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Comparison of Linear and Central Distribution Systems for Thickened Tailings Stacking

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ABSTRACT

One of the key parameters in successful implementation of thickened tailings schemes for tailings management is the achievable tailings beach slope. Study of geomorphology and hydrodynamics of tailings beaches has shown that the achievable beach slope is directly proportional to tailings solids concentration (i.e. rheology) and inversely proportional to discharge flowrate.

Splitting the total tailings flowrate from the process plant, into multiple spigots prior to discharge to a Tailings Storage Facility (TSF), will result in formation of a steeper beach profile which will increase the storage capacity. Additionally, uniform distribution and discharge of tailings into the TSF is a key element in filling the storage evenly and optimising the TSF effective storage capacity.

Two different generic spigot arrangement systems are usually used in practice for flow splitting: Linear Discharge System (LDS) and Central Discharge System (CDS). The main components and pros and cons of each system are discussed and compared in this paper. Items covered include hydraulics, operational challenges and effectiveness in flow splitting, minimising flows merging on the beach to achieve a uniform deposition and steeper beach slope, and the overall costs of the tailings management system (including tailings transport, distribution system and embankment construction).

There are many aspects to be considered, but overall it is concluded that in the cases for which that the comparison has been undertaken, the CDS is a more effective, easier to operate and a less costly design than the LDS.

INTRODUCTION

Thickened tailings disposal schemes in the form of either Central Thickened Discharge (CTD) or Down-Valley Discharge (DVD), have been utilised in the mining industry as an effective method of tailings management for the past 40-50 years. Recent improvement in thickening technology (i.e. larger diameter High-density and Paste thickeners) has made the technique more viable for large mining operations.

The correct implementation of the thickened tailings disposal technique in most cases results in significant reduction of earthworks and retaining embankments height and hence the risk and cost associated with high embankments. A thickened tailings scheme also improves the overall site water usage and makes the rehabilitation of the Tailings Storage Facility (TSF) easier and quicker at the end of the life of the facility by providing ready access to the surface of the deposited tailings.

One of the critical key elements to efficient implementation of the thickened tailings disposal technique is the achievable beach profile. Having an understanding of the parameters influencing beach slope and being able to predict the achievable beach slope accurately at the design stage will enable the designer to estimate the required footprint of the TSF and the height of the perimeter embankments correctly. For a given footprint of TSF, steeper beach slope means an increase in storage capacity and a reduction in perimeter embankments height.

Study of geomorphology and hydrodynamics of tailings beaches has shown that the achievable beach slope is directly proportional to tailings solids concentration (i.e. rheology) and inversely proportional to the discharge flowrate (Williams, 2014 and Pirouz et al. 2017).

The achievable solids concentration (rheology) of thickener underflow depends on the type of the thickener selected for the project, which is usually a cost driven decision which has to be made by considering the thickening testing result and the overall cost of the tailings management system and make-up water supply to the project. After the decision about the type of the thickener is made, there is not much more that TSF designer can do to improve the rheology and solids concentration of the thickener underflow apart from focus on achieving optimal operational performance. Therefore, the only other tool in the hand of designers and operators to improve the beach slope is the discharge flow rate.

Splitting the total tailings stream into multiple spigots prior to discharge to a TSF will result in formation of a steeper beach slope profile. Additionally, uniform distribution and discharge of tailings into the TSF is a key element in filling the storage evenly and optimising the TSF effective storage capacity. However, depending on geometry of the storage, there is a limitation to the number of flow splits which will be practical on a given site, as separate streams of flow will tend to merge on the beach if the discharge spigots are too close to each other.

Two different spigots arrangement systems are usually used in practice for flow splitting: Linear Discharge System (LDS) and Central Discharge System (CDS).

Some of the challenges involve in the design and operation of the LDS have been briefly outlined by previous work (Martinson, 2017), but to the knowledge of the authors no comparative analysis has been undertaken to demonstrate the practicality, limitations and pros and cons of LDS versus CDS.

METHODOLOGY

To demonstrate the pros and cons of the LDS and CDS, a hypothetical (but realistic) example of a mining operation with nominal throughput of 10 Mtpa has been considered. The assumptions and input parameters for the simulation are summarised in Table 1. The selected parameters for this example all fall within a typical mining operational range (Seddon, Pirouz & Javadi, 2018). The simulation of the TSF with CDS and LDS has been done for one year of operation.

Table 1 Assumed Parameters for Study Case

Parameter	**Unit**	**Quantity**
Nominal Plant Throughput	Mtpa (dry)	10.0
Maximum Plant Throughput	Mtpa (dry)	12.0
Nominal Daily Throughput	t/day	30,000
Annual Operating hours	hr	8,000
Solids Particle Density (SG)	t/m^3	2.65
In-Situ Dry Density	t/m^3	1.50
Thickener Solids Concentration (Ave. Min., Max.)	%	60.0, 50.0, 65.0
Tailings Rheology at 60%		
Yield Stress	Pa	38
Plastic Viscosity	Pa.s	0.0425
Tailings Flowrate (Mean, Min, Max)	l/s	362 - 319 - 574
Number of Discharge Spigots	No.	5
Tailings Flowrate per Spigot (Mean, Min, Max)	l/s	72.4 – 63.8 – 114.8
Predicted Beach Profile Slopes (Upper Section, Middle Section, Lower Section, Run-out)	%	2.1 - 1.6 - 1.2 - 0.5

The variation ranges adopted for the plant throughput and thickener underflow solids concentration are based on the previous data analysis of the variability of tailings thickener operations (Pirouz, Javadi & Seddon, 2017).

The predicted beach slopes and beach profile as indicated in Table 1 are based on the beach slope prediction model developed by the Pirouz et al. (2014). A concave beach profile is considered to allow for the variation in thickener underflow solids concentration and flowrate variation.

Using the above mentioned input parameters, an appropriate LDS and CDS setup for tailings distribution and the corresponding TSF arrangement to suit each distribution system have been proposed. For the purposes of this comparison, it is assumed that the TSF is constructed on flat topography with no topographical boundary or obstacle. It is also assumed that the land available for TSF construction enables a similar footprint area for both systems. The influence of existing topography on the selection of discharge options is considered further in the Discussion section of this paper.

The following aspects of the proposed LDS and CDS arrangement have been compared and pros and cons of each system are discussed in detail under the following categories

- Arrangement and set-up of the system
- Hydraulics of the system (complexity in design and operation)
- Flow splitting and remerging probability on the beach
- Efficiency of the storage and cost

RESULTS AND DISCUSSION

TSFs are usually constructed in multiple stages through the life of the mine to improve the cashflow of the project. However, for the purpose of this comparison exercises it is assumed that all of the infrastructure required for LDS and CDS is constructed upfront.

Comparison of arrangement and setup of the system

The proposed TSF arrangements for LDS and CDS are shown in Figure 1. The CDS arrangement includes the tailings pump station and main delivery pipeline which transports the tailings from the pump station to the central point of the deposition area, the central access causeway for installation of the tailings delivery pipeline, a flow distribution tank with outlets valves and short outlet pipe spools, a central platform for the location of the tailings distribution tank, and the perimeter toe embankments. The total surface area of the proposed TSF for CDS is about 113 ha.

The proposed arrangement for LDS includes the tailings pump station and main delivery pipeline, a cell type TSF with sloping crest embankments (higher RL at the discharge end), the discharge header pipe, and spigot outlets with control valves or orifice plates at the designed intervals. The total surface area of the proposed TSF for LDS is about 112 ha.

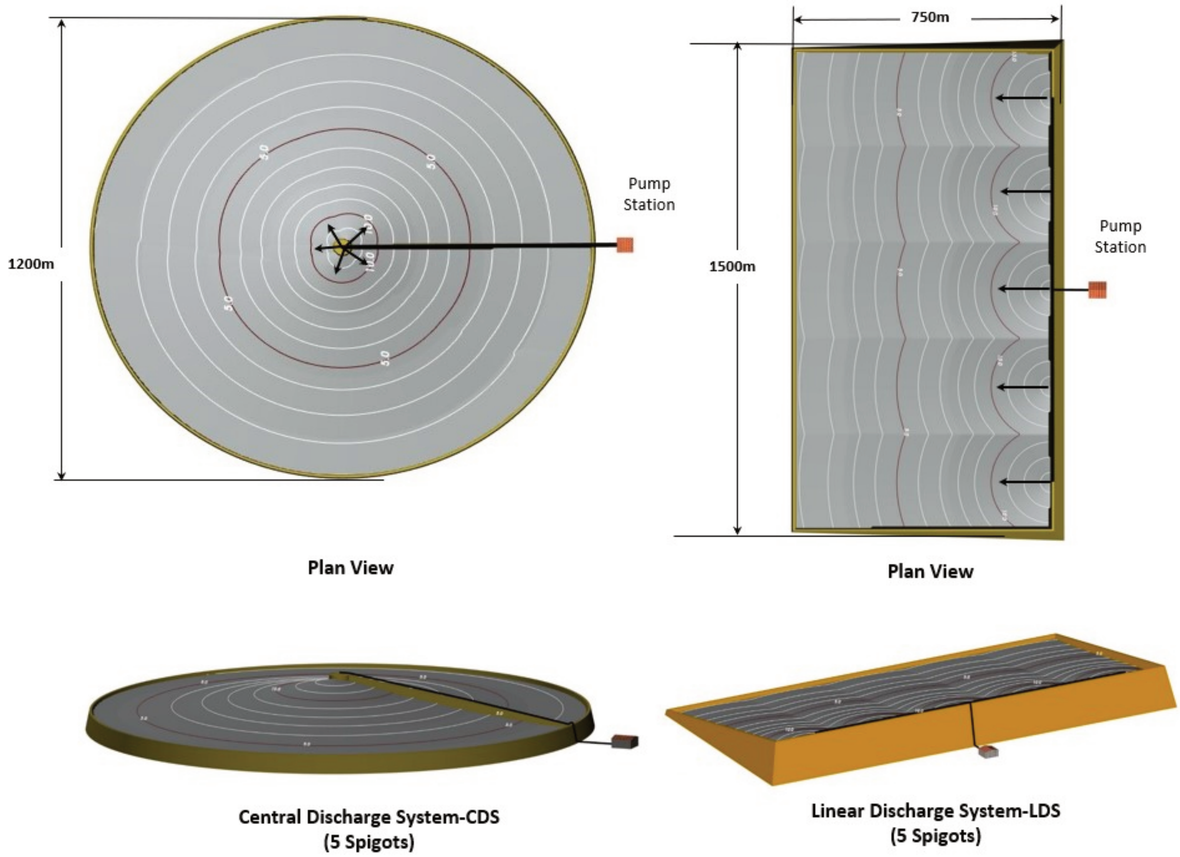

Figure 1 Arrangement and setup of CDS and LDS with 5 outlets (end of Year 1)

. Both CDS and LDS can be designed for multiple discharge outlets. For the purpose of this exercise and for comparison a five spigot arrangement has been considered for both systems. Figure 2 shows examples of the flow distribution arrangements for LDS and CDS in real operation.

Figure 2 Flow distribution arrangements for CDS and LDS

Comparison of the hydraulics of the system (complexity in design and operation)

The main objectives of the hydraulic design for both CDS and LDS is to achieve equal distribution of the total flow between different spigots to fill the storage capacity evenly and effectively (highly desirable), and to minimise the risk of pipeline blockage due to solids deposition in low flow condition (essential).

It could be argued that achieving uniform flow from each spigot is not absolutely necessary. However considerations of practical beach management make it highly desirable. Uneven flow rates result in variations in beach slope and profile, and unequal distribution of deposited mass of tailings over the footprint. This can lead to unexpected problems with lack of freeboard (both at the discharge end and at the toe, and can contribute to “dead spots” on the stack which inhibit water return.

To reduce the pipeline blockage risk during operation, the system should be designed in such a way that the operating velocity in the pipeline never drops below a pre-set value which is known as minimum transport velocity. This value is defined from the laboratory test works and tailings properties. For the purpose of this example a minimum transport velocity of 1.8 m/s has been adopted.

The pump station and delivery pipeline need to be designed with sufficient safety margins to accommodate the expected fluctuations of flowrate and solids concentration. To ensure that the operating velocity in the pipelines never drops to below the minimum transport velocity, the sizing of the system must be based on the minimum expected operating flowrate (i.e. 63.8 l/s which corresponds to minimum tonnage and maximum solids concentration in Table 1). Figure 3 shows the hydraulic design and sizing for the LDS and CDS. For the proposed design the minimum actual velocity in all of the pipelines is 1.8 m/s.

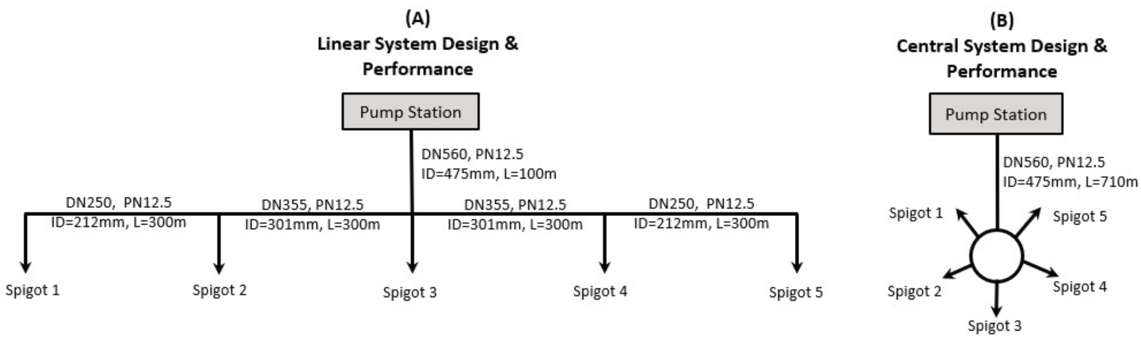

Figure 3 Hydraulic Design for CDS and LDS with 5 outlets

The hydraulic design and operation of the CDS arrangement is relatively simple as the entire flowrate from the tailings pump station is delivered to a central distribution tank via a single pipeline.

With the proposed design for the CDS any fluctuation in flowrate and pressure from the process plant is transferred to the central distribution tank from which it is equally distributed to the outlets of the tank resulting in equal flow distribution and discharge from all outlets in all flow conditions. The system is self-adjusting and does not require any manipulation or operator interference.

Figure 4 shows an example of distribution tank for CDS with fifteen installed outlets (in the example in this paper a lesser number of outlets would be installed, and only 5 outlets would be operated at a time).

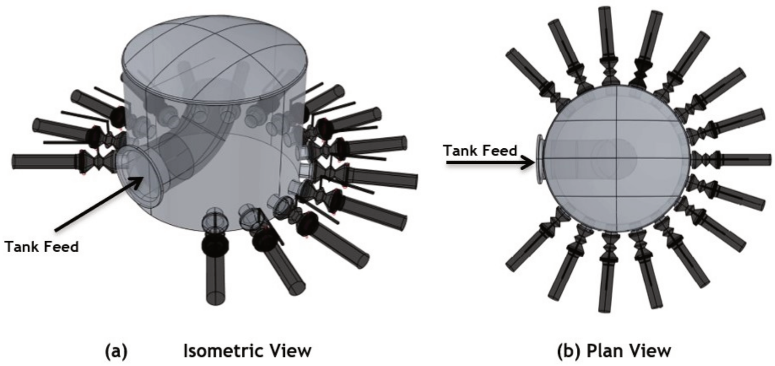

Figure 4 Flow distribution tank for CDS with 15 outlets (only 5 spigots are operated at a time)

In contrast to CDS the hydraulic design and operation of LDS is complex. The first challenge in designing the LDS arrangement is to prevent the flow velocity dropping in the header pipeline downstream of each spigot offtake from the pipe. For a fixed pipe diameter, after each spigot the flowrate and hence the operating velocity in the main header pipe drops. So, to prevent the solids deposition in the pipeline a reduction of the main header pipeline size is required after each outlet to maintain the operating velocity above the minimum transport velocity. This is shown in Figure 3.

The second challenge in LDS design is to achieve equal flow from different outlets at different operating conditions. If no control measure is installed on the discharge pipes, the upstream spigots that operate at higher pressures will discharge at a higher flowrate than the downstream spigots (Martinson, 2017). So, it is necessary to install flow control valves or custom designed orifice plates on all of the spigots to regulate the flow from different spigots. Although this may seem a simple solution to the problem, following complications apply:

- The valves or orifice plates that are set for a specific flow condition to discharge even flowrate from different spigots will not work exactly for other flow conditions (i.e. higher or lower flowrates).
- Valves or orifice plates have a narrow operating range meaning that all of the valves or orifice plates in the system need to be adjusted with every fluctuation of flowrate or pressure that occur in the upstream system. In addition, the adjustment of any of the installed valves or orifice plates will affect the discharge flowrate and pressure from all of the other spigots.
- To adjust the valves or orifice plates to achieve equal flow, it is required that an inline flowmeter to be installed on each outlet to control the adjustment. LDS outlets are usually

located at remote locations and supply of electric power (or pressurised air for pneumatic actuators), control signals etc. is costly and difficult if not impractical.

- The discharge velocity in the control valve and orifice plates will increase to very high velocities which results in wear and very high maintenance cost.

Figure 5 shows the performance of the proposed LDS and CDS arrangements in minimum and maximum flowrate conditions. The required orifice sizes and the discharge velocities in different outlets for each flow are also presented in the figure for both systems.

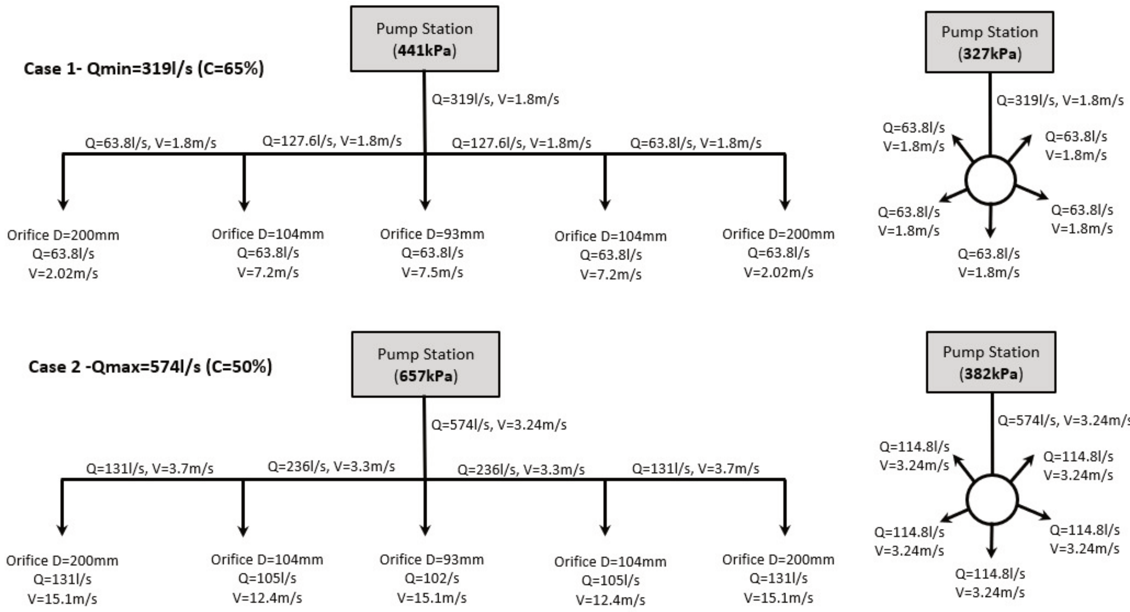

Figure 5 Hydraulic performance of CDS and LDS with 5 outlets in Min and Max flowrates

As seen in Figure 5, the CDS discharges equal flow from all of the outlets without any need for adjustment. The maximum velocity of the outlets at peak flow is 3.24m/s. On the other hand, the LDS arrangement that is designed for minimum flow condition (orifice velocity of up to 7.5m/s) if not adjusted, will not be able to regulate the flow equally between different spigots. As illustrated in Figure 5 a difference of up to 28% can be observed between the discharged flowrate of the first and last spigots while the maximum orifice velocity is 15.1m/s which will cause severe wear in the control valves or orifice plates.

Comparison of flow splitting and probability of remerging on the beach

One of the most important factors when designing an appropriate distribution system for a thickened tailings scheme is the consideration of the distribution of the self-formed meandering channels that transport the tailings down the beach, and the probability of individual flows merging on the developing beach. This factor influences the required arrangement and spacing between the spigots.

If the outlet spigots are too close to each other, regardless of the effort and cost spent on the flow distribution system, different flow streams on the beach are highly likely to merge and form a lesser number of channel flows which will adversely affect the beach slope. For a multiple discharge arrangement, some flow merging on the beach is inevitable and cannot be eliminated in total. As the spacing between the discharge spigots increases the likelihood of adjacent flow streams merging on the beach is reduced. However, increasing the spigots spacing means more embankment construction and earthworks which increases the overall cost of the TSF. In addition, if the spigots spacing is increased too much, the storage area between adjacent spigots cannot be filled effectively which results in storage capacity reduction.

A random walk technique can be used to analyse the probability of flow streams remerging on the beach (McPhail, 2015). Figures 6 and 7 show the application of this technique for analysis of stream flow patterns in LDS and CDS with modifications as discussed below (example plotted for one spigot only).

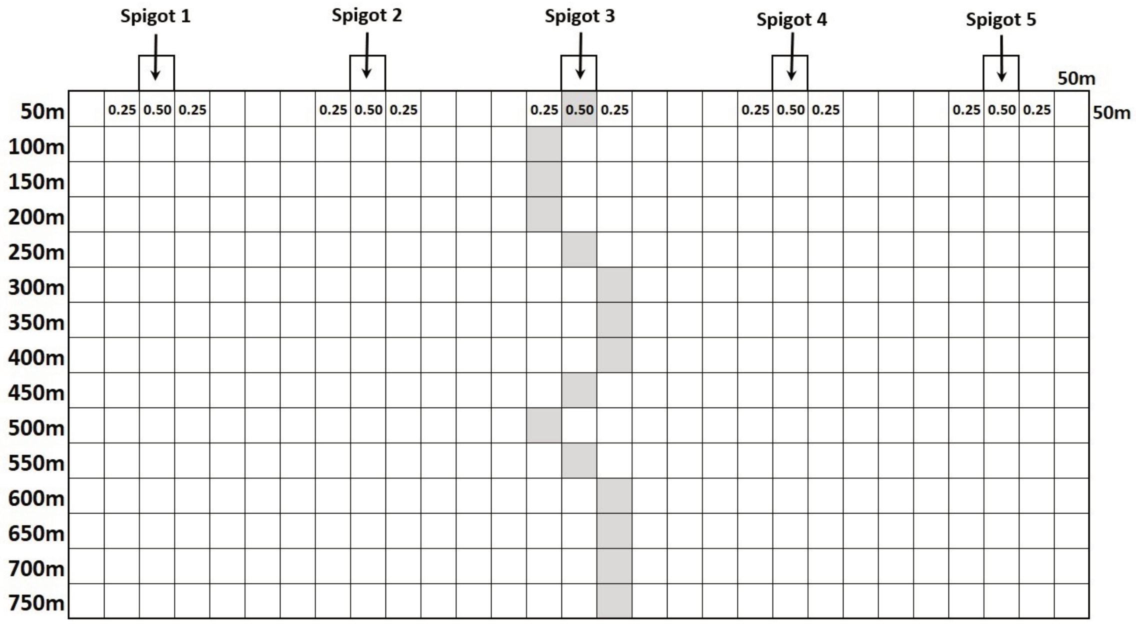

Figure 6 Random walk technique steps for analysis of CDS flow merging probability on the beach (Cells Aspect Ratio =1)

Observations from active tailings beach (Pirouz et al. 2014) show that although the tailings flow in self-formed channels on the beach always has a meandering movement pattern, the overall direction of the movement is always forward at the direction of beach slope. To simulate this forward moving trend the algorithm of random walk technique has been modified by assigning an unequal probability to grid cells so that at each step of movement the probability of the flow moving forward to the front cell is 0.5 and the probability of flow moving sideways to the side cells is 0.25.

For the results of the analysis for LDS and CDS arrangements to be comparable, the nominal aspect ratio of the cells (length/width) for movement should be the same for both LDS and CDS. An aspect ratio of one has been considered for both systems in the current analysis. For the LDS system this gives a regular grid pattern; for the CDS an expanding radial arrangement results, as shown in Figures 6 and 7.

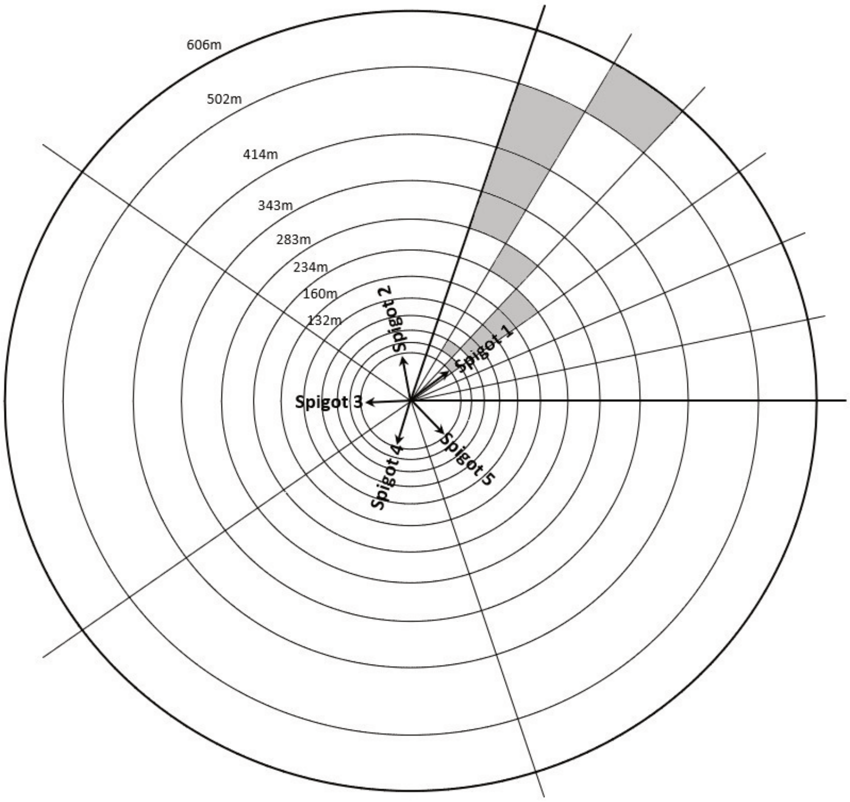

Figure 7 Random walk technique steps for analysis of CDS flow merging probability on the beach (Cells Aspect Ratio =1)

The results of one hundred independent runs of random walk algorithm for LDS and CDS arrangements are presented in Figures 8 and 9 in the form of the probability of "Single (Unmerged) Streams" and "Two Merged Streams" with distance from discharge point. (For simplicity the relatively small probability of more than two merged streams is not shown).

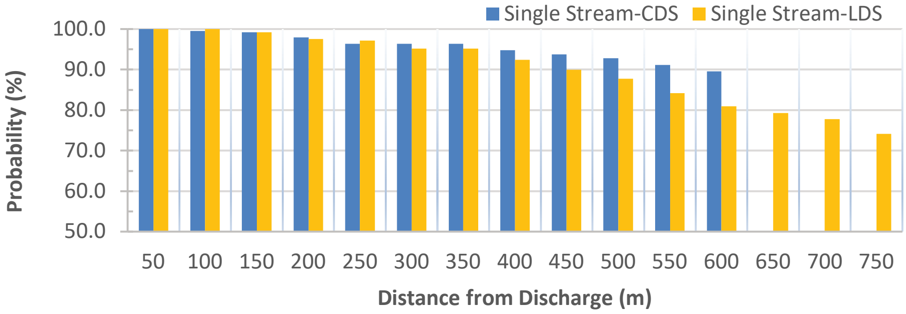

Figure 8 Percentage of single stream flows in CDS and LDS arrangement with distance from discharge point

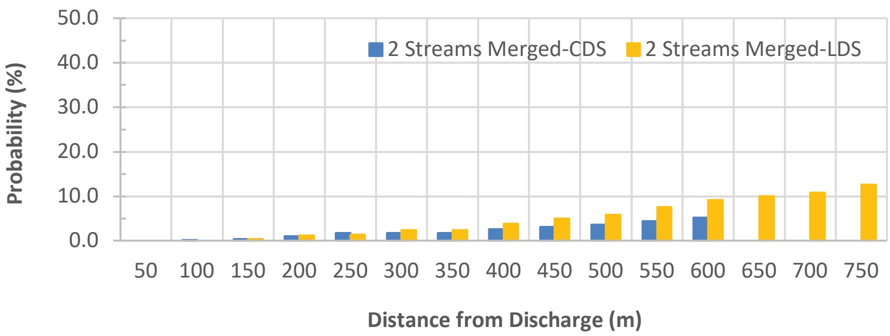

Figure 9 Percentage of two merged streams in CDS and LDS arrangement with distance from discharge point

A spigot spacing of 300 m and a central platform of 150 m diameter (spigot spacing of approximately 95m) have been considered for LDS and CDS arrangement respectively for this analysis. As seen in Figure 8 the percentage of single stream flows at a distance of 600 m from the discharge point is about 90% for the CDS arrangement while this percentage for LDS arrangement is about 80%. Similarly Figure 9 shows that the percentage of two merged streams is 5% for CDS and 10% for LDS arrangements respectively.

Comparing the results of the random walk analysis for the two systems reveals that a CDS arrangement with a central platform diameter of 150 m is a better setup than a LDS arrangement with spigots spacing of 300 m in minimising the flow streams remerging on the beach.

The Influence of Topography

It is generally accepted that the maximum value of a thickened discharge scheme is realised in cases where the overall ground slope is less than the overall beach slope, so that perimeter embankments can be minimised. However no two sites will ever be the same and selection of the most suitable discharge arrangement remains a critical design decision for any site (and indeed the outcome may vary for the same site but with different overall storage requirements). In view of these considerations, the discussion in this paper has been based on an idealised, flat horizontal surface.

It is recognised that the LDS arrangement may appropriate if it can be aligned so that discharge is off the side or top of a linear topographic feature, or down-stream in a broad valley arrangement. However experience has shown that with a degree of ingenuity a designer can also adapt a CDS scheme to achieve an optimised outcome for these types of features.

In any event, the final selection of a distribution scheme cannot be based on just considerations of earthworks costs, as demonstrated in this paper.

Efficiency of the storage and TSF cost (earthworks volumes, mechanical and piping requirements)

As mentioned earlier, for the purpose of this exercises it has been assumed that the land available for the construction of the TSF is the same for LDS and CDS arrangements and hence the TSF dimensions are selected in way to give the same surface area for both arrangements. Table 2 presents the characteristics and quantities for embankment volumes, required pumping pressure and pipeline system for LDS and CDS.

As seen in the Table 2 the earthwork volume for LDS arrangement on a flat topography, is nearly double of the volume needed for CDS arrangement. It is also seen that the maximum required pumping pressure for LDS arrangement is 660 kPa in comparison to 380 kPa required for CDS, which means higher energy consumption. The total length of the pipeline required for the CDS arrangement is also half of the length needed for LDS arrangement although the required pipes for LDS are smaller diameters. The CDS arrangement only needs a single isolation valves on each outlet while the LDS arrangement requires adjustable control valves or orifice plates and ideally flowmeters to be installed on each spigot. The orifice plates or control valves on LDS setup will be subject to very high velocities which result in severe wear, shorter life and higher maintenance cost. In the LDS arrangement because the spigots are 300 m apart, some dead storage area will form between the two adjacent spigots which will not be filled evenly similar to the rest of the area of the storage and hence the efficiency of the storage will drop.

Table 2 Earthworks, mechanical and piping characteristics and quantities for LDS and CDS

Description	Unit	Quantity (LDS)	Quantity (CDS)
TSF Cell Dimensions – LDS (Length x Width)	m	1500 x 750	-
TSF Cell Diameter - CDS	m	-	1,200
TSF Surface Area	Mm^2	1.125	1.130
Embankment Crest Width	m	6.0	6.0
Max. Perimeter Embankment Height	m	14.7	4.7
Min. Perimeter Embankment Height	m	2.0	4.7
Max. Causeway Embankment Height	m	-	13.5
Causeway Platform Diameter	m	-	150
Freeboard	m	0.5	0.5
Perimeter Embankment D/S and U/S Slope	-	2H:1V	2H:1V
Causeway Embankment Side slopes	-	-	1.5H:1V
Total Embankment Volume	Mm^3	1.13	0.685
Pump Station Maximum Pressure	kPa	660	380
Pipeline Lengths	m	DN560 (L=100m), DN355 (L=600m), DN250 (L=600m)	DN560 (L= 710m)

CONCLUSION

Different aspects of the Linear Discharge System (LDS) and Central Discharge System (CDS) which are the two most commonly used tailings distribution systems in the TSF design are compared. Overall, it is concluded that on flat topography the CDS is a more effective and less costly design in comparison to LDS.

The CDS has other intrinsic advantages as listed below:

- The hydraulic design and operation of CDS arrangement is much simpler and less costly than the LDS.
- The risk of pipeline blockage during operation due to low flow condition or slurry solids concentration variation is minimum in CDS while the LDS arrangement is always susceptible to gradual solids deposition in the pipe and pipeline blockage.

- The CDS arrangement is a self-adjusting system which always provide uniform flow distribution between different spigots but achieving uniform flow from different spigots in LDS arrangement in all flow conditions is very difficult and costly if not impractical.
- To regulate the discharge flowrate from different spigots in LDS arrangement, control valves, orifice plates and ideally flowmeters are required to be installed on each outlet. The discharge velocity in LDS arrangement can reach to very high velocity which will cause severe wearing of the instruments and increases the maintenance costs of the system.
- CDS arrangement if designed and sized properly, would provide a better flow streams splitting with lower probability of stream remerging on the beach in comparison to LDS arrangement.
- The earthwork volumes, required pumping pressure, pipeline length and energy consumption in CDS arrangement is generally less than what is needed for LDS arrangement.

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