ANNEX A2

SUPPORTING MATERIAL FOR THE SIMPLIFIED RISK ASSESSMENT FOR SAFETY

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A.2.1.1. Underground mine works

Underground mining is the process of safely extracting economic mineral resources from below earth's surface. There are different kinds of underground mining methods of which long wall and room and pillar mining are examples. There are two kinds of Safety Hazards associated with underground mining i.e. rock fall and falling from elevated structures and general ground instability. General criteria for applying guidelines in order to calculate the Probability Index for Underground Mining include:

- Access to mine entry

Access is the means by which people can enter the mine either on foot or by vehicle using existing or new roads and pathways. Easy access to mine is obtained especially if the mine is partially or completely open.

The presence of security personnel, erection of fences, gates, rock barriers, caps and similar features can help in enforcing entry restriction to the old mine.

- Mine subsidence

Mine subsidence is the downward movement of a surface. The presence of dolines or uneven ground may be an indication of the development of subsidence. Knowledge (through research or interviews with local people) of the location of underground works, the geology (e.g. dolomite) and mining methods is important in determining areas that may be prone to subsidence.

- Tension cracks

Tension cracks are surface evidence of subsidence. They usually develop along the edges of the subsiding zone (Figure 1) and are produced by uneven settling of the land. Tension cracks appear when deformation occurs before sinking.

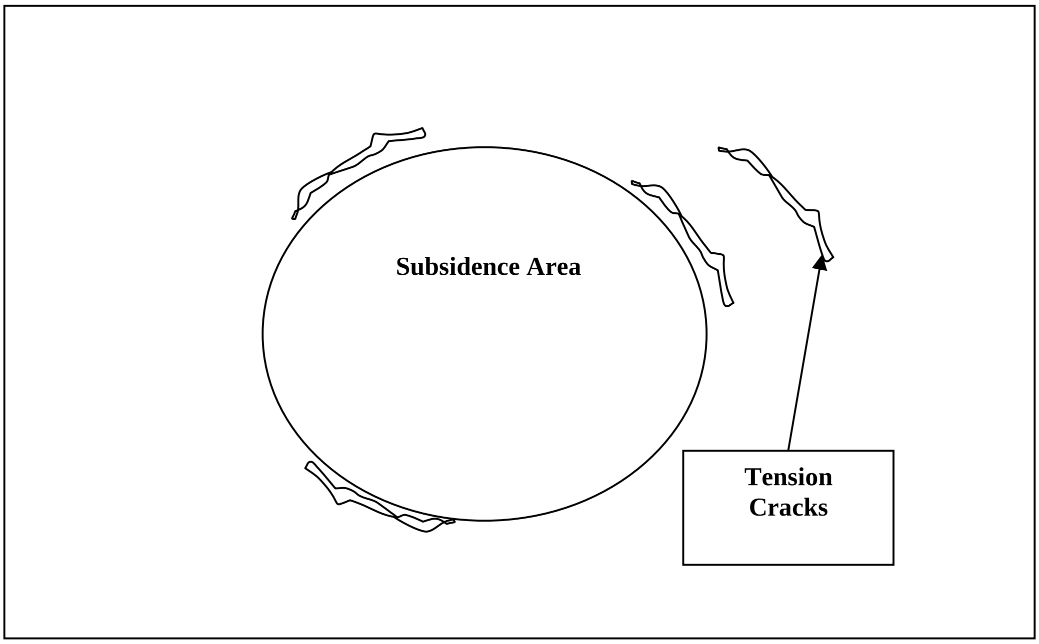

Figure 1: Location of tension cracks.

- Natural drainage.

Part of the underground mine inspection should be to verify whether the subsidence area or zones which may be susceptible to subsidence are located in areas of surface runoff. The location of mine water drainage paths is also important as they determine ways in which water enters the mine.

- Mining method

Certain mining methods create more extensive weak zones that affect the surrounding and overlying land to a greater or lesser degree, depending on the depth of the mine. Methods such as block caving or sublevel caving have a moderate influence, while mining in narrow veins has an almost negligible effect on the surface.

- Rock fall

Loose rocks, structures, or old mining equipment that are unstable could fall and harm persons. Such structures should be evaluated through observation of the condition of supporting structures. Records of previous rock falls including the presence of rock slabs on the ground, slide debris in mine tunnels and other indicators could point to possible future rock falls.

A.2.1.2. Surface mines (Open pits)

Open pit mining is the process of extracting resources from the earth by their removal from an open pit. Open pit mining like underground mining is associated with two main kinds of Potential Safety Hazard. The first is the potential of falling into the pit by people with unauthorized entry (and by livestock and game). The second safety hazard is as a result of ground instability of the abandoned works themselves. Where failures occur, the radius of influence is considered equal to one third of the maximum depth of the pit, and everything within that range from the edge of the pit could be affected by its collapse.

General criteria are provided below to facilitate the application of the Guides in Calculating the Probability Index for Open Pit Mines include:

- Unprotected open pit

Large open pits are generally easy to identify, due to their size and diameter which helps reduce the chances of anyone falling into them accidentally. Nevertheless, open pits which are not protected by some form of barrier can pose a serious hazard. Small pits and trenches on the other hand can be very difficult to see, especially if the area is overgrown, and can cause accidents to unsuspecting people, stock and game animals. Security measures including the presence of guards, fences and other barriers are important in reducing or preventing accidents from happening.

- Seismic Zone.

A seismic map showing seismic active zones and the location of the mine site in relation to the overall seismic active zones should be produced according to the available acceptable standards as required.

- Overall pit slopes

The overall pit slope refers to the inclination of the face of the pit wall or embankment. Different methods can be used to measure the slope including measurements from site plans, an inclinometer or estimation (see below). The overall slope angle is measured or estimated from the upper part of the pit edge to the foot of the pit (Figure 2).

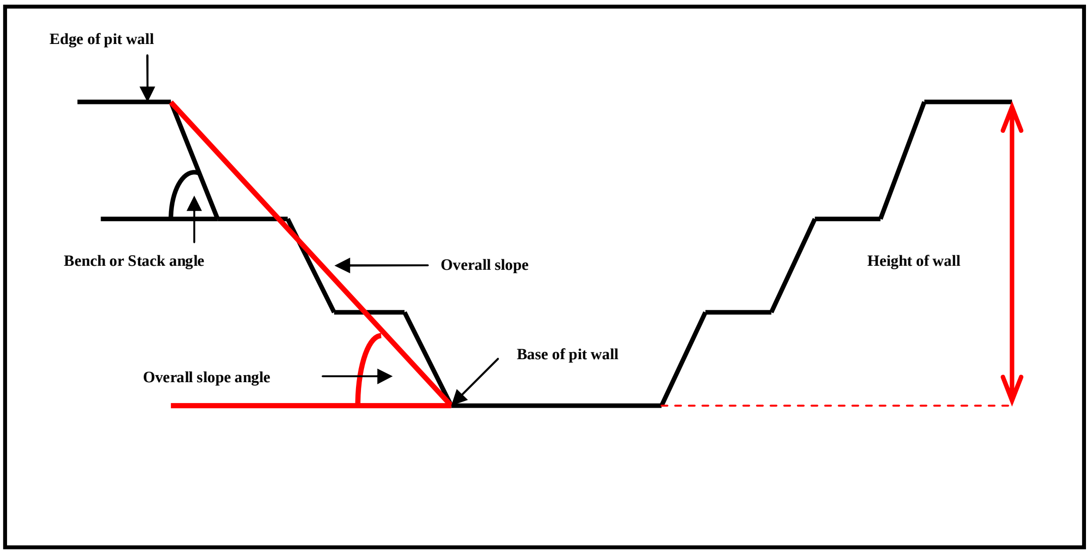

Figure 2: Overall Pit Slope

There are different methods that can be used to measure/determine the slope angle and height of a pit at a mine site.

Brunton compass or inclinometer.

1) Brunton compass with an inclinometer.

2) Ensure the compass is calibrated.

3) Once the instrument is calibrated, the edge of the compass should be projected over the inclined surface of the slope.

4) The inclinometer should be rotated until the tube bubble is centred between the lines of precision.

5) Measure the angle of inclination of the slope directly over the sights.

Procedure for measuring the height of the slope

The height of the pit wall is the difference in vertical elevation between the foot and the edge of the pit, as shown in Figure 2. This height can be measured using topographic methods or maps with contour lines, taking the estimated difference between the edge and foot of the structure. Survey methods can also be employed; either tachometric or a GPS can be used.

- Evidence of partial sloughing/failures/rock fall

Partial sloughing/failures or rock fall refer to the accumulation of rocks from wall failures or slides that occur between ramps or benches. When the slough/failure or rock fall affects more than one bench or the entire slope, then it is considered to be an overall slope failure. The presence of loose material at the foot of the slope is one indicator of its instability.

- Tensile cracks in and around the pit.

Tensile cracks form on the surface and within the pit, generally close to and parallel to the edge (Figure 3). In general they are evidence of deformations that precede failure. Their presence weakens the slope's rock structure by allowing water to penetrate; this deteriorates rock structures lower within the rock mass.

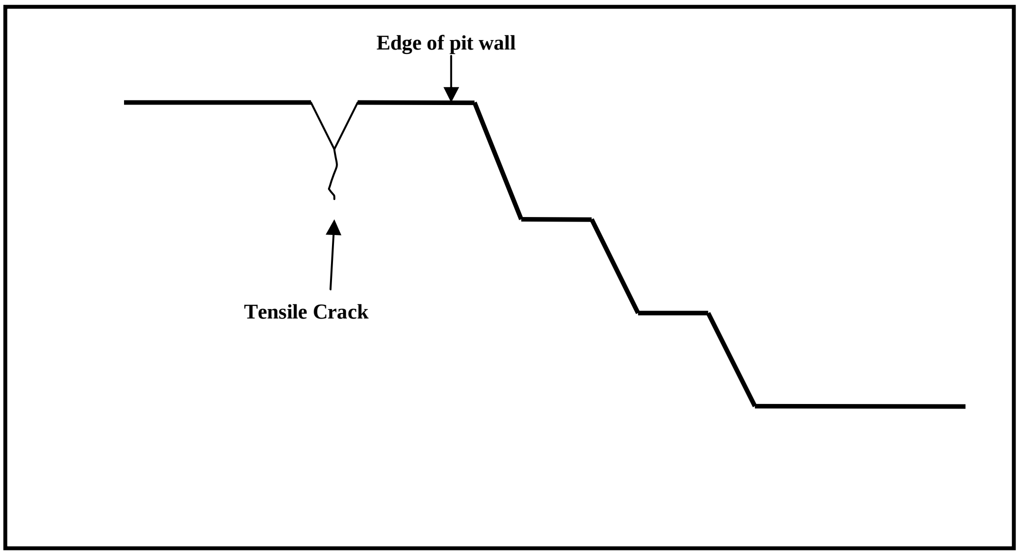

Figure 3: Tensile cracks near the pit edge.

- Presence of water table

In high precipitation zones or where the water table is naturally close to the surface, care should be taken in identifying upwelling of water in local slope walls or at the bottom of the pit (Figure 4).

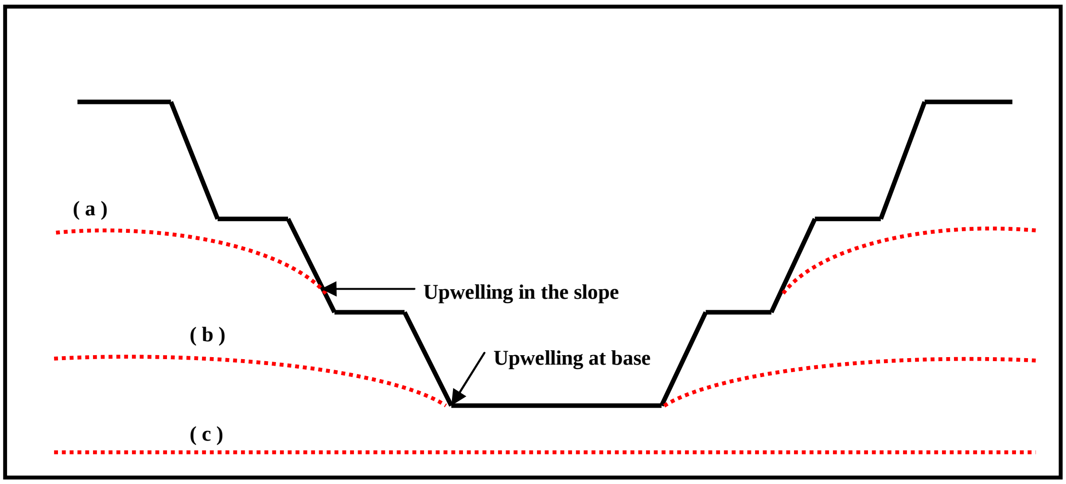

Figure 4: Location of water level in relation to the pit slope.

- Erosion ditches

Erosion ditches are discontinuities on the slope surface which results from the action of climatic agents such as rain and wind. They are considered evident when they are visible on a large portion of the exposed pit surface.

A.2.1.3. Processing plants

There are a number of safety risks that are associated with abandoned processing plants. The risks include falling of unstable structures that could cause serious injuries. Some of these risks are detailed below:

- High, unstable structures inside the plant that could easily fall and harm people

In assessing the integrity of an abandoned processing plant, the physical stability and structural characteristics must be analyzed through visual inspection in order to verify if any of the structures are in a state of disrepair and if any movement could exacerbate their collapse.

- Unsafe elements

Unsafe elements include floors with objects that could cause harm, openings that could lead to falls from elevation, broken stairs and ladders, unprotected walkways, open tanks with no escape routes, deep pools, places with little or no ventilation and all other elements that could seriously harm people.

A.2.1.4. Tailings deposits (dams and impoundments)

To characterize the safety status of a tailings deposit the Assessor should consider its construction and structural behaviour. The paragraphs below summarize some basic concepts related to these types of facilities.

- Wall building techniques

A tailings storage facility is usually constructed in stages, often using one of the following methods:

- Upstream Method;
- Centre Line Method;
- Downstream Method.

Upstream Method

The upstream method is the lowest initial cost and most popular design for a raised tailings embankment. One of the reasons for this is mainly due to the minimal amount of fill material required for initial construction and subsequent rising which normally consists entirely of the coarse fraction of the tailings.

The construction of an upstream designed embankment starts with a pervious (free draining) starter dyke foundation. The tailings are usually discharged from the top of the dam crest creating a beach that becomes the foundation for future embankment raises. Figure 5 shows a simplistic diagram of the stages of construction of an upstream raised embankment. Where the tailings properties are suitable, natural segregation of coarse material settles closest to the spigot and the fines furthest away. Cyclones can be used to accelerate this particle segregation for certain tailings characteristics to send the slime proportion to the centre of the impoundment and the sand fraction to the beach behind the crest. The conventional method of upstream raises relies on no compaction of the spigotted beach that forms the embankment shell. Today compaction by earthmoving equipment is common to increase the degree of safety of raised embankments. Generally the settled coarse fraction from the spigots/discharge point is used as the raise material for the embankments. For multiple spigot discharge a series of shallow pits are dug in front of the spigots (once the tailings have dried and consolidated) and tailings placed on the embankment crest, then they are compressed, the tailings lines lifted and reassembled then normal operation commences.

It is not surprising that the upstream method is the most common design to fail causing huge environmental consequences all over the world (ICOLD and UNEP 2001). Davies *et al.* (2000) note that there are reported to be just over 3,500 tailings dams worldwide of which 50% are of the upstream design. It was also noted that the key failure mode of upstream embankments is a static/transient load induced liquefaction flowslide event. This is not surprising considering the low relative density of the tailings and the potential for water mismanagement to generate high saturation of the embankment and subsequently creating liquefaction induced flows of the tailings.

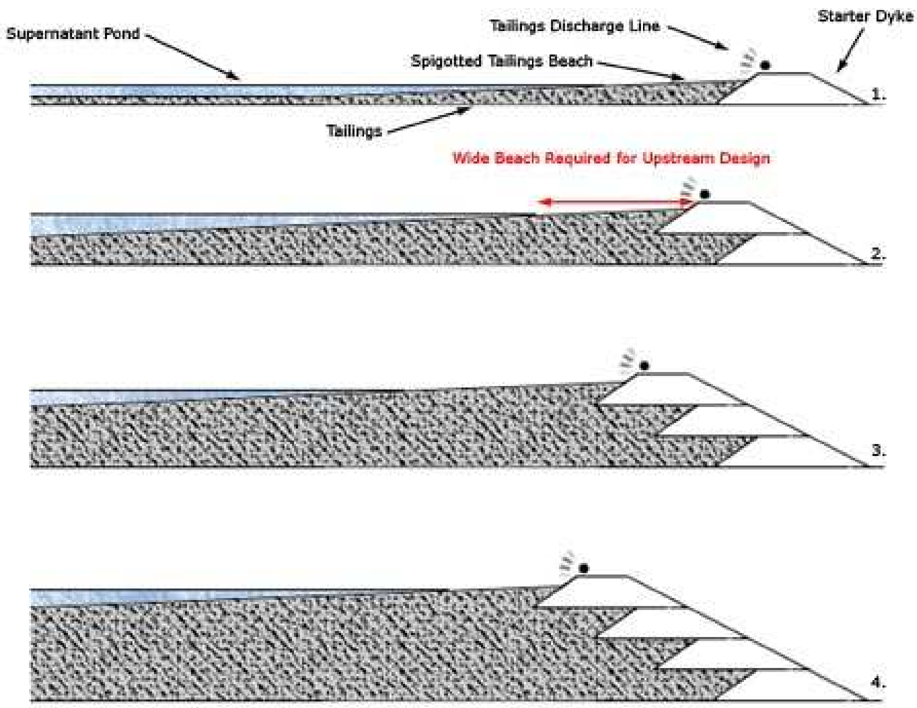

Figure 5: Upstream method of embankment construction

This coarse beach material is essential for upstream designed impoundments to aid drainage and prevent saturation of the embankments. This allows for a stronger and more permeable crest to develop which reduces the height of the phreatic surface as the embankment progressively rises. The best way to reduce the phreatic surface is to have a wide Beach Above Water (BAW) between the dam crest and the supernatant pond (free water) within the impoundment. The closer the supernatant pond is to the dam crest, the higher the phreatic surface of the embankment and thus the greater the risk of failure. The filter under-drain system of the embankments is a key component in reducing the phreatic surface of an upstream designed embankment (ICOLD and UNEP 2001).

Upstream embankments are suited to areas where the climate is arid, minimal amounts of water require storage in the impoundment and rapid water accumulation is improbable (e.g. upstream water inundation and flooding). This helps to promote wide beaches and prevent frequent water level deviations that can dramatically alter pond geometry, freeboard and the phreatic surface within the impoundment area. Upstream embankments are not suited to areas of seismic activity as the risk of liquefaction increases as a result of the potential for dynamic loading by earthquakes.

Rates of rise of upstream embankments have to be controlled to prevent increased pore pressures that can reduce the shear strength of the fill material. Excessive rates of rise have been a trigger for static liquefaction that has been the underlying cause for many upstream tailings impoundment failures.

Centre Line Method

The centre line method is really a compromise between both the upstream and downstream designs. It is more stable than the upstream method but does not require as much construction material as the downstream design. Like the upstream method the tailings are generally discharged by spigots from the embankment crest to form a beach behind the dam wall. When subsequent raising is required, material is placed on both the tailings and the existing embankment. The embankment crest is being raised vertically and does not move in relation to the upstream and downstream directions of subsequent raises, hence the term, centre line design (Figure 6).

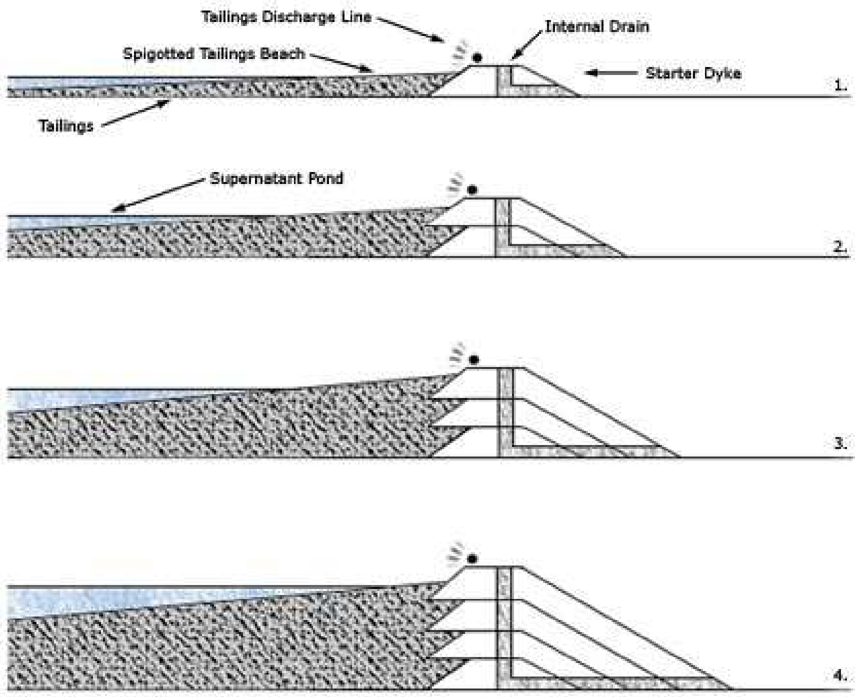

Figure 6: Centre line method of embankment construction

The design incorporates the internal drainage zones that are similarly found in the downstream method. Therefore, the free water can encroach closer to the dam crest than the upstream method without the worry of increasing the phreatic surface and causing a potential failure risk. However, a centre line dam cannot be used as a large water retention facility solely due to the subsequent raises being partially built on consolidated tailings. A suitable decant system needs to be installed to prevent the free water submerging the beach around the dam crest.

In many cases the centre line design is a good compromise between the seismic risk and the costs associated with construction.

Downstream Method

The downstream design was developed to reduce the risks associated with the upstream design, particularly when subjected to dynamic loading as a result of earthquake shaking (ICOLD and UNEP 2001). The installation of impervious cores and drainage zones can also allow the impoundment to hold a substantial volume of water directly against the upstream face of the embankment without jeopardising stability.

The downstream embankment design starts with an impervious starter dyke unlike the upstream design that has a pervious starter dyke. The tailings are at first deposited behind the dyke and as the embankment is raised the new wall is constructed and supported on top of the downstream slope of the previous section (Figure 7). This shifts the centre line of the top of the dam downstream as the embankment stages are progressively raised (Vick 1990). An advantage to the downstream design is that the raised sections can be designed to be of variable porosity to tackle any problems with the phreatic surface of the embankment. This can be particularly useful where a processing plant has made changes to increase efficiency and as a result, the tailings characteristics may be altered. This may result in pumping more water to the tailings facility or alter the drainage characteristics of the newly deposited tailings.

The downstream design is very versatile for a range of site specific design parameters and behaves similarly to water retention dams. Their main advantage is that the downstream design can have unrestricted heights due to each raise being structurally independent of the tailings. The main disadvantage is the cost of raising the embankment as large volumes of fill are required which increases exponentially as embankment height increases, and subsequently a large area around the dam itself is required as the toe of the dam moves out as more raises are added. This can cause problems where limited space has been taken into consideration prior to building, or if property line and utilities are in close proximity. Although a downstream embankment can theoretically have no height limit, the dam's ultimate height is determined by the restriction of the advancing toe.

- Deposition methods

Spigots

Spigot disposal (normally sub-aerial) is used where the tailings are discharged generally around the perimeter of the tailings facility to create a beach between the embankment and the supernatant pond. This generally means the pond is completely surrounded by beached tailings (Figure 8). The spigots are changed over as set out by the deposition plan to promote bleeding and drying prior to further layering and raising. It is essential that a deposition plan be established during the design stage and implemented and managed throughout the operational stage.

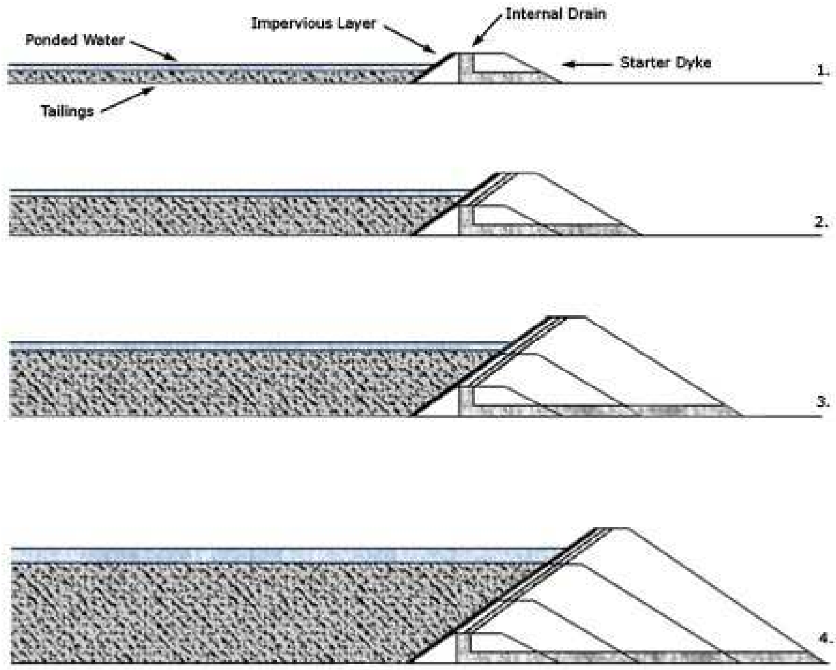

Figure 7: Downstream method of embankment construction

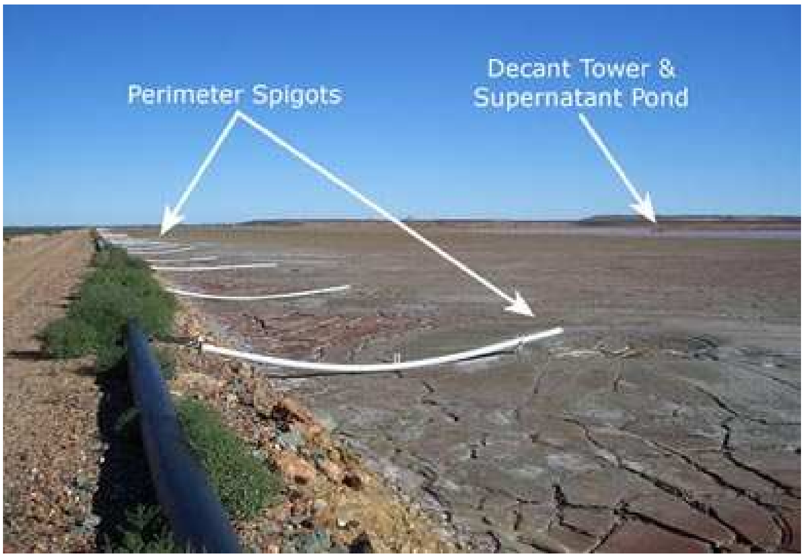

Figure 8: Multiple spigot discharge at the Jundee Gold Mine, NT, Australia

The ideal spigot spacing can be determined by deposition trials to establish likely beach slope angles and widths. Incorrect spacing can lead to undulating beaches between spigots that can ultimately reduce the efficiency of tailings deposition.

Multiple sighting creates pipework management challenges as blockages and ruptures can occur. Monitoring and maintenance schedules are also intensified to ensure that tailings are being delivered to the correct areas, for the correct time period and in the intended quantities. Normally multiple spigots are small diameter pipes that feed off ring main configurations (sometimes known as distribution lines) that then feed off the larger diameter main delivery lines from the plant. The pipeline size reduction ratios and incorrect flow velocities can lead to sanding and plugging of lines. Valve stations and flushing lines are also required for multiple spigots to allow lines to be flushed to prevent sanding after they have been shutdown.

Multiple spigotting helps to reduce the discharge velocity of the tailings being pumped to the storage facility compared to single point deposition. This helps to promote laminar rather than turbulent flow allowing the coarser particles to settle nearer the spigot creating a greater drainage potential. This will also promote a slightly steeper angled beach that will aid the removal of fluids from tailings deposited near the spigot.

Single point

Single point discharge requires irregular movement of the discharge lines. Vick (1990) reports that deltas are normally formed or a single beach deposit of tailings is created within the impoundment (Figure 9). This normally means that the supernatant pond is restrained to a certain area of the impoundment which may be against one of the embankment walls resulting in high and low ends of the impoundment. The lower end of the impoundment will collect the slimes increasing the possibility of seepage erosion. This type of deposition is not suitable where the pond and/or the slimes must be kept away from an embankment.

Figure 9: Single point discharge at Glebe Mines, Derbyshire, England

Single point deposition can place the tailings in fairly thick layers causing the tailings to remain saturated for years if not dried before new layers are deposited. This method of deposition is suited to valley type impoundments (downstream and some centre line embankment designs) where the supernatant pond can be forced to reside against a valley face (i.e. against the hillside away from the retaining embankments)

- Water balance and release

Establishing a stable water balance for a TSF during the design stage is one of the most important considerations to prevent water management problems occurring during operation and closure. Water plays a key role in the day to day responsibilities of a tailings operator and it is essential that a facility is designed to handle and control the required inflows and outflows as well as any unpredictable fluctuations (e.g. storms). Poor design of water management infrastructure and control methods can increase the risk of problematic situations occurring during the operating and closure stages (e.g. upstream inrushes, pipe bursts, low freeboard, seepage). During operation the plant will also demand a certain, and sometimes variable, flow of water that the surge capacity of the decant systems and reclaim/holding ponds have to cater for. Any water balance survey for a proposed tailings facility should take into account that higher volumes of water may require storage during the dry season to maintain plant production. Ice and snow melt, upstream inundation (valley impoundment) and severe storm reoccurrences (e.g. 1 in 100 year) should be considered when designing a TSF to prevent any loss of minimum freeboard levels.

When determining the water balance the various inputs and outputs of the proposed TSF will need to be considered. Wels et al. (2003) noted that determining the water balance of a tailings storage facility can be a difficult task if all the physical processes of water movements are to be considered. During the design stage a conceptual water balance of all inflows and outflows should be determined for a particular location and include all the worst case combination of risk factors (e.g. decant failure, storm, upstream snow/ice melt). A simple and accurate method to determine water balance of a TSF is to determine average annual water inflows and outflows as well as estimating seepage and evaporation rates. A more complex method is to use hydrogeological modelling methods. Estimating the phreatic surface will help to determine seepage plumes and groundwater movement. Figure 10 shows the various water gains and losses for a typical conventional TSF. The seepage and evaporation losses will be predictions and should be included in any design proposal.

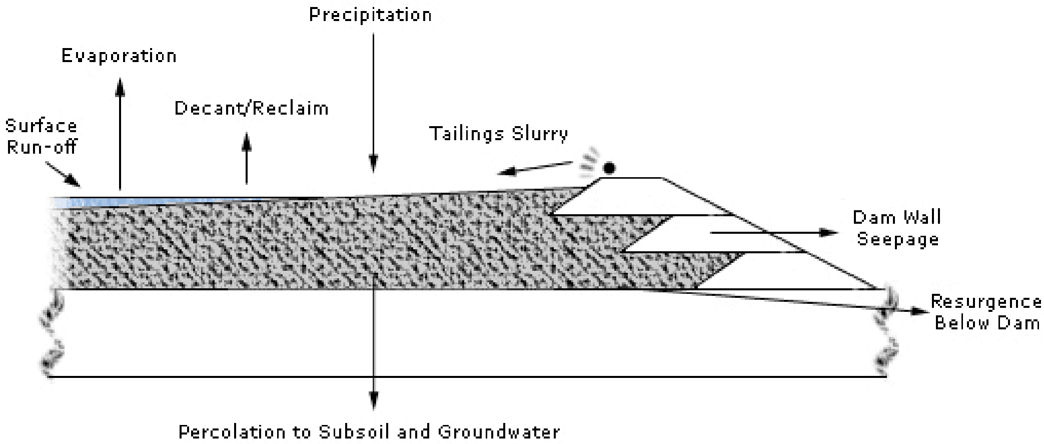

Figure 10: Water balance of a typical conventional tailings storage facility (Adapted from Vick, 1990)

Water stored in a tailings facility is either decanted to reclaim ponds or sent directly to the processing plant. If the plant requires none or only a small volume of the stored water then the remainder will need to be either sent to evaporation ponds or treated and discharged to the environment.

- Supernatant pond

The control of the supernatant pond is probably one of the most important procedures in managing a TSF. Inadequate pond control can result in overtopping, increase in pore pressures, reduction of freeboard, high seepage rates and embankment settlement. These few consequences can lead to instability and high risks of problematic situations occurring. For a conventional impoundment (particularly upstream and centreline designed) it is essential that the ponded water be kept to a minimum volume and the freeboard be sufficiently high all along the tailings embankment(s). Suitable monitoring and management of the supernatant pond is required to operate a TSF safely.

- Decant systems

The decant system(s) of a TSF should be designed to cope with the day-to-day management of the supernatant pond as well as storm condition surges. The design of the decant should allow for a high surge capacity of storm water to compensate for near future storm events. If the pond cannot drain fast enough (decant system or reclaim/evaporation pond ingress restriction), then the freeboard of the TSF may be lost if a near future storm reoccurs. As a guide the decant system should be able to remove storm water in 2 – 4 weeks, but this is highly dependent on climate conditions.

The two most common methods of water control within a tailings storage facility are a decant barge and a decant tower. A decant barge consists of a floating platform that houses the pumps used to reclaim water from the supernatant pond back to the processing plant or holding ponds. A decant tower is an intake structure consisting of a vertical hollow tower (riser) that is connected to a horizontal conduit or pipe that normally travels beneath the impoundment and through/under an embankment. The vertical riser is extended as the level of tailings in the impoundment rises. The decant tower skims off the clear water from the surface of the supernatant pond and carries it away by gravity through the underlying conduit.

- Decant tower

Decant towers (Figure 11) can be very effective at removing ponded water from a tailings facility but can be very problematic. Decant tower systems come under increasing stress as more tailings are disposed of in an impoundment. The ever increasing weight of the tailings can crack and damage a decant conduit that flows underneath and through an impoundment facility. Failures of decant conduits and towers can lead to water management problems that have caused impoundment failures in the past (ICOLD and UNEP 2001). It will not be immediately apparent to an operator that a decant system has failed until the decant outfall is showing signs of low flow or the presence of sediment (tailings). Water levels in the impoundment can rise rapidly and overtopping can occur if contingency plans are not implemented. The Stava disaster in Italy in 1985 was a good example of a decant conduit failure that created a rise in the phreatic surface of the embankment. A rotational slip occurred causing tailings from the upper impoundment to inundate the lower impoundment which eventually overtopped and failed. Tailings escaped down the hillside engulfing the town of Stava claiming the lives of 269 people. Stava remains as one of the world’s worst tailings disasters in terms of loss of human life.

Figure 11: Decant tower with walkway (left), view inside the tower showing riser pipe and submerged decant collars (right).

One major disadvantage to a decant tower is that the water has to be continuously positioned around the tower as unlike a decant barge a tower cannot be relocated. If a decant tower becomes inoperative (beached tailings moving the pond away from the tower) then emergency pumping or spillways will need to be implemented. Any tailings facility operating plan should have precise contingency plans documented in case a decant tower becomes inoperative either by isolation, blockage or failure.

Cracking of a decant conduit can cause internal erosion which will eventually lead to impoundment instability. Repairing the buried conduit is a near impossible task and far too expensive to carry out. The Aitik tailings dam failure in Sweden was triggered by a damaged concrete decant conduit. Cracks developed causing settled tailings to pipe through creating a sink hole. Figure 12 shows the extent of the breach and the cracks in the washed away conduit.

Figure 12: Aerial view of the embankment failure at Aitik (left) and the cracks in the decant conduit (right).

- Decant barge

Unlike decant towers that are gravity fed, a decant barge (Figure 13) requires power to operate the pumps that decant the water from the supernatant pond. This increases operating costs as a constant and reliable power source is required to ensure the pumps operate. If a power failure occurs then no water can be decanted. It is good practice to have standby pumps and diesel generators to use in emergency or when a decant barge cannot cope with rapid ingress (e.g. storm conditions or when process water is required in vaster quantities). Before power or equipment failures occur there should be emergency procedures and response plans to rapidly mitigate any decant problems that can be implemented in both normal and storm conditions.

Figure 13: Fixed decant barge (left) and a mobile barge (right).

The capacity of the barge(s) should be adequate enough to remove day-to-day decant demands as well as storm water accumulation. The barge should also be situated in an easily accessible location for maintenance and inspection purposes. Ideally this should be against the side of a valley wall (for a valley impoundment), or against the side of a jetty wall (either floatable walkway or purpose built) in an area of the impoundment where the ponded water is at its deepest. The water depth below the barge can influence the clarity of the decant water and prevents tailings being sucked up by the barge.

A decant barge or submersible pump can be moved as the decant pond location changes and/or the tailings volume increases. For valley impoundments or in-pit disposal the decant barge or pump is generally retracted to keep the equipment close to the valley or pit walls. This makes it easier to access and prevents the use of heavy anchoring to control varied movement which can be expected the further away the equipment is from surface anchoring points. Each time a barge is moved to other cells the plant water demand should be calculated to ensure the barge is capable of meeting the demand from the water in the new cell.

- Reclaim pond(s)

The reclaim pond(s) (or return pond(s)) store the water that is being decanted from the tailings dam. Reclaim ponds are sometimes referred to as decant ponds which in most parts of the world is another name for the supernatant pond. A reclaim pond is situated outside the confining walls of the tailings storage area a short distance away (

Figure **14**). The water in the reclaim pond is either sent to treatment/polishing ponds for discharge to the environment or pumped back to the plant for use in the processing operation. Some reclaim water can be sent to evaporation ponds or sprays if the climate is suitable.

Figure 14: Reclaim ponds at Kalgoorlie, Western Australia.

The reclaim ponds should be suitably sized to balance the water inflows from the TSF's supernatant pond with the normally variable outflows to the plant. For this reason the reclaim ponds can vary in volume and so an adequate depth is required to prevent overtopping and ensure the return pumps have sufficient head. The surge capacity should also be adequate to remove storm water flow rates from the TSF. This should be similar to the TSF's (2 – 4 weeks depending on climate conditions) to allow for reoccurring storms. This should be checked against the plant volume requirement and overspill/evaporation pond volumes.

The degree of design specification will be determined by the quality and quantity of the return water. The ponds will need to be suitably lined to prevent groundwater contamination (e.g. clay or normally HDPE/LLDPE lined). Prior to installation, the liner system should be checked to determine if the decant liquor will cause any chemical degradation. This is particularly true for HDPE where even UV radiation can degrade the liner (SANS 1998).

Reclaim ponds are particularly useful for tailings facilities that utilise the subaerial deposition technique as the supernatant pond can be drained into reclaim ponds increasing the beach exposure. This aids the drying and consolidating rates of the tailings in the TSF.

- Freeboard

Normally the minimum freeboard is determined by national/local legislation and/or company policies. It is essential in the design stage that water balance calculations take into account average and extreme conditions to prevent loss of freeboard during operation.

Freeboard is used to establish the elevation of the lowest point of the embankment crest relative to the normal or maximum operating levels of the supernatant pond (SANS 1998). Freeboard (Figure 15) management is a critical factor used to control water of a conventional tailings storage impoundment (DME 1998). To promote good drainage of the embankments, the supernatant pond has to be as far away from the embankments as possible (maintain a high freeboard and wide beach). Ideally the pond should be of a small area, to reduce seepage, and be at a maximum depth at the decant facility to improve reclaim water clarity.

Figure 15: Loss of freeboard (left) and high freeboard (right). (Right picture courtesy of Anglo America)

The definition of freeboard varies in tailings guidance and legislation documents around the world. Confusion can arise where the freeboard is interpreted as the vertical height between the pond and the top of the beach OR the top of the embankment crest. This is further confused where the embankment crest is measured as the external rather than the internal height. The correct definitions of freeboard are (DME 1999):

Total Freeboard (freeboard) – The vertical height between the waterline and the top of the embankment crest (internal). Total freeboard (freeboard) = beach freeboard + operational freeboard 56

Beach Freeboard – The vertical height between the waterline and the beached tailings against the embankment crest.

Operational Freeboard – The vertical height between the beached tailings against the embankment crest and the crest itself.

The following (Figure 16) are diagrams explaining freeboard:

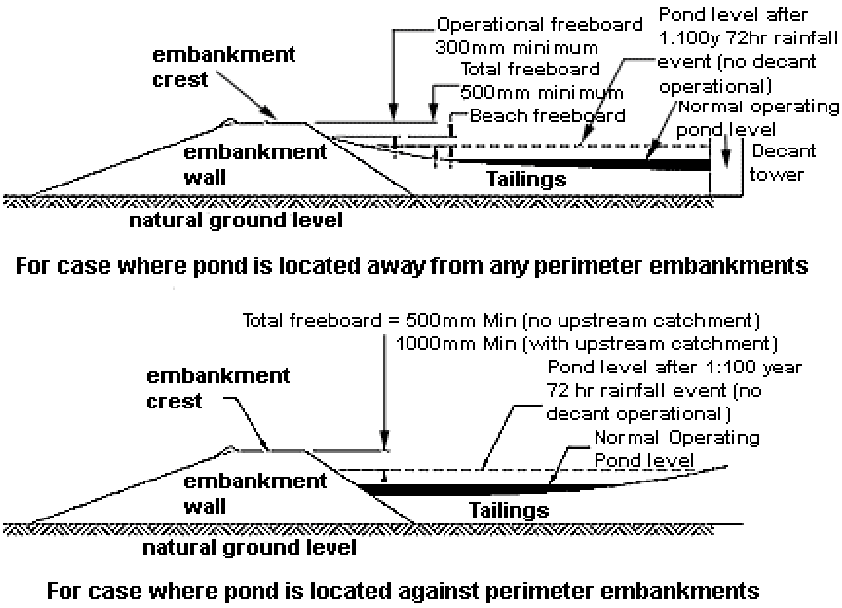

Figure 16: Freeboard of a tailings facility explained (Adapted from DME, 1999)

The freeboard limit for a TSF depends on the type of embankment raising, the method of deposition, geographical location, beach angles (if any beaching occurs), regulations, and the climate.

The use of wing walls around a decant tower can help to prevent the movement of a supernatant pond away from a tower and give more control over its location. This lowers the risk of a pond encroaching an embankment and subsequently lowering the freeboard. Wing walls are particularly suited to arid climates and TSF’s that experience minimal water balance changes (e.g. no high inflow fluctuations).

- Storm considerations

The design of a TSF has to cater for storm events both during and after operation. The storm conditions vary depending on the climate, but as a guide the TSF’s minimum freeboard should not be met even after a 1 in 100 year, 72 hour duration storm (DME 1998). Suitable storm condition mitigation measures should be in place if the minimum freeboard will be lost during a storm event. Typical mitigation measures are emergency spillways, overflow/storage ponds and emergency decant facilities (e.g. floating pumps).

The impacts of a storm on a TSF are not just specific to the impoundment area but also the surrounding environment. Suitable mitigation techniques will need to be in place to prevent storm water eroding and inundating a TSF. For a valley impoundment this is more difficult compared to the ring dyke facility. In this case, spillways and diversion channels will be required to prevent inundation and the risk of overtopping.

- Seepage control

Seepage flow through the tailings stored in a surface impoundment is inevitable. Vick (1990) notes that zero discharge of seepage from a tailings facility remains an elusive goal, even with complex liner systems. For this reason the control of seepage is an important water management requirement both during the operational and post-operational phases of a TSF (DME 1998). The design stage of a tailings storage facility should take into account seepage control methods to ensure the facility remains perpetually stable and that environmental regulations are not compromised, even after closure.

Seepage can be controlled by using either barrier or collection systems. Barrier systems retain or resist the flow of seepage outside the impoundment area whereas collection systems intercept and safely focus the seepage as it leaves the tailings storage facility. Barrier control methods consist of liners and embankment barriers to prevent or hinder seepage passing through the tailings containment area and into the surrounding environment. Collection methods create pathways for the seepage to accumulate then flow to controlled locations such as embankment and toe drains. Other types of collection systems intercept the seepage as it migrates into the environment by using extraction wells and ditch systems.

The monitoring of seepage is an essential part of any tailings management strategy to understanding how the facility is performing within. Visual inspections of a tailings facility can determine the superficial operations (e.g. pond control, discharge management, pipework integrity) but the internal performance of a TSF can only be identified by monitoring changes and anomalies of the seepage effluents. Understanding seepage can determine the consolidation of the tailings, high seepage pathways (e.g. caused by liner damage or internal erosion), and groundwater contamination and movements (e.g. plumes).

Lowering the water content of the delivery tailings can help to reduce seepage as the water handling and storage volumes of the TSF are reduced. One of the reasons for utilising thickened, paste and dry stack tailings storage is to reduce and even eliminate the water management requirements associated with conventional impoundment storage. Fourie (2003) notes that this lowers evaporation and seepage losses and reduces the potential for groundwater contamination, as there is less moisture present in the deposited tailings and no supernatant pond.

- Phreatic surface

The phreatic surface is essentially the water table in the tailings and is defined as the position between the zone of saturation and the zone of aeration. The exact level at where the phreatic surface resides is the point where the water rises have pressure equal to that of atmosphere.

The stability of a tailings embankment under static and seismic loads is influenced by the position of the phreatic surface. For long term stability, tailings embankments rely on the drawdown of the phreatic surface and therefore adequate internal and under drainage systems should exist. Essentially, the phreatic surface can be successfully controlled by using materials of differing permeability within the embankment. Drainage zones and low permeable cores are common methods of controlling material saturation. Vick (1990) reports that the objective of prime importance is to keep the phreatic surface as low as possible in the vicinity of the embankment face. It is important that the properties of the materials used in the embankment zones are adequate and that low permeable cores will not crack and allow seepage through, and that drainage zones will not clog and become inoperative (ICOLD and UNEP 2001).

- Internal embankment zones

Blanket and chimney drains are the most common types of drainage zoning to use in tailings embankments. A chimney drain is a vertical or inclined zone that captures lateral seepage flows, and a blanket drain runs along the base of the embankment. Chimney drains are usually connected to the blanket drains to aid the flow of seepage migration. Finger drains are similar to blanket drains but are not continuous. They can be used in areas of high seepage (e.g. where water is designed to be against the upstream face).

Internal filters are required to prevent fines washing through into drainage zones and creating internal erosion. The Omai tailings impoundment failure of 1995 occurred as a result of inadequate internal filters. Synthetic materials such as geotextiles may be used if suitable filter material is not available locally or is too expensive to import. It is important to realise that the filter material should be adequate to prevent piping as well as drain the embankment, thus lowering the phreatic surface. If an unsuitable filter is chosen the filter may become clogged rendering the drain useless.

All drainage zones installed during tailings embankment construction need to be suited to the particular effluent and tailings characteristics. If for example seepage effluent has suspended particles then the drains may become blocked over time and render them useless. If coarse limestone is used for the drains and effluent of a low pH were to pass through, then erosion of the drains can cause instability of the dam wall, thus increasing the risk of catastrophic failure.

For downstream and centre line embankment design the use of low permeable cores can help to reduce the phreatic surface of the embankment. It is essential that the ratio of permeability be such that the embankment can drain easily compared to the seepage entering from the low permeable cores. Vick (1990) reports that cores are essential for embankments that are designed to have water against the upstream face.

- Collection systems

The two main methods used to collect seepage from a tailings impoundment are a collection ditch or a collection well (Figure 17). Ditches are the most common and cheapest method of entrapping seepage with the idea of eventually pumping the seepage back into the dam. A collection ditch is usually dug around the perimeter of a ring dyke impoundment, or at the toe of an embankment wall allowing the seepage to flow through the pervious strata material underneath the impoundment to the ditch. The return system to the impoundment can simply be a submersible pump that steadily removes the seepage, and thus allowing more to import through the pervious layer into the ditch.

Figure 17: Seepage collection ditch (left) and a seepage well (right)

A collection well is basically the same as a dewatering system for a mine, in that a cone of depression is created when pumping starts. Several wells can be installed around the impoundment in the same vicinity as a collection ditch. The effectiveness of the well depends on the permeability of the soil, and the depth of extraction. Such wells are expensive to install and each well has to be pumped dry and so a ditch is preferred. Collection wells can be installed at the toe of a tailings embankment to reduce the phreatic surface. The well creates a drawdown through the dam wall and can help increase the strength of the embankment. This can be used as a remedial measure for an embankment with drainage problems, and/or where there is a risk of a liquefaction event occurring.

A.2.1.5. Heap Leach Waste

Estimating the Probability Index (PI) for Hazard Scenarios related to heap leach residue dumps is very similar to that of tailings storage facilities. As a result, the supporting information for calculating PI can be found in the sections above. Some aspects specific to heap leach residue dumps are discussed below.

- Presence of drainage systems (pipes, drains)

Most heap leach **residue dumps** are developed on a lined surface with sub-surface drainage systems to manage the phreatic surface within the heap and to ensure the stability of the heap leach pad.

The solution collection system consists of a redundant system that is comprised of a solution collection piping network placed directly on the geomembrane, and is within a free draining granular overliner material.

- The overliner for the HLP should be designed to account for the following:
    - Static Loading (maximum ore depth)

  - Construction loading (dissipate construction loads and prevent construction equipment damage to the geomembrane during overliner placement)

  - Dynamic Loading (ore loading from truck or track mounted ore stacking and reclaiming system)

- A key issue that impacts the performance of a HLP is the long term performance of the overliner material

- For an on-off HLP, the performance of the overliner is particularly sensitive to a low permeability boundary that can be created at the ore and overliner interface from one, or a combination of, the following:

  - Reclaim stacker compacts the surface

  - Breakdown of particles from the repeated trafficking of the track mounted stacking and reclaiming equipment

  - The migration of fines from the ore through the leaching process

In addition to increasing the solution recovery time, would increase the thickness of the saturated zone in the ore and stability

A.2.2 CONCEPTS ASSOCIATED WITH ASSESSING THE SEVERITY OF CONSEQUENCES

A.2.2.1. Open Pits

Slope failure in an open pit may cause harm to anybody or anything in its vicinity. To quantify the area that could be affected by a slope failure, the following general criteria should be applied:

Radius of influence of the pit (m) = Total depth (m) / 3

Where: 3 is a non dimensional term.

A.2.2.2. Tailings (ponds, dams and deposits)

To assess the consequences of a release of tailings it is necessary to estimate the area that would be affected by the released tailings and/or the distance they would travel. One way of calculating the hazard Distance (D) is as follows:

$$\mathbf{D = 2 \cdot 10^{-6} T \cdot i}$$

Where:

I = the hydraulic slope expressed as a %

T = tons of material in the deposit, including fine and coarse tailings susceptible to liquefaction

An alternative formula that could be used to calculate the general area that could be affected by the sudden release of tailings is as follows:

Area covered by Tailings (m^2) = Volume Stored (m^3) / 1.5

In using the above formula to more precisely estimate the potential area affected by the sudden release of tailings, a number of factors that should be considered are outlined below:

- Volume of Tailings Stored: The volume of tailings stored is directly proportional to the surface area that would be covered if the entire deposit was released. It can be assumed that greater volumes of tailings can ultimately cover a larger area. This value should be estimated.

- Natural Slope: Places with a steeper slope or drop will result in faster movement of tailings. This implies that the tailings will travel a greater distance and have a higher carrying capacity and therefore destructive potential than when they are released on flat terrain. In addition, the area of impact of the released tailings would be limited to the area down slope of the dam, as the driving force would be gravity. In general, the route that released tailings follow is determined by the local drainage system. Estimating the direction in which the tailings will travel is crucial for determining which receptors could ultimately be affected by a release event.

- Geomorphology of the site: Topography can play a major role in determining the consequences of this kind of event. The movement of tailings stored in ponds located in narrow valleys is limited by the walls of the valley, and the area affected will be focused downstream. In contrast, tailings in ponds located in open areas could disperse laterally, thereby reducing the distance that the tailings are transported for the same volume of material released.

- Distance to Receptors: An important factor when assessing the consequences of potential hazard related to tailings deposits is the distance from receptors, especially the distance from local communities or populated areas.

A.2.2.3. Hazardous Waste

The consequences of Potential Hazard associated with hazardous waste is based on the toxicity of the substances stored, which is regulated by the draft Pollution Control and Waste Management Bill. This Bill lists all chemicals considered acutely toxic, flammable, corrosive or explosive; as well as waste catalogued as hazardous. Until such time that the Bill is enacted and Regulations are published, the information contained in the International Maritime Dangerous Goods Code can be used to determine the Severity of the Consequences in cases where people come into direct contact with the respective substances. Based on this rating, the public safety scale can then be applied.