

# Technical and operational considerations for the design of filtered tailings storage facilities in heavy precipitation areas

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## ABSTRACT

Most of the mining operations or mining projects in Peru are located along the Andes, marked by its aggressive topographical conditions, which is a challenging environment for the design of mining facilities, including filtered tailings storage facilities, but especially because of the heavy precipitation conditions which significantly complicates the filtered tailings disposal process, making it necessary to take into account certain technical and operational aspects during the design process.

Filtered tailings disposal is a relatively new technique which optimizes the use of water to reduce water losses, reduces the risk of failure of the facility and minimizes the disposal area. Reduction of failure risk is given since the water content is low enough and the tailings are placed compacted, preventing the buildup of excess pore pressure. However, a filtered tailings project implies relatively high capital costs (costs of the filtration plant mainly) and operation costs, requiring an adequate management of rainwater and strict control of the tailings arrangement. These costs are offset by water saving considerations. Cost considerations combined with the complexity associated with the operation of filtered tailings are highlighted by the fact that there are few mining projects with filtered tailings disposal in the world with high precipitation areas, where water savings are of a lower priority, from which we can learn and extract important experiences.

This paper aims to discuss the water management and technical and operational considerations for the design of filtered tailings storage facilities in wet climate conditions, based on experiences in the development of such projects in some mining companies in Peru.

**Keywords:** rainy areas, filtered tailings, raincoats.

## INTRODUCTION

Most of the mining units or mining projects in Peru are located along the Andes Mountain range, where the relief conditions, in some cases, make it difficult to find areas with the sufficient storage capacity for conventional tailings (thickened or pulp). In other situations, the need to recover the largest amount of water, to impact the low amount of land suitable area or the lack of sufficient space to develop tailings storage facilities projects is critical. Under such conditions, filtered tailings disposal represents a good alternative for tailings storage for many mining projects. In addition, filtered tailings disposal significantly reduces the risk of installation failures and the implicated negative impacts, as it requires water usage optimization

during mining operations both to save water as well as ensure that the tailings can be raised at a the required rate without a build-up of excess pore water pressures. However, filtered tailings disposal requires high capital and operating costs. While, in some instances, these costs are justifiable on the basis of water savings, in areas of water abundance the high costs often result in projects being unfeasible, particularly considering in addition, the complex Andean weather conditions (rain, solar radiation, wind, among others). Consequently, a storm water management system must be implemented, for contact and non-contact waters, and a cover or additive irrigation system must be considered to prevent dust emission from the exposed tailings slopes.

The tailings are usually fine grading and of low shear strength, therefore the deposited tailings must be compacted to increase its strength, especially in seismic areas. However, equipment accessibility to areas like the bench and slope crests can result in poor compaction, resulting in sludge-like slides along these sections during heavy precipitation periods especially towards the lower section of the storage facility. For this reason, the design should consider the provision of additional dyke or berm free board which will allow the control of this issue.

This article aims to show the technical and operational considerations that are taken into account during the design of filtered tailings storage facilities, based on experience acquired developing such projects in Peru. The article focuses on the following topics: contact and non-contact water management, use of cover systems, operational parameters specifications, and operational aspects, among the most important.

## DESCRIPTION OF THE INSTALLATION

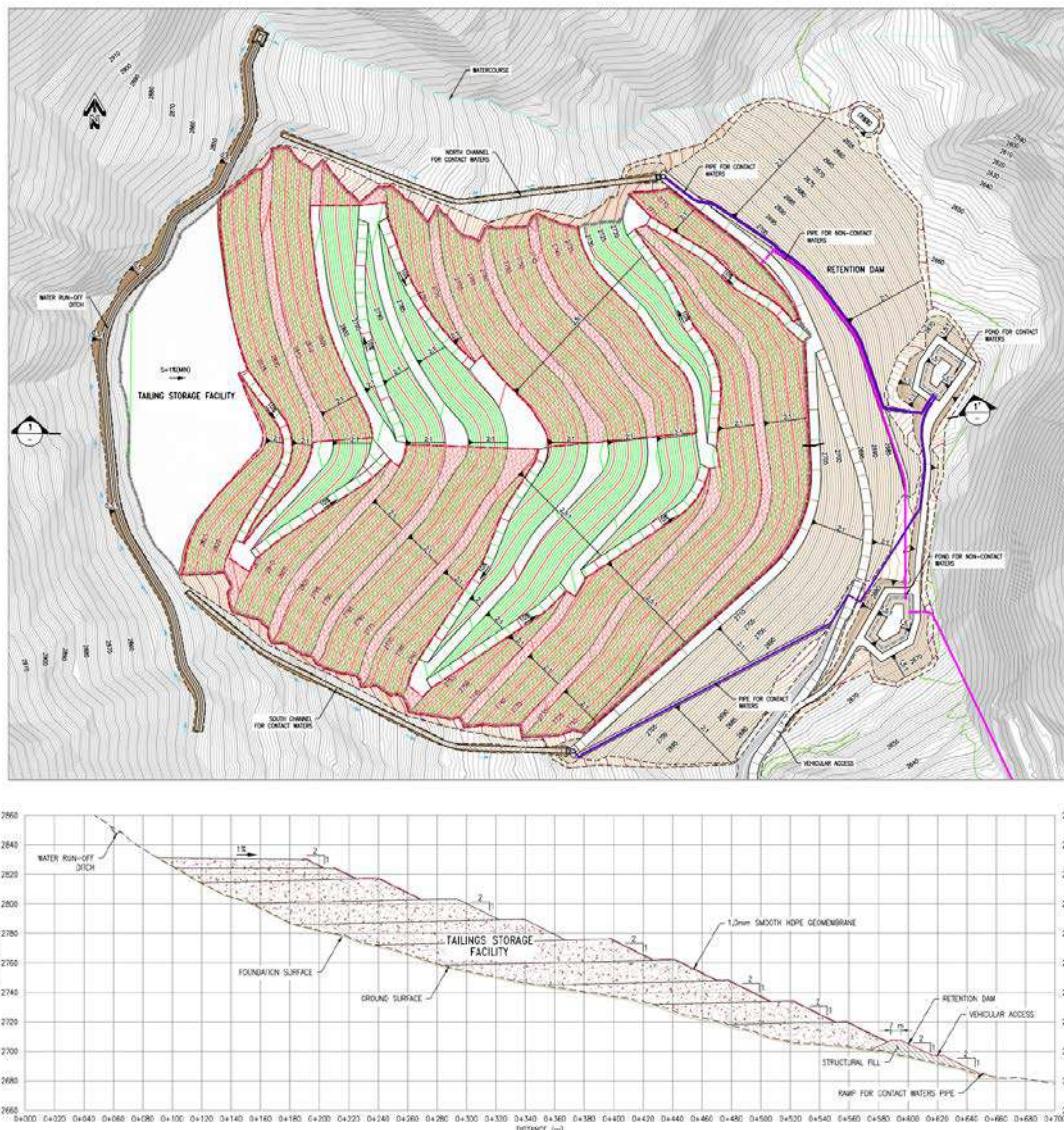
The filtered tailings storage facility construction described in this paper is being designed in an area of Peru with high precipitation during the wet season, called amazon forest rim, where wet forests occur. The average annual precipitation in the area of the project is in the order of 1200 mm with an average altitude of 2700 masl. In addition, the filtered tailings storage facility construction area evidences steep slopes which mean a greater challenge for the geotechnical, civil and hydraulic design.

The filtered tailings storage facility consists of a retention dam, contact water pond, and a non-contact water pond. The filtered tailings will be transported with trucks to the tailings storage facilities area, dumped, spread and compacted to achieve minimum shear strength to ensure geotechnical stability.

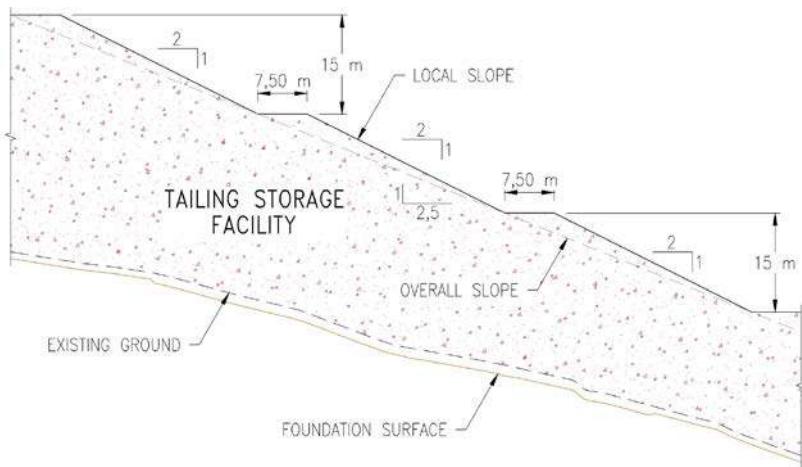
Waterproof covers also called "raincoats" (1 mm thick geomembrane) are to be placed over the tailings final elevation to control rainwater, which will be collected and discharged into a "raincoat" pond located at the toe of the retention dam. Figure 1 presents the plan view and section arrangement of the analyzed filtered tailings storage facility. The natural surface steep slopes and the filtered tailings configuration can be appreciated.

The filtered tailings will be dumped in the storage facility and compacted forming 2H:1V slope benches and 7.5 m berms, setting up a 2.5H:1V overall slope, which can be appreciated in Figure 2. The tailings stockpile conformation will consist of compacted 30 cm layers with 95%

maximum dry density with gabled slopes, i.e. towards the far ends of the storage facility. The compaction will allow the increase of the shear strength guaranteeing the stability of the installation provided excess pore water pressure build up is avoided.



**Figure 1** Plan view with the waterproof covers (above) and section (below) of the filtered tailings storage facility



**Figure 2** Typical configuration of the 2.5H:1V overall slope.

The contact water pond will be constructed at the toe of the retention dam and will collect water that has been in contact with the exposed surface of the compacted tailings through the lateral channels, fed with the ditches of each tailings stockpile bench.

The raincoat pond will store direct rain water precipitation onto the geomembrane covers placed over tailings surface and which has therefore not had contact with the exposed compacted tailings surface. The water stored in this pond will be monitored and discharged to the environment, if not contaminated, the usual situation with design details such as those indicated.

### **WATER MANAGEMENT PLAN**

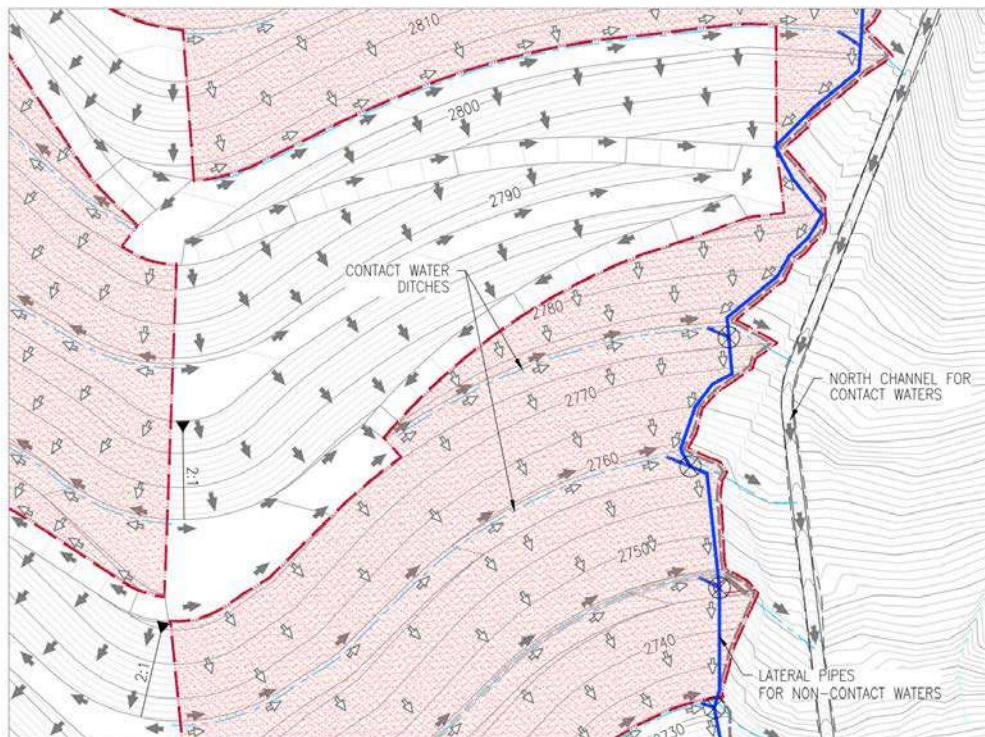
For legally compliant surface runoff management around and in the filtered tailings storage facility, the design considers the separation of contact and non-contact water flows. Contact waters are those that run over the exposed tailings surface with a possibility of contamination, while non-contact waters correspond to the surface runoff water outside the tailings storage facility area. Thus, it is also been considered as non-contact water to the flow that will be collected as runoff from the cover systems which will be installed over the deposited tailings, however, these waters should be monitored prior to its discharge to the environment.

For both flows, contact as well as non-contact, the channels have been designed to be located adjacent to the tailings storage facility, and incorporate culverts crossings and retention ponds. The non-contact waters are diverted by a contour channel which will divert surface inflows deriving from natural side hill surface run-off (upstream from the tailings storage facilities) to natural the watercourses.

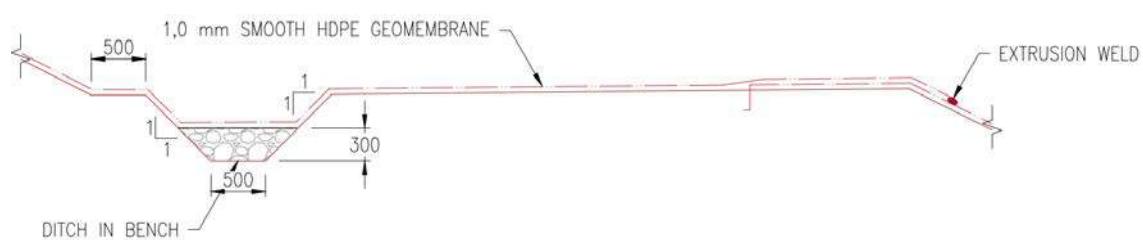
#### **Contact Water Management Plan**

Contact water is to be diverted through ditches which will be excavated at the toe of each bench slope and evacuated through the adjacent reservoir channels, and into the contact water pond through culverts and/or pipes.

The ditches placed along the toe of each bench will capture flows from the stockpile slopes (exposed tailings) providing drainage over the final filtered tailings stockpile surface. In some sections, the ditch will run below the geomembrane with the aim to divert to the contact water channels, as shown in Figure 3. The ditches are to be of trapezoid cross-section, as shown in Figure 4, without a liner, constructed by excavating into the compacted deposited tailings, and backfilled with drainage materials such as gravel. The longitudinal slope is the same as the berm slope, with a minimum of 1% and graded to either side of the deposit towards the diversion channels.



**Figure 3** Contact water ditches at the toe of the slope of each bench. It is observed that some ditches are under cover routed towards the adjacent channels. Water flow directions are shown in black for contact waters and in white for non-contact waters.

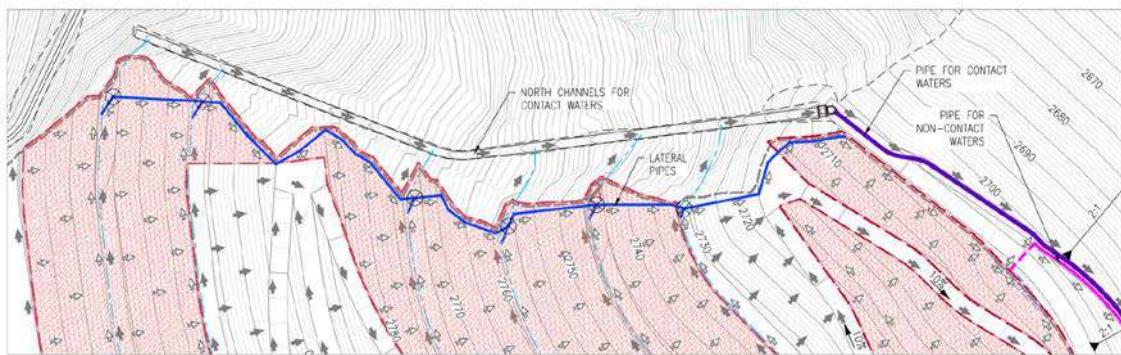


**Figure 4** Contact water channel cross section underneath the raincoat liner and along the slope toe of each bench Trapezoidal layout with 1H:1V slopes.

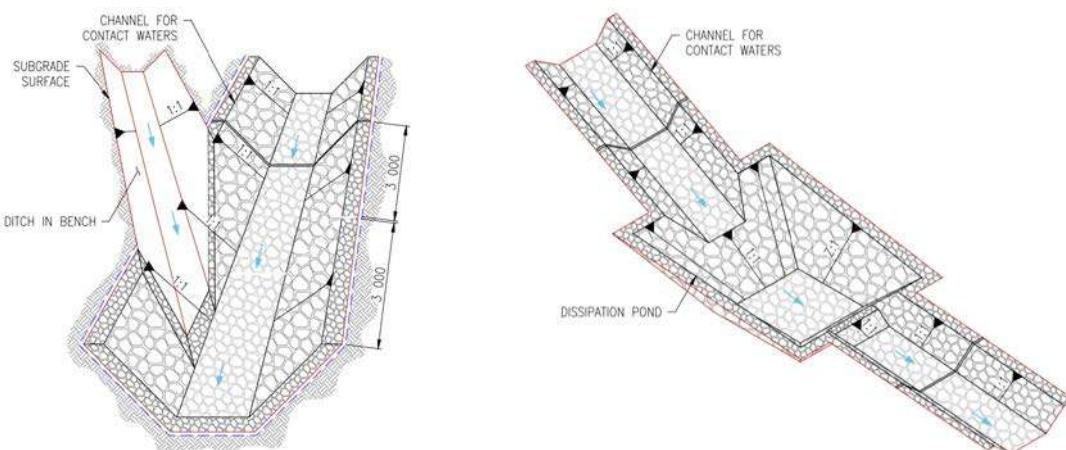
All the ditches are to be routed from the center of the stockpile towards the North and South extremes of the storage facility, and will discharge into the adjacent diversion channels (see

Figure 5 and 6) to convey the flows to the most under downstream level of retention dam and discharge in the contact water pond.

Due to the steep channel slopes, greater than 50% in some cases, energy dissipation ponds must be constructed, which will be distributed along the center lines of the adjacent channels, as shown in Figure 7. The typical section of these channels varies from 0,5 to 1,0 m base and 0,50 to 0,60 m in height, with a maximum flow rate of 0,9 m<sup>3</sup>/s.



**Figure 5** Plan view of the contact water channel supplied by the contact water ditches.



**Figure 6** Isometric view of the arrival of the ditch to the storage facility adjacent channel

**Figure 7** Isometric view of the dissipation ponds

Contact water will be stored in a lined 1.5 mm smooth HDPE geomembrane pond with 1000 m<sup>3</sup> capacity, located downstream from the retention dam. The storage depth of this pond will be 3.0 m. The stored water will be pumped via a 600 mm diameter HDPE pipe, to a treatment plant, prior discharge to the environment.

### Non-Contact Water Management Plan

Non-contact waters will be collected by a contour channel located upstream from the tailings storage facility and will discharge to the natural gorge, as presented in Figure 8. The contour channel will divert surface runoff flows from South to North, towards contingency detention pond from where the flows are to be discharged to the gorge located to the North of the tailings

storage facilities. The contour channel will be of trapezoidal cross-section with 1.20 m base and 1.20 m high, with 200 mm thick stone clad and 1H:1V side slopes.

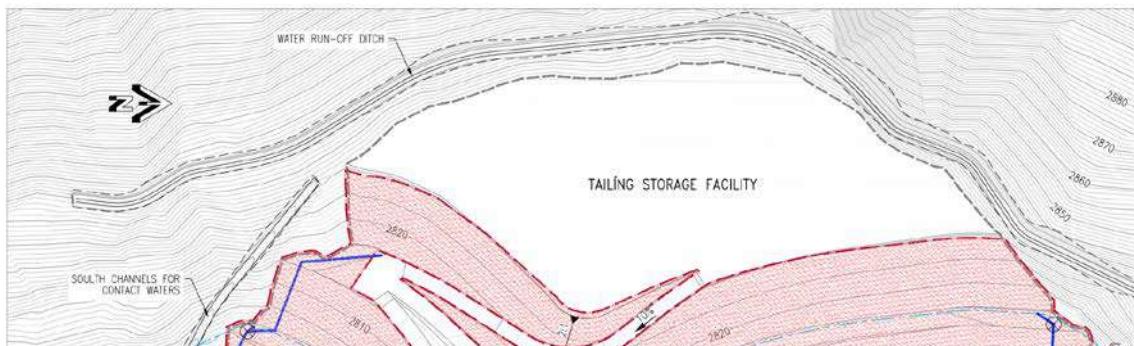


Figure 8 Non-contact water coronation channel view, upstream from the tailings storage facility

### Collection using a cover system

A cover system with a geomembrane will be installed. This is referred to as the cover system (raincoat system), which will entail the installation of 1 mm HDPE geomembrane over the largest practicable area of the tailings storage facility. The purpose of the cover system is to:

- Avoid tailings erosion during high precipitation periods.
- Prevent rain water infiltration to the tailings, thereby avoiding excessive tailings wetting and eventual saturation, which because of the fine nature of the tailings, can cause geotechnical instability problems.
- Facilitate the placement and compaction of the tailings in open surfaces free of run-on water.
- Reduce the size of the contact water pond
- Reduce contact water treatment costs which will need to be incurred before its discharge to the natural watercourses.

The tailings area to be covered should be the largest practicable according to the water management configuration on the inside of storage facility, therefore, it is important to develop a tailings disposal or discharge plan that allows the planning of truck accesses for the transport of tailings, as well as rollers for the compaction process. This will define the approximate area percentage that must be covered. Figure 9 presents the plan configuration of the cover systems, achieving in this case, coverage of 60% of the total tailings surface area.

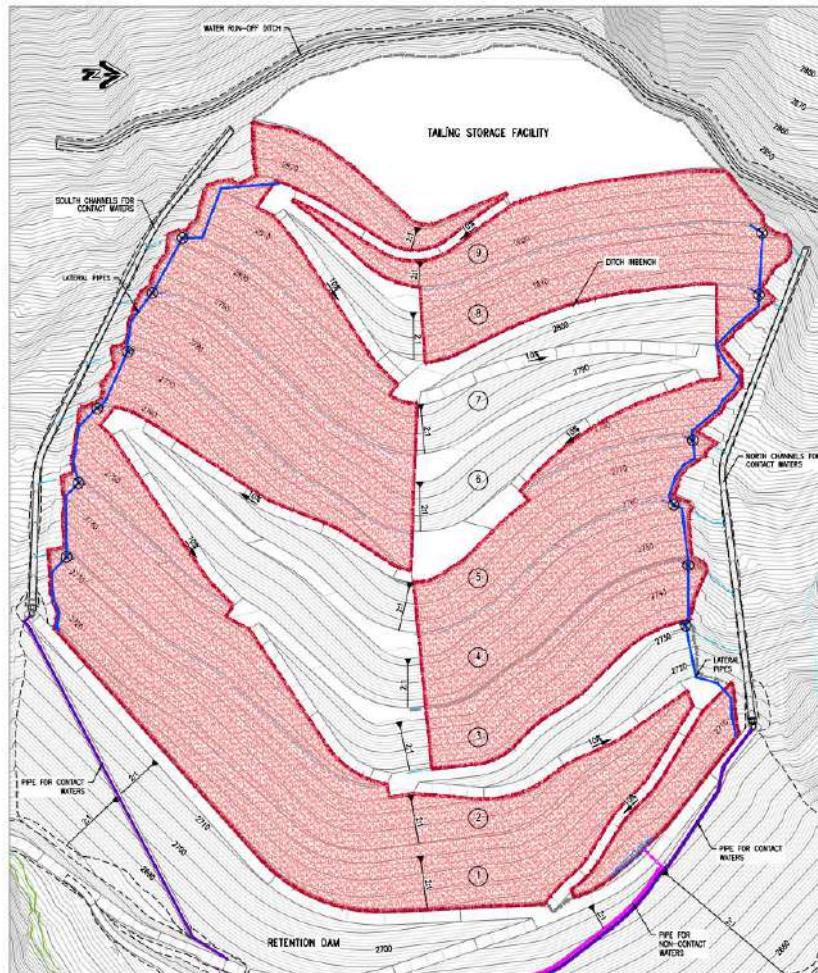
The precipitation flow over the covers will be collected through ditches to be located at the toe of each bench slope, using the same alignment as the contact water ditches, but separated by the geomembrane of the cover system, avoiding the combination of the both flows. The collected flow will be discharged to a 1200 mm HDPE well, located at the far end of the tailings storage facility berms. Figure 10 shows the cover system water collection ditch and the pipe discharge to the well, while Figure 11 shows the ditches at the toe of each bench that discharge into the well.

The flows from the cover system are to be discharged into a pond located downstream from the storage facility, and will be monitored permanently. Provided this water comprises only rain water; it can be discharged by gravity to the gorge. The overflow will comprise a solid 600 mm, HDPE SDR 17 pipe.

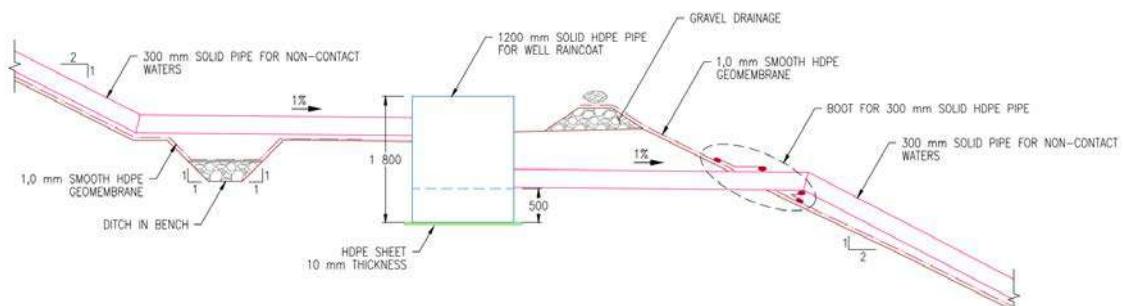
## OPERATIONAL CRITERIA FOR FILTERED TAILINGS DISPOSAL

In order to achieve an adequate filtered tailings management in rainy climates with aggressive topographies is to note the following:

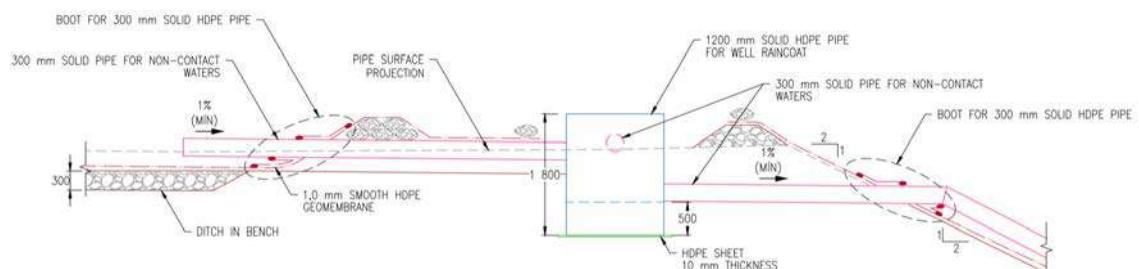
- Where waterproof covers cannot be installed the filtered tailings placement should not have benches exceeding 15 m, in order to avoid slope failures caused by erosion through extreme rainfall events.
- A drying pad should be provided near the storage facility, with the purpose of depositing tailings that have a greater than the optimum moisture content. Placement of such tailings without further water reduction would complicate its placement and compaction and generate excess pore pressures. On the drying pad, tailings must be subjected to some kind of moisture content reduction process, and then transported to the storage facility once optimal moisture content has been achieved.
- Regular monitoring of the materials to be placed is essential in order to ensure that the tailings may be properly compacted.
- The filtered tailings storage facility operations must be carried out in accordance with an operations manual developed specifically for the operation, detailing transportation procedures, drying in pad, tailings placement in storage facility, layer compaction, cover installation, contact and non-contact water management systems, etc.
- The installation of geotechnical monitoring instrumentation is essential. This would include inclinometers and piezometers to check the proper functioning and operation of the tailings storage facility over its lifetime. The records of the geotechnical monitoring must be reviewed by a geotechnical engineer for its interpretation.



**Figure 9** Plan view showing the tailings surface to be covered



**Figure 10** Ditch view and berm discharge to the well



**Figure 11** Ditch discharge view located at the toe of each bench to the well

## CONCLUSIONS

- Water management is of utmost significance for the design and operation of a filtered tailings storage facility. Contact and non-contact waters must be differentiated, captured and derived separately. Non-contact waters are usually discharged to the environment, while the contact waters should be stored in a pond, prior treatment and subsequent discharge.
- The contact water collection design, i.e., rain water that will fall over the exposed tailings surface, must take into account the cover system layout to keep the flows from mixing or combining.
- A filtered tailings deposit design should consider the placement of waterproof cover on the surface of the existing tailings, in order to prevent erosion, prevent rainfall water infiltration into the tailings, facilitate the placement and compaction of the tailings, reduce the contact water pond size, and reduce contact water treatment costs.
- The cover system design must take into account the filtered tailings disposal or discharge plan in order to schedule truck access and tailings compaction. The tailings area to be covered should be the largest possible according to the configuration of the water management plan in the inside of the storage facility.
- The filtered tailings storage facility operation must be carried out in accordance with an operations manual that describes the transportation procedures, drying, placement, compaction, cover system installation, contact and non-contact water management systems.
- Continuous verification of the materials to be placed, strength properties and general characteristics, as well as monitoring of the performance of the placed tailings through the installation and monitoring of the geotechnical monitoring instrumentation is essential.

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