme, conceptually.

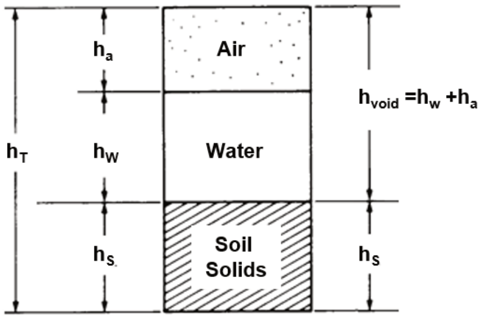

Figure 6: One-dimension column scheme for sheet flow

For an operational time (T_{op}) in a defined cycle, the layer flows to a portion of the total area (ξA) as shown in Figure 5. The total water inflow (h_{wi}) in the cycle is defined as (γ_w is the water unit weight, generally 1 t/m^3).

$$h_{w_i} = \frac{T_{op}\, P}{\xi A \cdot \gamma_w} \frac{(1 - c_w)}{c_w} \tag{3}$$

The total water inflow (h_{wi}) can also be defined as a water column distributed in retention (h_{ret}), evaporation (h_{evap}) and rewetting (h_{rewett}).

$$h_{w_i} = h_{ret} + h_{evap} + h_{rewett} \tag{4}$$

Retention is defined as

$$h_{ret} = \frac{T_{op} \cdot P \cdot w_i}{\xi A \cdot \gamma_w} \tag{5}$$

Evaporation is defined in terms of the potential evaporation (v_{pe}) and pan coefficient (ε)

$$h_{evap} = \frac{1}{\xi A} \int_0^{T_{op}} \varepsilon\, v_{pe} \cdot A^{fresh\ tailings}(\mathrm{t}) \cdot dt$$

If the growing fresh tailings area, $A^{fresh\ tailings}\,(t)$ is a linear function of time, from 0 to ξA, then

$$h_{\mathrm{evap}} = \frac{1}{2} \varepsilon \cdot v_{pe} \cdot T_{op} \tag{6}$$

In a similar way, rewetting could be defined in terms of infiltration velocity.

$$h_{\mathrm{rewett}} = \frac{1}{2} v_{inf} \cdot T_{op} \tag{7}$$

Using equation (4)

$$A = \left(\frac{\varphi}{\xi(\varepsilon + \beta)}\right) \frac{P}{v_{pe} \cdot \gamma_w} \tag{8}$$

Where,

$$\varphi = 2\left(\frac{1 - C_w}{C_w} - w_i\right) \;;\quad w_i = \frac{\gamma_w}{\gamma_{dry_i}} - \frac{1}{S_G} \quad and \;\; v_{inf} = \beta \cdot v_{pe}$$

The minimum Area (A) needed to fill one layer of sheet flow is shown in equation 8. Note that is not dependent of the operational time (T_{op}) but the quantity of tailings. The total depth (h_t) of the layer (sheet flow) can be estimated using Errazuriz (2018)[3].

$$h_t = \frac{1.5 \cdot \tau_y}{\rho \cdot g \cdot \sin\theta} \tag{9}$$

So, as the minimum hydraulic radius (R_H) is required for a sheet flow deposition, the operational time (T_{op}) is defined for one layer.

$$h_t = h_s + h_{wi} = \frac{P \cdot T_{op}}{S_G \cdot \gamma_w \cdot \xi A} + \frac{P \cdot T_{op}}{\xi A \cdot \gamma_w} \frac{(1 - C_w)}{C_w} \tag{10}$$

Using equation (8) and equation (10)

$$T_{op} = \left(\frac{\varphi}{\Psi(\varepsilon + \beta)}\right) \frac{h_t}{v_{EP}} \tag{11}$$

Where,

$$\Psi = \frac{1}{S_G} + \frac{(1 - C_w)}{C_w}$$

When T_{op} is reached, the current active zone will become inactive zone and the next zone will became active. In the zone where tailings have been recently deposited fresh saturated tailings are assumed (with water income (W_i) and dry density, which is a consolidated state due to high density tailings). Tailings need enough time to become a proper hard surface for receive a new sheet flow deposition above it.

Atmospheric evaporation densifies tailings while desaturation mechanism is available. The process requires inactive time ($T_{inactive}$) to reach the shrinkage limit ($T_{inactive1}$) and induce desaturation ($T_{inactive2}$) after the limit has been reach.

[3] Using Equation 7 from Errazuriz (2018) and considering h=1.5 when N=1 (h and N defined in Errazuriz (2018)).

The water associated with the shrinkage limit is presented in Eq. 12. Considering the work by Jefferies and Been (2016), the effect of reaching the shrinkage limit can be assessed in order to have less contractive tailings.

$$w_{SL} \cdot h_s \cdot S_G = h_{W_{SL}} \tag{12}$$

Where,

$$w_{SL} = \frac{\gamma_w}{\gamma_{dry_{SL}}} - \frac{1}{S_G} \tag{13}$$

According to equation (4), the water evaporated to reach the shrinkage limit (SL)

$$\Delta h_w = \frac{P \cdot T_{op}}{\xi A \cdot \gamma_w}(w_i - w_{SL}) \tag{14}$$

Since before shrinkage limit is reached, tailings are in a saturated condition, Δh_w could be evaporated in this condition. The inactive time to reach shrinkage limit ($T_{inactive1}$) is define as

$$T_{inactive1} = \frac{P \cdot T_{op}}{\xi A \cdot \gamma_w}\frac{(w_i - w_{SL})}{\varepsilon v_{p_E}} \tag{15}$$

After $T_{inactive\ 1}$, additional time is needed to reach enough desaturation ($T_{inactive2}$). Minimum desaturation is considered, as the air voids required to accept infiltration water during the active zone. Since evaporation after shrinkage limit is low (Wilson, 1994), then extra time for $T_{inactive2}$ could be represented as Eq 16. If more desaturation is required, for achieving enhanced residual strength or cyclic resistance to liquefaction (Simms, et. al 2013), this $T_{inactive2}$ can be increased. Here desaturation is the minimum required for having a drying cycle with rewetting.

$$T_{inactive\ 2} = \frac{v_{inf} \cdot T_{op}}{v_{pe} \cdot \eta} \qquad \text{Where } \eta < \varepsilon \tag{16}$$

The total inactive time required, $T_{inactive}$ as the sum of $T_{inactive\ 1}$ and $T_{inactive\ 2}$

$$T_{inactive} = \left(\frac{P \cdot (w_i - w_{SL})}{\xi A \cdot \gamma_w \cdot \varepsilon} + \frac{v_{inf}}{\eta}\right)\frac{T_{op}}{v_{p_E}} \tag{17}$$

In order to provide enough total inactive time, in terms of the (already defined) operational time, a minimum number of sectors of deposition should be established.

$$T_{inactive} = (n-1) \cdot T_{op} \tag{18}$$

From equation 18, a dimensionless expression for n is obtained.

$$n = \frac{\left(w_i - w_{S_L}\right)}{\varphi} \cdot \frac{(\varepsilon + \beta)}{\varepsilon} + \frac{\beta}{\eta} + 1 \tag{19}$$

Once the number of sectors (n) is defined, the total area of deposition (A_{total}) is determined with equation (8) and equation (19).

$$A_{Total} = A \cdot n = \left(\frac{n \cdot \varphi}{\xi(\varepsilon + \beta)}\right) \frac{P}{v_{PE} \cdot \gamma_w} \qquad (20)$$

Introducing the rate of rise (RoR) as follows, the model can estimate the growing of TMF for different site conditions as shown in Figure 7. The minimum size of the tailings storage area in terms of the tailings production is shown in Figure 8.

$$RoR \leq \frac{P}{\gamma_{drySL} \cdot A_{Total}} = \left(\frac{\xi \cdot (\varepsilon + \beta)}{n \cdot \varphi}\right) \frac{v_{PE} \cdot \gamma_w}{\gamma_{drySL}} \qquad (21)$$

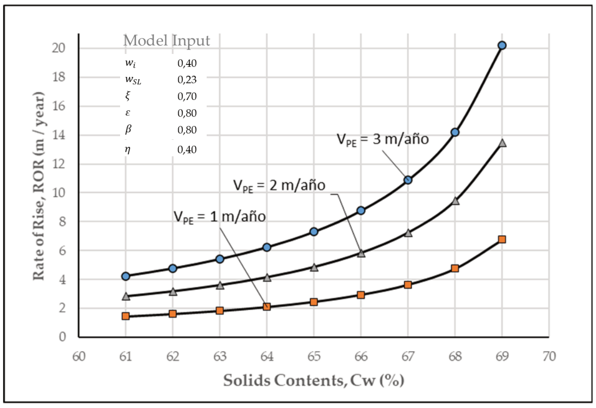

Figure 7: Rate of Rise vs Solids Contents.

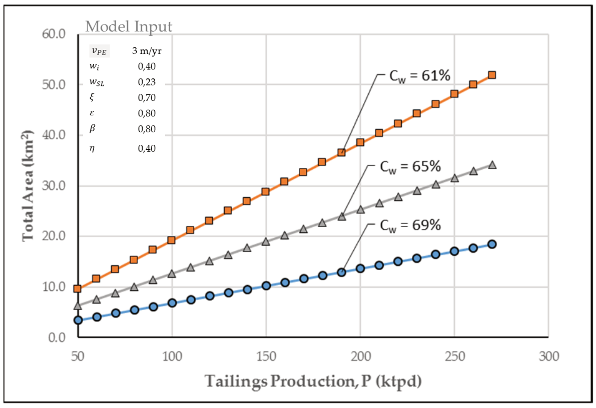

Figure 8: Total Area vs Tailings Production.

An example of the applicability of the model for 2 different hypothetical TMF is shown in **Note: Using the Errazuriz (2018) model, the width of the total flow can be also estimated using this model, providing an estimation for the minimum width for the tailings distribution system.*

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Table 1: Theoretical example of Model Application

Parameter	Units	TMF 1	TMF 2
Production (P)	tpd	100.000	300.000
Solids Content (C_W)	%	65 %	70 %
Specific Gravity of Solid (S_G)	-	2,7	2,7
Initial Surficial Dry Density (γ_{dry_i})	t/m³	1,35	1,40
Shrinkage Limit Dry Density ($\gamma_{dry_{SL}}$)	t/m³	1,65	1,65
Potential Evaporation (v_{PE})	m/yr	3,0	2,5
Yield Stress (τ_y)	Pa	30	45
Bingham Plastic Viscosity	Pa*s	0,10	0,15
Initial Water Content (w_i)	-	0,37	0,34
Water Content at SL (w_{SL})	-	0,24	0,24
Beach Slope*	%	4	5
Sheet flow layer depth (h_t)	m	0,07	0,08
ξ	-	0,70	0,70

Parameter	Units	TMF 1	TMF 2
ε	-	0,80	0,80
β	-	0,80	0,80
η	-	0,40	0,40
φ	-	0,34	0,17
ψ	-	0,91	0,80
Number of Sectors (n)	-	4	5
Operational Time (T_{op})	days	2,0	1,6
Inactive Time ($T_{Inactive}$)	days	5,5	5,1
Area per Sector (A)	km^2	3,7	6,6
Rate of Rise (RoR)	m/yr	6,1	10,0
Total Area (A_{Total})	km^2	13,9	28,3

**Note: Using the Errazuriz (2018) model, the width of the total flow can be also estimated using this model, providing an estimation for the minimum width for the tailings distribution system.*

CONCLUSION

This integrated approach provides an additional design and operational tool for having steeper beach slopes for a given rheology and discharge rate, by means of managing the flow shape to promote sheet flows. The key concept is: Promoting a thin layer deposition scheme with drying cycles is an additional tool for having steeper beach slopes, along with increasing the tailings thickening and the discharge rate division using multiple spigots. So the integrated approach for estimating beach slope proposed is 1) first evaluate if this type of deposition scheme is possible (available area, morphology, climate) with this paper, and 2) If this is possible, you should estimate a range of beach slopes with a sheet flow based model, like Errazuriz (2018).

Depending on tailings production, tailings properties, climate and site morphology, the basic model presented describes a minimum area per sector (Eq. 8), minimum number of sectors (Eq. 19) and maximum operational time per sector (Eq. 11), with simple equations for reaching enough drying for having the possibility of sheet flows. Putting all together, a maximum RoR (rate of rise) expression is found for a TMF (Eq. 21), depending on the tailings properties and site evaporation rate – which becomes a useful design parameter to evaluate the feasibility of having sheet flows given the site condition and project settings.

The basic model allows a straightforward evaluation of existing TMF (the possibility of enhancing the number of sectors in the same area), and at a design stage, allows to include stochastically analysis for a range of probable input values for having a whole range of area requirements, number of sectors and operational times.

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REFERENCES

McPhail, G. (2008). 'Prediction of the beach profile of high-density thickened tailings from rheological and small-scale trial deposition Data ', Proceedings of the 11th International Seminar on Paste and Thickened Tailings, Paste 2008.

Fitton, T.G. and Slatter, P.T. (2013). 'A tailings beach slope model featuring plug flow', Proceedings of the 16th International Seminar on Paste and Thickened Tailings, Paste 2013.

Errazuriz, T. (2018). 'Tailings beach slopes as a dimensionless parameter of non-Newtonian flows', Proceedings of the 21st International Seminar on Paste and Thickened Tailings, Paste 2018.

Wilson, G., Fredlund, D. and Barbour, S. (1994). 'Coupled soil-atmosphere modelling for soil evaporation', Canadian Geotechnical Journal, 1994, 31 (2): 151-161.

Fisseha, B., Bryan, R. and Simms, P. (2010). 'Evaporation, Unsaturated Flow, and Salt Accumulation in Multilayer Deposits of "Paste" Gold Tailings'. Journal of Geotechnical and Geoenvironmental Engineering 136: 1703-1712.

Jefferies M. and Been, K. (2015). *Soil liquefaction: a critical state approach,* 2nd Ed., Taylor and Francis.

Jewel, R. (2010). 'The evolution of paste and thickened tailings', Newsletter volume No. 35, December 2010. Australian Centre for Geomechanics.

Simms, P., Sivathayalan, S. and Daliri, F. (2013). 'Desiccation in dewatering and strength development of high-density hard rock tailings', Proceedings of the 16th International Seminar on Paste and Thickened Tailings, Paste 2013.

Li, A. (2011). 'Prediction of tailings beach slopes and tailings flow profiles', Proceedings of the 14th International Seminar on Paste and Thickened Tailings, Paste 2011.

Fitton, T.G. (2007). 'Tailings beach slope prediction', PhD thesis. RMIT University, Australia, Published as book by VDM Verlag, Saarbrücken, Germany 2010.

Peck, R. (1969) 'Advantages and Limitations of the Observational Method in Applied Soil Mechanics', 9° Rankine Lecture.

D'Appolonia, E. (1990). 'Monitored Decisions', 24° Terzaghi Lecture, ASCE Journal of geotechnical engineering, Vol 16.