SUSTAINABLE TAILINGS MANAGEMENT

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1 INTRODUCTION

Tailings management is waste management and while waste management itself could never be construed as being potentially sustainable there are aspects of tailings management for which more sustainable practices can be identified.

Over the past 30 years the environmental revolution has brought about significant changes in approaches to tailings management and rightly so. Tailings engineers have moved from simple design criteria of lowest cost, closest to the processing plant, to criteria that now incorporate consideration of water contamination, dusting, aesthetics and long term liability. However, these criteria represent a reactive response to changing societal requirements which ultimately are evolving into the concept of sustainability where this is seen to embrace the principle of ensuring that we meet the needs of the present without compromising the ability of future generations to meet their needs. Continuation of the reactive response mode has, in the past been translated into a “moving of the goalposts” reaction by mine owners and tailings engineers. However, it is now appropriate to progress beyond the reactive response by becoming proactive and fully embracing sustainability considerations in the course of siting, designing and developing tailings storage facilities.

But how does one translate the idealized objective of sustainability into a workable sustainability strategy?

This paper explores a potential methodology for effecting a proactive response by describing three commonly used alternative methods of tailings management and comparing these on the basis of sustainability issues. These issues are grouped according to the four pillars of corporate social responsibility so as to ensure that issues addressed are drawn from the full spectrum of sustainability issues filtered only to ensure that they are directly relevant to tailings management. This ensures that not only are environmental and, of course, economic sustainability issues addressed, but also relevant social, and corporate governance issues.

The methodology is illustrated by three examples where the weightings of the sustainability issues are varied according to the mine setting.

2 SUSTAINABILITY ISSUES FOR TAILINGS MANAGEMENT

The literature is full of lists of sustainability issues from which to identify issues pertinent to a specific mine setting. The list of issues below has been developed for the purposes of illustrating the application of sustainability thinking to tailings management:

- Environment Pillar
  - Air pollution (through dusting)
  - Water source depletion
  - Water degradation
  - Ecosystem destruction
  - Ecosystem alteration
  - Land use/sterilisation
  - Long term liability through nuisance or negligence.
- Economic pillar
  - Capital expenditure
  - Operating costs
  - Reagent loss
  - Energy costs
- Social pillar
  - Safety issues on site
  - Safety issues for the public particularly after closure
  - Cultural significance impacts
  - Health issues due to dusting
  - Health issues due to water degradation

- Governance pillar
  - Legal compliance
  - Stakeholder expectations
  - Adherence to Codes of conduct

The above list will be applied in comparing three alternative methods of tailings management that are described below.

3 ALTERNATIVE METHODS OF TAILINGS MANAGEMENT

In a situation where the final tailings product has been treated to the extent practicable to render it as innocuous as possible, such as by dosing with lime to raise the pH, options for addressing the sustainability issues revolve primarily around the water content of the tailings during transport and placement. This is because water is so influential in determining the behaviour of the tailings as it is placed and the movement of water-borne as well as airborne contamination after placement.

For decades there have been only two broad options for tailings management, namely, conventional tailings management entailing the pumping of the tailings in slurry form to a storage facility specifically designed to receive a slurry, and mechanical transport of the tailings to the storage site usually using belt conveyors and where it is ultimately placing using stackers.

These two methods are described below.

3.1 Conventional tailings management

Conventional tailings management requires systems to manage not only the solids as these naturally beach out on the tailings facility after discharge but also systems to manage the supernatant or free water that is liberated from the slurry during the beaching process. Invariably the volume of the supernatant water results in the formation of a pool within the storage facility which therefore requires that the conventional tailings facility has a concave-shaped surface. Water, made up of supernatant liquor as well as storm water, is decanted from the pool for return to the processing plant for re-use. At least this is the norm although there are mineral processing situations where the water cannot be reused for fear of “poisoning” the processing plant and the water then needs to be evaporated. This paper focuses on the norm.

The placed tailings mass is porous. It is saturated at surface where tailings is being deposited and has a pond whose depth can be anywhere between 0.5m and 10m or more depending on the geometry of the facility. This results in the generation of a water table within the mass. The height of the water table is dependent on the drainage characteristics of the tailings, the foundation and any filter drains built into the structure by the designer.

Formation of the side slopes is usually carried out mechanically and to reduce costs these slopes are usually in the range of 1:2 to 1:4 depending on the number and elevations of berms or step backs.

The issues the tailings facility designer has to take into account for a conventional facility are as follows:

- Slope stability which is addressed through appropriate filter drain design and slope specification
- The method of raising the facility so as to provide containment and freeboard.
- They hydrological performance addressed through consideration of the geometry of the concave basin formed through beaching of the tailings
- Groundwater contamination
- The water balance as significant volumes of water are lost through evaporation on the wet beaches, in the supernatant pond and through un-recovered seepage. Significant volumes of water may be gained during the wet season and, since it is unwise to store this water on the tailings facility, a reclaim dam is usually provided to serve as a ground-level water storage/balancing facility. This dam itself will also will lose water through evaporation and seepage as well as gain water during rainfall.
- Closure requirements to ensure long term stability, minimise erosion, minimise and contain seepage, and prevent dusting.

Elements of conventional tailings facilities that have major cost implications are:

- The delivery system costs – pumps, pipelines etc

- The cost of establishing the facility – starter works, decant works, filter drains etc
- The cost of raising the facility periodically
- Decommissioning cost.

3.2 “DRY”TAILINGS MANAGEMENT

To use a conveyor and stacker system to transport and place the it is necessary to have the tailings at the moisture content of a filter cake ie minimal free water otherwise this runs down the belt and spills onto the ground. Most mill tailings processes will require a filtration system comprising screens. Belt filters or filter presses or the like to bring the tailings to the required water content. The capital cost for these items of equipment are high so there needs to be a significant payback in the recovery of the tailings liquor through the saving of water and/or reagents.

Since the placed mass is close to saturation at the time of placement the porous placed mass will still generate a water table and seepage management will need consideration. Management of storm runoff requires careful consideration of erosion and containment. Frequently, dusting is a significant issue as the tailings dries en-route to the stacker. To counter this sprays are sometimes provided at the stacker.

Issues that the designer needs to take into account in designing a “dry” disposal facility therefore include:

- Generation of the “dry” tailings
- Conveyor and stacker sequencing and operation
- Stability and specifically the slope angle to which the tailings should be dozed down to as during stacking the tailings will be at natural angle of repose
- Hydrological control
- Groundwater contamination
- Dust control

- Closure requirements to ensure long term stability, minimise erosion, minimise and contain seepage, and prevent dusting.

Elements of “dry” tailings facilities that have major cost implications are:

- The filtration system to dewater the tailings
- The conveyor and stacker system
- The cost of establishing the facility – starter works, decant works, filter drains etc
- Decommissioning cost.

3.3 HIGH DENSITY TAILINGS MANAGEMENT

Improvements in thickener and pump technology over the past 20 years have rendered a third alternative increasingly viable. This entails removing water from the slurry either at the processing plant or out at the tailings storage facility and then pumping the higher density tailings into place. In the extreme this slurry could have the consistency of a paste but at this consistency the tailings is difficult to pump as well as difficult to manage after discharge as it does not flow. For practical reasons a slurry consistency is usually chosen where a compromise is struck between pumpability of the slurry, beach profile and water recovery.

An optimal high density system enables the formation of a convex landform that does not pond water after closure. The landform is of gentle slope, commonly 1:20 to 1:40, which mirrors the natural topography and, as a result, erosion is less problematic. The volume of supernatant water is minimal since the water content at which the tailings are pumped is usually close to the water content that the tailings initially settle out at. Recharge to the placed tailings below a new layer is low and as a result a low water table is formed. This is further assisted by the fact that the convex landform sheds water rather than containing it as is the case for conventional deposition.

While capital and operating costs to generate the higher density tailings are high these costs are more than offset by the fact that it is unnecessary to raise the side slopes of the facility and lower operating costs on the facility. Most importantly there are significant savings in water as a result of reduced evaporation.

Since the high density facility is convex the volume stored on the same footprint is similar or sometimes greater depending on the high density beach slope angle notwithstanding the fact that the outer containment embankments are not raised.

Decommissioning a high density facility is considerably simpler since there are no steep, high side slopes and water is shed from the facility.

Issues a designer needs to take into consideration in designing a high density tailings management system are:

- Reliable generation of the high density tailings taking into account variations in ore mineralisation
- Pumping the tailings
- Prediction of the beach profile
- Surface water runoff control
- Groundwater contamination
- Decommissioning and closure

Elements of high density tailings facilities that have major cost implications are:

- The thickeners to dewater the slurry
- The delivery system– pumps, pipelines etc
- The cost of establishing the facility – starter works, decant works, filter drains etc
- Decommissioning cost.

4 METHOD OF COMPARISON

Frequently the journey to develop a new mine and mineral processing facility is dictated by the prevailing metal price, short term trends in this price and financing constraints – all too familiar in the current economic times. Under these conditions mine developers tend to favour options that are low tech, have the lowest capital cost and are quickest to bring into operation even in the knowledge that the selected option may not be optimal. The potential to optimize the option after commissioning is usually incorporated into the argument for going the low tech, low capital cost route.

However, for those new mines that have the luxury of time, or are more focused on lowest life of mine cost as opposed to lowest capital cost, it is important to evaluate optimization options in terms of the four pillars of sustainability. The optimization process will entail comparing alternatives with the current situation forming the base case.

One method of doing this entails the following steps:

1. Identify the sustainability issues that influence the selection between alternatives ensuring that all four pillars are addressed.
2. Weight the issues on the basis of the context of the mine, its surrounding communities, stakeholder expectations, and corporate values.
3. Assess the relative performance of each alternative in respect of each of the issues.
4. Identify the alternative that performs the best against the spectrum of weighted issues.

When working through this process it is useful to assemble a team of people from a broad range of disciplines and standpoints and then to apply a pair-wise comparison process to agree the weightings. This process ensures that all issues are addressed with equal voracity but limits the scope of discussions at any time to only two issues thereby minimizing disruption and confusion. In the course of this process there tends to be a "meeting of minds" as the various members of the team are given full opportunity to express the basis for their opinions.

The next section describes application of the process to a number of typical mine settings so as to illustrate its application.

5 EXAMPLES

5.1 EXAMPLE 1

Consider a new mine to be established in an arid developing nation 500km inland from the ocean so that the cost of delivering desalinated water are exceedingly high. Rural communities running livestock are scattered in pockets all around the mine and are surviving through subsistence farming. The reagents used in the processing plant will degrade the water to the extent that it will no longer be suitable for livestock consumption and the ore contains sulfides that have the potential to generate acid drainage.

Table 1 below shows a typical issues matrix that would be developed in the course of a workshop to compare the issues on a pair-wise comparison basis and in so doing generate a shared weighting matrix for the issues. These weightings would be specific to the mine setting, the attitudes of the stakeholders participating in the workshop and the mining company's sustainability policy. The matrix is generated by working horizontally across an issue and, for each other issue, asking the question "is this issue of greater, lesser or equal importance in the context of the mine setting" and then assigning a ratio between 1/9 and 9 according to the rating table indicated on Table 1. It is only necessary to work through the upper (yellow) half of the table from the diagonal as the numbers in the lower half are simply the inverse values of those allocated in the upper half.

Table 2 below shows the anticipated relative performance of each of the three tailings management alternatives in relation to the issues. The table is generated by taking an issue and giving each alternative a percentage score of how well it would perform in relation to the other alternatives with a higher percentage score indicating better performance.

Table 1: Pair-wise comparison matrix – Example 1

Issues	Air pollution	Water source depletion	Water degradation	Ecosystem destruction	Ecosystem alteration	Landuse/sterilisation	Liability thru nuisance or negligence	Capital expenditure	Operating costs	Reagent loss	Energy costs	Safety issues on site	Safety after closure	Aesthetic impact	Cultural significance	Health issues - dust	Health issues - water degradation	Legal compliance	Stakeholder expectations	Adherence to Codes of conduct
Air pollution	1	9	9	6	3	1	1/3	9	9	9	9	9	9	1/6	9	9	9	9	1	1
Water source depletion	1/9	1	1	1/6	1/9	1/9	1/9	3	3	1	1	3	3	1/9	1	3	3	1	1	1/3
Water degradation	1/9	1	1	1/6	1/9	1/9	1/9	3	3	1	1	3	3	1/9	1	3	3	1	1	1
Ecosystem destruction	1/6	6	6	1	1/6	1	1/6	9	9	9	6	9	9	1	1	9	9	6	3	1
Ecosystem alteration	1/3	9	9	6	1	3	1/3	9	9	9	9	9	9	1	1	9	9	9	6	6
Landuse/sterilisation	1	9	9	1	1/3	1	1	9	9	9	9	9	9	3	1	9	9	9	1	6
Liability thru nuisance or negligence	3	9	9	6	3	1	1	9	9	9	9	9	9	6	1	9	9	9	1	1
Capital expenditure	1/9	1/3	1/3	1/9	1/9	1/9	1/9	1	1/3	1/3	1/3	9	9	1/9	1/3	9	9	1	1/6	1/6
Operating costs	1/9	1/3	1/3	1/9	1/9	1/9	1/9	3	1	1	1	9	9	1/9	1/3	9	9	1	1/6	1/3
Reagent loss	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	3	1	1	1	9	9	1/9	1/3	9	9	6	1/6	1/3
Energy costs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	3	1	1	1	9	9	1/9	1/9	9	9	6	1/6	1/3
Safety issues on site	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/9	1/9	1/9	1/9	1	1/6	1/9	1/9	1	1	1	1/6	1
Safety after closure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/9	1/9	1/9	1/9	6	1	1/9	1/6	1	1	6	1	6
Aesthetic impact	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/6	9	9	9	9	9	9	1	1	9	9	9	6	6
Cultural significance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	3	3	3	9	9	6	1	1	9	9	9	1	1
Health issues - dust	1/9	1/3	1/3	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1/9	1/9
Health issues - water degradation	1/9	1/3	1/3	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1/9	1/9
Legal compliance	1/9	1	1	1/6	1/9	1/9	1/9	1	1	1/6	1/6	1	1/6	1/9	1/9	1	1	1	1/9	1/9
Stakeholder expectations	1	1	1	1/3	1/6	1	1	6	6	6	6	6	1	1/6	1	9	9	9	1	1/3
Adherence to Codes of conduct	1	3	1	1	1/6	1/6	1	6	3	3	3	1	1/6	1/6	1	9	9	9	3	1

Numerical scale	Rating basis
1/9	Absolutely less important
1/6	Strongly less important
1/3	Weakly less important
1	Equal to
3	Weakly more important
6	Strongly more important
9	Absolutely more important

Table 2: Relative performance of each alternative against each sustainability issue – Example 1

	Tailings Management Alternatives		
Issue	**Conventional**	**Dry**	**High density**
Air pollution	60%	30%	30%
Water source depletion	20%	70%	60%
Water degradation	20%	70%	60%
Ecosystem destruction	40%	50%	40%
Ecosystem alteration	40%	50%	40%
Landuse/sterilisation	60%	60%	60%
Liability thru nuisance or negligence	30%	30%	60%
Capital expenditure	60%	20%	40%
Operating costs	20%	40%	70%
Reagent loss	20%	70%	60%
Energy costs	40%	40%	50%
Safety issues on site	50%	40%	60%
Safety after closure	30%	30%	70%
Aesthetic impact	20%	30%	70%
Cultural significance	50%	50%	50%
Health issues - dust	60%	40%	50%
Health issues - water degradation	20%	60%	50%
Legal compliance	50%	50%	50%
Stakeholder expectations	40%	40%	60%
Adherence to Codes of conduct	50%	70%	60%

Matrix arithmetic is applied to calculate the weighting of each issue and this is combined with the performance score to arrive at a value for each alternative and each issue. Since the issues list incorporates a broad range of performance criteria a wide spectrum of performance issues are brought into consideration.

Established decision algorithms are applied to rank the alternatives from most preferred to least preferred as indicated in Table 3 where rank 1 is the most preferred.

Table 3: Ranked listing of alternatives – Example 1

Rank	Alternative	Value
1	High density	0.618943
2	Dry	0.567921
3	Conventional	0.523464

In this example high density tailings management emerged as the highest ranking alternative.

5.2 EXAMPLE 2

The first example was dominated by an issue, namely water availability, which falls under the environmental sustainability pillar. This second example focuses on the issue of reagent consumption, an issue from the economic sustainability pillar.

Consider a remote mine located in rural Australia where there is an adequate supply of water but where acidic reagents are used to leach an ore that is alkalinic. The result of this combination is that the longer the dissolved reagents are in contact with the tailings the greater the neutralization. Since the reclaim water is reintroduced into the process so as to be able to reuse the acid any neutralization of the reclaim water represents a loss of acid. The acid is costly to import and represents the largest cost item in the processing plant operating cost list to the extent where acid consumption accounts for 40% of their operating cost. The current method of tailings management involves conventional tailings deposition and, in order to limit the contact time with the tailings and thereby reduce reagent losses, consideration is being given to two alternative methods of tailings management ie “dry” disposal and high density thickened discharge.

As in Example 1, a team is assembled to consider the broader sustainability landscape because the mining company is keen to ensure that maximum gain beyond the simple economic benefit is made out of any change to the tailings management system.

Table 4 below shows a pair-wise comparison matrix such as that which could be generated by the team. The relative performance matrix developed in Example 1 is unchanged in this example so as to illustrate the difference between the two examples. Table 5 shows the ranking of alternatives.

Table 4: Pair-wise comparison matrix – Example 2

Issues	Air pollution	Water source depletion	Water degradation	Ecosystem destruction	Ecosystem alteration	Landuse/sterilisation	Liability thru nuisance or negligence	Capital expenditure	Operating costs	Reagent loss	Energy costs	Safety issues on site	Safety after closure	Aesthetic impact	Cultural significance	Health issues - dust	Health issues - water degradation	Legal compliance	Stakeholder expectations	Adherence to Codes of conduct
Air pollution	1	1	1	6	3	1	1/3	9	9	9	9	9	9	1/6	9	9	9	9	1	1
Water source depletion	1	1	1	1	1/3	1/3	6	9	9	9	9	9	9	1	1	9	9	9	3	6
Water degradation	1	1	1	1	1	1/3	6	9	9	9	9	9	1	1	1	9	3	1	1	1
Ecosystem destruction	1/6	1	1	1	1	1	1	9	9	9	9	9	9	1	1	9	9	1	3	1
Ecosystem alteration	1/3	3	1	1	1	1	1	9	9	9	9	9	9	1	1	9	9	9	3	3
Landuse/sterilisation	1	3	3	1	1	1	6	9	9	9	9	9	9	3	1	9	9	9	6	6
Liability thru nuisance or negligence	3	1/6	1/6	1	1	1/6	1	9	9	9	9	9	9	1/6	1/6	9	9	9	1	1
Capital expenditure	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	6	3	9	9	1/9	1/3	9	9	1	1/6	1/6
Operating costs	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	6	1	9	9	1/9	1/3	9	9	1	1/6	1/3
Reagent loss	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/6	1/6	1	1/6	9	9	1/9	1/3	9	9	6	1/6	1/3
Energy costs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/3	1	6	1	9	9	1/9	1/6	9	9	6	1/6	1/3
Safety issues on site	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/9	1/9	1/9	1/9	1	1/6	1/9	1/9	1	1	1	1/6	1
Safety after closure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/9	1/9	1/9	1/9	6	1	1/9	1/6	1	1	6	1	6
Aesthetic impact	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	9	9	9	9	9	9	1	1	9	9	9	6	6
Cultural significance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	3	3	3	6	9	6	1	1	9	9	9	1	1
Health issues - dust	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1/9	1/9
Health issues - water degradation	1/9	1/9	1/3	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1/9	1/9
Legal compliance	1/9	1/9	1	1	1/9	1/9	1/9	1	1	1/6	1/6	1	1/6	1/9	1/9	1	1	1	1/9	1/9
Stakeholder expectations	1	1/3	1	1/3	1/3	1/6	1	6	6	6	6	6	1	1/6	1	9	9	9	1	1/3
Adherence to Codes of conduct	1	1/6	1	1	1/3	1/6	1	6	3	3	3	1	1/6	1/6	1	9	9	9	3	1

Numerical scale	Rating basis
1/9	Absolutely less important
1/6	Strongly less important
1/3	Weakly less important
1	Equal to
3	Weakly more important
6	Strongly more important
9	Absolutely more important

Table 5: Ranked listing of alternatives – Example 2

Rank	Alternative	Value
1	High density	0.639438
2	Dry	0.609811
3	Conventional	0.516244

It is evident from Table 4 that in this example the high density disposal system is preferred over the other two alternatives.

5.3 EXAMPLE 3

In example 3 we consider a situation where a new mine is to be located on fallow land immediately adjacent to the suburbs of a small town, in fact the boundary of the mine property forms the boundary with a housing estate. The land has no cultural significance. The community is split in their opinion on whether the mine should go ahead. Those looking for employment opportunities as well as the town fathers favour development of the mine as it will bring much needed income to the region but, naturally, those who will be living directly adjacent to the mine are concerned. They are still more concerned about the fact that the only practical site for the tailings facility is along the fence boundary and they fear for their children's safety during operation of the mine and for the long term nuisance and negligence risk that will be posed, after closure, to future generations of children who may be injured or become ill through playing on the closed tailings facility. There are other closed mines in the area and they have seen the extent of gullying and erosion from the abandoned tailings facilities.

The mine developers are keen to ensure that they maintain a sound working relationship with the residents and have espoused a strong sustainability focus in the mine development. They convince the residents to elect representatives to work join the mine team to ensure that these sustainability issues are fully considered in the selection process for an appropriate tailings management system.

The mine is located in a high rainfall, tropical area so that water supply is not a serious issue although minimization of pollution beyond the footprint of the tailings facility will be a high priority.

The team, incorporating the community representatives, get together and work through the pair-wise comparison process. The team agrees that the list of sustainability issues needs to be extended to include considerations of noise and light pollution given the proximity of the tailings facility and particularly given that conveyor systems form one of the alternatives.

Table 6 below shows the pair-wise comparison matrix generated by the team. Table 7 shows the relative performance matrix incorporating the two additional sustainability issues. Table 7 shows the ranking of the alternatives.

Table 6: Pair-wise comparison matrix – Example 3

Issues	Air pollution	Water source depletion	Water degradation	Ecosystem destruction	Ecosystem alteration	Landuse/sterilisation	Liability thru nuisance or negligence	Capital expenditure	Operating costs	Reagent loss	Energy costs	Safety issues on site	Safety after closure	Aesthetic impact	Cultural significance	Health issues - dust	Health issues - water degradation	Legal compliance	Stakeholder expectations	Adherence to Codes of conduct	Noise pollution	light pollution
Air pollution	1	1/6	1	1	1	1/6	1	9	9	3	3	9	9	3	1/6	9	9	9	1	1	1	1
Water source depletion	6	1	9	9	9	1/3	1	9	9	6	9	9	9	6	1	9	9	9	6	6	6	6
Water degradation	1	1/9	1	1	1	1/3	6	9	9	9	9	9	1	1	1	9	3	1	1	1	6	6
Ecosystem destruction	1	1/9	1	1	1	1/6	1	9	9	3	3	9	9	1	1/9	9	9	1	1	1	1	1/6
Ecosystem alteration	1	1/9	1	1	1	1/6	1	9	9	9	9	9	9	1	1/9	9	9	1	1	1	1	1/6
Landuse/sterilisation	6	3	3	6	6	1	9	9	9	9	9	9	9	9	1	9	9	9	9	9	9	6
Liability thru nuisance or negligence	1	1	1/6	1	1	1/9	1	3	3	1/6	1/3	9	1	1/9	1/9	9	9	9	1	1	1	1
Capital expenditure	1/9	1/9	1/9	1/9	1/9	1/9	1/3	1	1	1/6	1/6	9	9	1/9	1/9	9	9	1	1/3	1/6	1/6	1/9
Operating costs	1/9	1/9	1/9	1/9	1/9	1/9	1/3	1	1	1/6	1	9	9	1/9	1/9	9	9	1	1	1	1/6	1/9
Reagent loss	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	6	6	1	3	9	9	1/9	1/9	9	9	6	6	6	6	1/9
Energy costs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	6	1	1/3	1	9	9	1/9	1/9	9	9	3	3	1/3	1/6	1/6
Safety issues on site	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1	1	1/9	1/9
Safety after closure	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1	1	1/9	1/9
Aesthetic impact	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	9	9	9	9	9	9	1	1	9	9	9	6	6	6	6
Cultural significance	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	9	9	9	9	9	9	1	1	9	9	9	1	9	9	9
Health issues - dust	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1	1	1/9	1/9
Health issues - water degradation	1/9	1/9	1/3	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1	1	1/9	1/9	1	1	1	1	1	1/9	1/9
Legal compliance	1/9	1/9	1	1	1	1/9	1/9	1	1	1/6	1/3	1	1	1/9	1/9	1	1	1	1	1	1/3	1/6
Stakeholder expectations	1	1/6	1	1	1	1/9	1	3	1	1/6	1/3	1	1	1/6	1	1	1	1	1	1/3	1	1
Adherence to Codes of conduct	1	1/6	1	1	1	1/9	1	6	1	1/6	3	1	1	1/6	1/9	1	1	1	3	1	1	1/6
Noise pollution	1	1/6	1/6	1	1	1/9	1	6	6	1/6	6	9	9	1/6	1/9	9	9	3	1	1	1	1
light pollution	1	1/6	1/6	6	6	1/6	1	9	9	9	6	9	9	1/6	1/9	9	9	6	1	6	1	1

Numerical scale	Rating basis
1/9	Absolutely less important
1/6	Strongly less important
1/3	Weakly less important
1	Equal to
3	Weakly more important
6	Strongly more important
9	Absolutely more important

Table 7: Relative performance of each alternative against each sustainability issue – Example 1

	Tailings Management Alternatives		
Issue	**Conventional**	**Dry**	**High density**
Air pollution	60%	30%	30%
Water source depletion	20%	70%	60%
Water degradation	20%	70%	60%
Ecosystem destruction	40%	50%	40%
Ecosystem alteration	40%	50%	40%
Landuse/sterilisation	60%	60%	60%
Liability thru nuisance or negligence	30%	30%	60%
Capital expenditure	60%	20%	40%
Operating costs	20%	40%	70%
Reagent loss	20%	70%	60%
Energy costs	40%	40%	50%
Safety issues on site	50%	40%	60%
Safety after closure	30%	30%	70%
Aesthetic impact	20%	30%	70%
Cultural significance	50%	50%	50%
Health issues - dust	60%	40%	50%
Health issues - water degradation	20%	60%	50%
Legal compliance	50%	50%	50%
Stakeholder expectations	40%	40%	60%
Adherence to Codes of conduct	50%	70%	60%
Noise pollution	80%	30%	80%
light pollution	80%	30%	80%

Table 8: Ranked listing of alternatives – Example 3

Rank	Alternative	Value
1	High density	0.737847
2	Dry	0.710875
3	Conventional	0.468424

It is evident from Table 7 that once again the high density system would be preferred.

6 COMMENT

Incorporation of sustainability thinking into tailings management decision-making is not only vital if mining companies and tailings engineers are to become proactive about trends in tailings management but it will generate more appropriate solutions both for the short as well as the long term. One practical method for including sustainability issues in tailings design been illustrated through three examples. But, while the mechanics of the method are straight forward, and the answers immediately obtainable, what is not evident from the examples is the less tangible engendering of buy-in. The pair-wise comparison process allows disparate parties to come together as a team and to hear and understand, through an uncluttered process, the opinions of the other team members and to debate these opinions until agreement is reached. This is made possible by the fact that, at any time in the process, the team members only have to agree on whether any given issue is of more, less or equal importance than another issue or, in the case of assessment of the relative performance of the alternative tailings management alternatives, to rate the relative performances of each alternative in respect of a given issue. In so doing the impact of hidden agendas is limited and discussions remain focused.

Most importantly, the process is documented and tangible and is therefore a clear demonstration of the mining company's commitment to ensuring sustainability thinking is built into its tailings management decisions.

7 FINAL WORD

While each of the examples resulted in ranking of the high density system as the most preferred this does not mean that high density is the way to go in every situation. It is important to allow the sustainability comparison process to run its course without pre-conceived notions on what the preferred alternative may be. The efficacy of high density disposal will be dependent on a wide range of issues not necessarily embodied in the examples which have been set up only to illustrate the process. That said, it is a matter of wonderment to tailings engineers that high density disposal is not being carried out on many more sites as it truly represents a major improvement over the current, common, conventional system.

References:

1. World Commission on Environment and Development

2. Karadogan A., Kahriman A., Ozer U. *Application of fuzzy set theory in the selection of underground mining method* Jnl of the Southern African Institute of Mining and Metallurgy, Vol 108, Feb 2008