The Effect of Filter Cake Moisture Targets on Ancillary CAPEX and OPEX for Tailings Filtration

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SUMMARY

As head grades of mines around the world decline, generation of tailings is increasing. Along with the increased tailings generation, reduction in water availability, and recent tailings dame failures, are causing mining companies to look at different disposal methods. One of the methods that is gaining traction is filtered tailings. Filtered Tailings currently provides the greatest water recovery and the smallest footprint among all the tailings disposal methods.

Final filtered tailings cake moisture is dependent upon a few major requirements – 1.) geotechnical behavior of the dewatered tailings for disposal in a stable stack, 2.) water recovery requirements to maintain water balances at the mine, 3.) capital and operating expense feasibility. One unit operation that can significantly affect the capital and operating expenses is the cake air blow step to dewater the filter cake.

The cake air blow step is typically required to desaturate the cake and remove water from the solids to reach the target cake moisture. Airflow consumption and the time of the cake blow step can significantly affect the filter size, air compressor requirements and in some cases making filtered tailings not feasible.

This paper will present two case studies that analyze the filter and air compressor costs associated with a change in the final cake moisture target (i.e. a change from 17-wt% to 15-wt% cake moisture), for a base metal mine and gold mine.

1. Introduction

The demand for minerals and metals, especially copper is growing. As the World Bank's 2017 report titled "The Growing Role of Minerals and Metals for a Low-Carbon Future" shows, demand for metals, including copper, could rise tenfold by 2050 if the world moves towards a low-carbon energy future. This growth in demand is coinciding with continued declines in ore body quality. Mudd (2009) showed that ore body grades for copper, lead, zinc and other minerals have been declining globally. This has forced companies to process larger tonnages to achieve economy of scale. These larger throughputs require larger amounts of water and result in larger amounts of tailings that will have to be safely stored into perpetuity.

This increase in water consumption and tailings generation are coinciding with investor pressure for more sustainable mining practices (Global Sustainable Investment Alliance 2018, RBC Global Asset Management 2018). More mining companies are investigating filtered tailings as part of their long-term sustainability plans and to reduce risks associated with tailings storage. Additional benefits of filtered tailings are:

- Water reclamation and makeup water minimisation reduces costs
- Minimised tailings management facility (TMF) area – footprint can be less than 50% of a conventional TSF
- Reduction in closure costs at end of mine life – progressive closure possible
- Reduced tailings risk improves safety
- Suited to areas of high seismic activity

FLSmidth (FLS) recommends that miners conduct tailings solutions technology trade-off studies which includes analyzing different tailings solution options, including different flowsheets and equipment. This analysis includes determining the most economic approach for each solution. Filtered tailings is often included to determine if the increased recycling of process water can be part of the mine's sustainability plan. FLSmidth's own program in support of sustainability, MissionZero, has the goal of offering solutions that support zero water waste by 2030. We already have technology that enables our customers to recover up to 95% of their process water. This filtered tailings solution also solves problems associated with wastewater management and is economically competitive with alternative water management options such as desalination, even for high tonnages.

Below are items for consideration that impact the rate at which the slurry will dewater and its impact on the cycle time or filtration area required to meet the specified conditions.

- Feed Solids – The feed solids percentage by weight determines the hydraulic loading the filtration or dewatering equipment will process.

As the feed solids increases, the amount of liquid to be removed decreases. Filtration rates will be increased as feeds solids are increased. In many flowsheets a high-density thickener will be installed to increase the feed solids to a high performance secondary dewatering device such as a filter or centrifuge. This is desirable as the capital and operating costs for a thickener are typically an order of magnitude less than most filters or centrifuges.

- Particle Size Distribution – The particle size distribution or PSD will provide insight into how the slurry will react to pressure filtration. A narrow band can impact cake formation by packing tightly, limiting flow. Having a disproportionate number of fine particles smaller than 10 microns can cause poor cake formation, with the fines limiting the flow through the cake.
- Particle Shape – The shape of the particle plays a role in the expected filtration. When the aspect ratio of the face to edge increases, the particles are more platelet in nature (Clays, Mica, etc.). This type of particle creates bridging and blinding, drastically reducing filtration rates and limiting the effectiveness of the air blow step.
- Minerology – Clay concentrations above 10 %, especially swelling clays, will have a very negative impact on filtration rates.
- Target Moisture – The target moisture for the product discharged from the filter determines the total amount of energy required by the equipment. As the target moisture, liquid remaining in the cake, decreases it typically requires a greater amount of energy and time. Low target moisture rates often result in the need for more filtration surface area.

However, it can be difficult to justify the extra capital expense associated with filtered tailings during studies due to unquantified or underestimated costs. As discussed by Carneiro and Fourie (2019) studies often underestimate closure costs and less tangible costs are not included. Even if as many costs are known/estimated as possible, the difference in risks and consequence of failure for different tailings solutions are often ignored. Pyle et al (2019) have shown that if past tailings failures are used to assign a value to the risk and cost of failure of a traditional wet impoundment then filtered tailings can become economically competitive for some projects. As each mine site is different, it is important to understand the factors that can help guide the process to determine which solution is best. These factors include:

- Water cost and availability
- Space requirements for waste (tailings and waste rock)
- Regulatory requirements

One of the reasons that these trade-off studies can show filtered tailings to be cost prohibitive at some mines is due to low cake moisture targets. These target moistures can be set by several (sometimes competing goals) requirements such as ; the geotechnical requirements of the stack, water balance requirements, goverment regulations, etc.. If the moisture target can be loosened to allow for wetter cakes through modifications to the stack design or other procees improvements for water recovery then the filtration cycle time can be shortened and subsequently the costs associated with the filter and ancillary equipment. Examples of this are reviewed in the case studies below.

2. Test Methodology

Pressure filtration tests were conducted using a bench-scale filtration testing unit. The bench-scale testing unit allows FLSmidth to simulate its recessed chamber and membrane chamber configurations allowing for various feed solids concentrations, pressure profiles and cake thicknesses. An image of the filter press testing apparatus is shown in Figure .

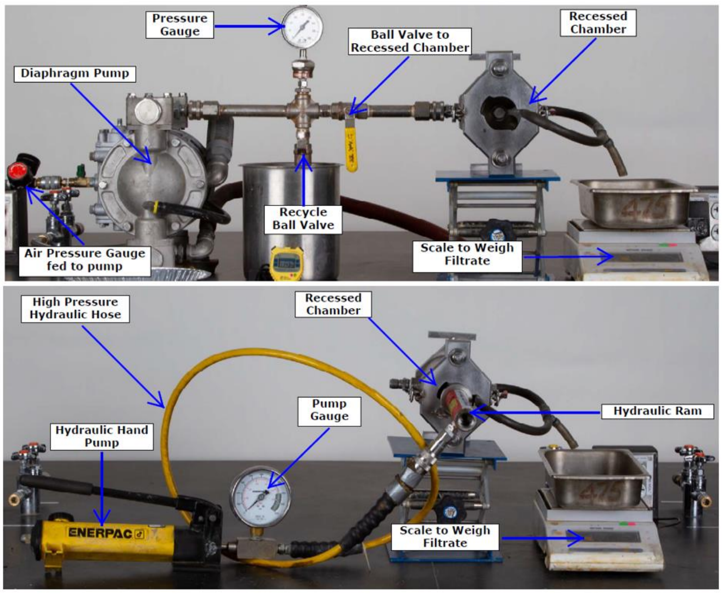

Figure *1*: Pressure Filtration and Membrane Squeeze Test Set Up

The test apparatus allows for variations in fill pressures, cake thicknesses, fill times, air blow times as well as air blow pressures. This in turn facilitates accurate design of the optimum filter press.

The filtration tests were conducted using filter media designated POPR 966 with an air permeability range of

15 to 25-m^3 of air volume per m^2 of filter area per minute at 125-Pa. This specific filter media is typically effective in similar processes and exhibited good performance based on filtration rate, filtrate clarity, cake release, and resistance to blinding.

The recessed chamber test begins by pumping feed slurry into the double-sided chamber. FLSmidth records filtrate production and the resulting pressure profile with respect to time while the chamber fills. When the filtrate flow subsides, the cake consolidation portion of the test is complete. The graphs depict this scenario indicated by the curve flattening.

Following the cake washing step, the cake blow begins simulating cake drying. During the cake blow, filtrate production is measured with respect to time along with air pressure and the flow rate through the filter cake. Air flow is limited to applicable levels available on full-scale filters by adjusting air pressure.

FLSmidth calculates the full-scale filtration rate using the form time, a standard mechanical time of three- and one-half minutes, a standard pump time of one minute and the cake blow time required to achieve the target cake moisture. Full-scale filtration rates may vary depending on the size, pumping rate, and configuration of the filter press.

It should be noted that any discussion of moisture or water values in this paper are in weight percent moisture (wt%). This should not be confused with geotechnical moisture content (%), which are not reported in this paper.

3. Case Studies

These case studies are based on lab testing and are conceptual in nature with an accuracy of ±30% for the major equipment CAPEX/OPEX. Throughputs have been rounded to respect customer confidentiality. It should be noted that the FLS sizing methodology requires a minimum of 15% excess capacity on filters to allow for maintenance. While FLS normally recommends a spare filter, no spare filter(s) are included in these studies. Potentially shared equipment (feed pumps, compressors, receivers, etc.) are not optimized at the conceptual stage of these studies.

All CAPEX is for equipment only and does not include spares or installation. The CAPEX covered in this paper includes ; filter feed pumps, filter presses, air compressors and discahrge belt feeders. The are the high CAPEX and OPEX contributors and will provide an estimate on the affect of cake air blow time. The OPEX includes labor, power, filter media, and spares/consumables.

3.1. Case Study 1

The first case study is for a gold mine that was investigating filtered tailings for increased water recovery. This operation currently produces 1500 tph of thickened tailings at 62 wt% solids. The PSD of the tailings are described in Table 1.

Table 1: Gold Tailings PSD

Sample	Tailings
P80 (µm)	75
P20 (µm)	13

The costs used for determination of OPEX are shown in Table 2.

Table 2: Case Study 1 OPEX Assumptions

Normalized Labor Cost ($/hr)	$38.00
Normalized Power Rate ($/kWhr)	$0.15
Filter Media Cost ($/chamber)	$240

The moisture targets for the filter cake were 13, 15, and 18 wt% moisture. The pressure filter testing was conducted using 10 bar feed pressure and 10 bar cake blow air pressure. The results of the lab testing indicated that the cake consolidation time was 1 minute, with the cake blow times to reach the different moisture targets shown in Figure 2 and Table 3 below.

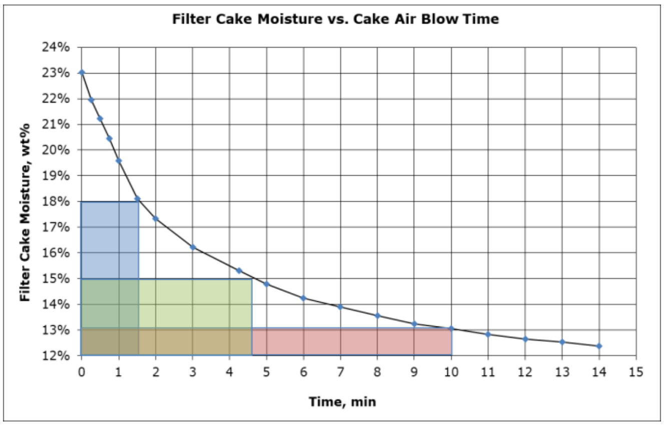

Figure 2 : Gold Tailings Lab Test Cake Air Blow Dry Curve

Table 3: Cake Blow Time Requirements

Moisture target (wt%)	Cake Blow (min)
13	10
15	4.5
18	1.5

3.1.1. 13 wt% Cake Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake with 13-wt% moisture :

- Ten (10) filter feed pumps
- Ten (10) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Nine (9) Air Compressors
- Ten (10) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 14.2 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.1.2. 15 wt% Cake Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake of 15 wt% solids:

- Seven (7) filter feed pumps
- Seven (7) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Five (5) Air Compressors
- Seven (7) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 9.5 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.1.3. 18 wt% Cake Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake of 18 wt% moisture:

- Five (5) filter feed pumps (2 in series per filter)
- Five (5) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Two (2) Air Compressors
- Five (5) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 9.5 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.1.4. Case Study 1 Comparison

A comparison of the reduction in CAPEX & OPEX and additional water recovery for the three cake moistures in this case study are shown in Figure 3. The costs are normalized to those costs of achieving 13 wt% moisture in the filter cake. This is to highlight the cost impact of achieving dryer cakes.

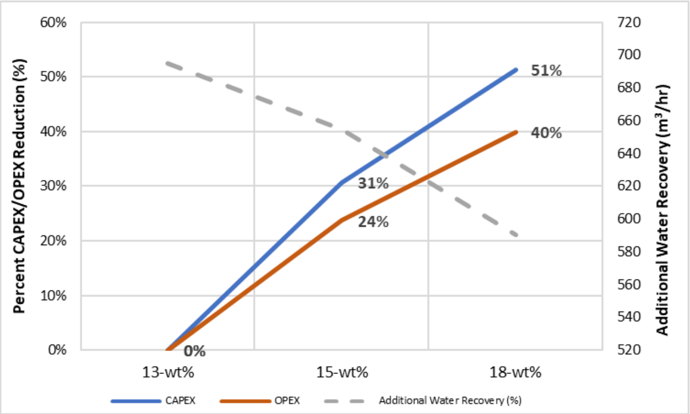

Figure 3 : CAPEX/OPEX Differences and Additional Water Recovery at Different FIlter Cake Moistures

The data shown above indicates that for this case, there was a significant change in Capex and OPEX when trying to achieve dryer filter cakes. For this case, there was a reduction of approximately 50% and a decrease in water recovery of 105 m^3/hr if the filter cake moisture can be increased to 18-wt% from 13-wt%.

The differences can also be seen in comparing the equipment lists. Table 4 is a summary of the equipment for the different filter cake moistures.

Table 4 : Equipment Quantities Relative to Cake Moisture Obtained

Equipment	13-wt%	15wt%	18wt%
Filter Feed Pumps	10	7	5
M2500 Filter Presses	10	7	5
Discharge Feeders	10	7	5
Air Compressors	9	5	2

Increasing the cake moisture for this case, can lead to significant saving in both CAPEX and OPEX. In Table 4 , there is a 50% reduction in filter CAPEX by increasing the filter cake moisture by 5wt%. There is an even higher reduction in the quantity of air compressors from 9 to 2.

3.2. Case Study 2

The second case study is for an iron mine that was also investigating filtered tailings for increased water recovery. This operation currently produces 1000 tph of thickened tailings at 60 wt% solids. The particle size distribution of the tailings are described in Table 5.

Table 5: Iron Tailings PSD

Sample	Tailings
P80 (µm)	120
P20 (µm)	5

The costs used for determination of OPEX are shown in Table 6.

Table 6: Case Study 2 OPEX Assumptions

Normalized Labor Cost ($/hr)	$50.00
Normalized Power Rate ($/kWhr)	$0.05
Filter Media Cost ($/chamber)	$240

The moisture targets for the filter cake were 13, 15, and 17 wt% moisture. The pressure filter testing was conducted using 15 bar feed pressure and 10 bar cake blow air pressure. The results of the lab testing indicated that the cake consolidation time was 1 minute, with the cake blow times to reach the different moisture targets shown in Figure 4 and Table 7 below.

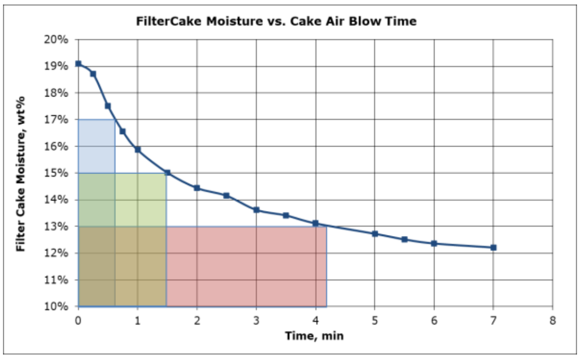

Figure 4 : Iron Tailings Lab Test Cake Air Blow Dry Curve

Table 7: Cake Blow requirements

Moisture target (% Solids)	Cake Blow (min)
13	4.2
15	1.5
17	0.6

3.2.1. 13 wt% Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake of 13 wt% moisture:

- Four (4) filter feed pump systems (high pressure)
- Four (4) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Five (5) Air Compressors
- Four (4) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 3 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.2.2. 15 wt% Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake of 15 wt% moisture:

- Three (3) filter feed pumps (high pressure)
- Three (3) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Three (3) Air Compressors
- Three (3) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 3 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.2.3. 17 wt% Moisture

The lab testing resulted in the following dewatering equipment list to achieve a filter cake of 17 wt% moisture:

- Three (3) filter feed pumps (high pressure)
- Three (3) AFP IV M2500 pressure filters with 32 mm chambers and greater than 24 m^3 of total filtration volume each
- Three (3) Air Compressors
- Three (3) Discharge Belt Feeders

The installed power includes the filter feed pumps, filter presses, air compressors and discharge feeders, is 9.5 MW. The consumed power is lower due to the batch operation of the pressure filters. The reduction in power does not include pumping efficiencies or the base loading of auxiliary equipment when not in use.

3.2.4. Case Study 2 Comparison

A comparison of the reduction in CAPEX & OPEX and additional water recovery for the three cake moistures in this case study are shown in Figure 5. The costs are normalized to those costs of achieving 13 wt% moisture in the filter cake. This is to highlight the cost impact of achieving dryer cakes.

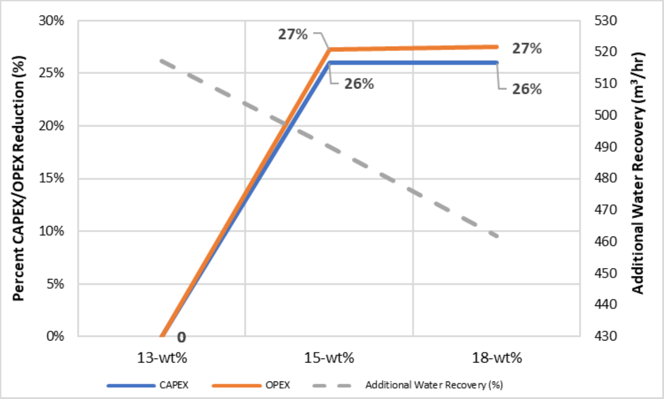

Figure 5 : CAPEX/OPEX Differences and Additional Water Recovery at Different Filter Cake Moistures

The data shown above indicates that for this case, there was a reduction in CAPEX and OPEX from 13-wt% to 15-wt% but not an advantage to reducing the moisture content to 17-wt%. By reducing the cake moisture from 13 to 15 wt%, there is a decrease in the water recovery of 28 m^3/hr.

The differences can also be seen in comparing the equipment lists. Table 8 is a summary of the equipment for the different filter cake moistures.

Table 8 : Equipment Quantities Relative to Cake Moisture Obtained

Equipment	13-wt%	15wt%	17wt%
Filter Feed Pumps	4	3	3
M2500 Filter Presses	4	3	3
Discharge Feeders	4	3	3
Air Compressors	5	3	3

Increasing the cake moisture for this case, can lead to saving in both CAPEX and OPEX when gong from 13-wt% to 15-wt%. In Table 8 , there is a 25% reduction in filter CAPEX by increasing the filter cake moisture by 2wt%. OPEX is also affected by reducing the overall air consumption thereby decreasing the quantity of compressors.

4. Discussion

There are many factors that go into the decision of the target filter cake moisture. These can include; water balance requirements, mill expansions, geotechnical stability of the tailings stack, government mandates, etc. whichever is the case, the final cake moisture can significantly impact a projects feasibility. In Case study 1, increasing the filter cake moisture from 13 wt% to 17 wt% decreases the air blow time in the filtration cycle from approximately 61% of the cycle for 13 wt% filter cake moisture to 41% (15 wt%) to 19% (17 wt%). By decreasing the air blow time portion of the filtration cycle, the total cycle time decreases and therefore decreases the quantity of filters required.

Case study 2 had a lower change in the air blow time as a portion of the total filtration cycle between final cake moistures. 36% of the total filtration cycle for a 13 wt% filter cake moisture down to 17% (15 wt%) and 7% (18 wt%)

When comparing the two case studies, there is a smaller change in the airblow portion of the filter cycle

There are other impacts on the decision of a final cake moisture. When there is a reduction in the quantities of filters, there are also reductions in the building footprint, construction and operational costs of a smaller building and lower power supply requirements.

Each site has a unique process and mineralogy. When investigating filtered tailings, it is imperative that lab scale testing is performed. FLSmidth recommends trade off studies be performed on the tailings. The tradeoff study can investingate the optimal tailings process for the unique mineralogy of a site. The results can help determine which final cake moisture is appropriate.

N. Conclusions

Mining companies are looking for ways to reduce the environment impact of their operations. This is part of their overall drive towards sustainable mining. Two ways to reduce this impact is to reduce the energy consumption and to reduce the use of fresh water. One way to reduce freshwater usage is to filter the tailings and recycle as much water for reuse as possible. As filtered tailings can be expensive, FLSmidth recommends conducting lab scale trade off studies to look for ways to reduce the cost such as evaluating different moisture targets and their impact on the cost of filtering the tailings.

This paper presented two case studies which showed the advantages of higher moisture targets for the filter cake. The first case study showed that for a Gold mine tailings:

- The CAPEX and OPEX were reduced by 31% and 24% respectively, when increasing the filter cake moisture from 13 wt% to 15 wt%
- The CAPEX and OPEX were reduced by 51% and 40% respectively, when increasing the filter cake moisture from 13 wt% to 18 wt%

The second case study showed that for a iron mine mine:

- The CAPEX and OPEX were reduced by 26% and 27% respectively, when increasing the filter cake moisture from 13 wt% to 15 wt%
- The CAPEX and OPEX were reduced by 26% and 27% respectively, when increasing the filter cake moisture from 13 wt% to 17 wt%. there was no increase from 15 wt% to 17 wt% for this case.

A comparison between the two case studies showed that:

1. A decrease in the filter cake air blow portion of the total filtration cycle (and the corresponding increase in cake moisture), reduced CAPEX and OPEX for filtered tailings by reducing the equipment required for the same throughput
2. When the air blow portion of the total filtration cycle decreases
3. In all cases, producing wetter cakes reduce the cost of filtered tailings
4. Increasing the cake moisture of filter cakes can have greater benefits outside of just a reduction in filter presses like smaller electrical requirements, reduced construction and operational costs and less overall building materials for a lower environmental impact.
5. Lab testing is a low cost, high value evaluation when comparing different options for investigating filtered tailings and the impact on the site or project.

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