In-pit Tailings Disposal at Langer Heinrich – Tailings Storage Facilities in a Unique Hydrogeological Setting

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Abstract

In-pit tailings storage can provide many advantages when compared to typical above-ground tailings storage facilities (TSFs). As regulations become more restrictive and existing mines expand into new pits, the motivation and opportunities for in-pit tailings disposal is increasing.

The Langer Heinrich uranium orebody follows a palaeo-river channel and is mined as an open pit operation. The mine pits intersect two main aquifer systems, one at the surface and one at the base of the orebody/pits. The tailings storage methodology is full in-pit disposal in multiple TSFs for the life-of-mine. Continuity of the initial hydrogeological conditions is incorporated in the design by the use of the pervious surround concept and the reinstatement of the lower aquifer (palaeochannel aquifer) at the base of the pit. Containment embankments are required to facilitate the staging of the TSFs development and are constructed using waste rock liberated during the mining of the pits. All of the TSFs are equipped with decant structures and an underdrainage system is included to improve water recovery, enhance consolidation and increase tailings density.

This paper presents the design of a unique in-pit tailings storage solution for the Langer Heinrich mine in Namibia owned by Paladin Energy Ltd.

Introduction

Paladin Energy Ltd (Paladin) is a uranium production company which operates the Langer Heinrich Mine (LHM) located in the Republic of Namibia in southern Africa. The mine is located within the Namib-Naukluft National Park, which is formed by the Namib Desert and the Naukluft mountain range. A unique ecosystem exists in the park as a result of the unique climate. The desert area in which the Langer Heinrich operation is located has an extremely arid climate. The rainfall is very low with an annual average of 67 mm. Fresh water is therefore extremely valuable and to be protected. Dense fogs off the Atlantic Ocean bring additional moisture to the area, upon which many of the native organisms rely. Evaporation is approximately 35 times precipitation, and in excess of 2300 mm per annum. Additionally, occasional storms on the surrounding granite mountains result in flash floods in the area. The surface and subsurface flows from these floods are key to the environment and to the design and closure criteria of the LHM tailings storage facilities (TSFs). The Langer Heinrich orebody follows an ancient riverbed which has resulted in a long, sloping pit shell. The tailings storage methodology is full in-pit disposal. The mine pit will contain nine TSFs storing the full life-of-mine (LOM) tailings production. Two aquifer systems are present in the mining areas; the surficial Gawib shallow alluvium aquifer and the basal palaeochannel aquifer. Mining typically requires the excavation of a portion of the shallow Gawib and the deeper palaeochannel aquifer systems. During mining, groundwater gradients are towards open pits, preventing seepage flows from the TSF entering the two aquifers downstream. As part of the construction of the in-pit TSFs these aquifers will be partially reconstructed to allow for the re-establishment of hydraulic continuity through the mining lease. The re- establishment of the lower aquifer presents a waste rock short haul opportunity which is implemented in the mining plan. The closure criteria for the mine also includes re- establishing the original riverbed topographic features of the site. Likewise, placement of waste rock as a cover material on decommissioned TSFs presents a short haul opportunity for the mining operations.

The ore is separated at the plant where 60 per cent proceeds to the leaching process and the remaining 40 per cent is scrubber reject. The scrubber rejects produce two waste materials; a coarse (cobble sized) reject and a fine (coarse sand) reject material. After the leach process, the spent ore is dewatered in a thickener and disposed of as tailings in the prepared pit void TSFs.

TSF 3 is the first full in-pit TSF at LHM and is currently in operation with TSF 4 under construction. The tailings disposal containment system is designed to achieve the following minimum objectives:

- capacity to accommodate the tailings arising from LOM (15 years) production
- maximise the storage capacity within the TSFs

- reduce the volume of supernatant water produced
- reduce seepage of supernatant water into the surrounding natural environment
- minimise risk of contamination of the groundwater
- reinstate the shallow alluvium and palaeochannel aquifers
- separate impacted and non-impacted waters
- compliance with environmental standards including the Australian and New Zealand Standards, Australian National Committee on Large Dams (ANCOLD) guidelines, International Atomic Energy Agency and Paladin's internal standards and sustainability guidelines.

The key criteria utilised in the TSF 3 design are summarised in Table 1.

Design

The TSF design is an exercise in storing tailings while isolating the tailings from surface and subsurface water flows, and optimising mine waste disposal costs. The containment concept for the in-pit TSFs is to utilise the physical containment provided by the mined-out pit where possible. This also ensures that the TSFs remain on previously disturbed areas. Fill embankments are used to contain the TSF within designated sections of the main-pit where required. The fill embankments are constructed of mine waste material. This not only provides a ready supply of embankment material, but also presents a short haul opportunity for the mining operations that reduces costs. In the case of TSF 4, the fill embankments also provide foundations for flood channels which reinstate the flow paths for surface water across the pit. These have been designed in parallel with TSF 4 to ensure a compatible overall design.

The natural gradient of the Gawib Riverbed is 1–1.5 per cent and the overall TSF plan is to mimic this slope during operation with the beach slope by utilising upstream deposition. This will minimise the closure earthworks required to re-establish the natural topography.

TABLE 1: Tailings Storage Facility 3 original design criteria.

Design criteria	Value
Target production rate	269 dry t/h for 7448 hours per annum
Tailings slurry (wet) density at discharge	1.5 t/m^3
Tailings specific gravity (particle density)	2.70
Tailings deposited (48 hr settled) dry density	1.08 t/m^3
Tailings average deposited dry density (medium term)	1.3 t/m^3
Long-term interstitial water content	30%
Tailings deposited average beach angle	1%
Design storms 100 year average recurrence interval 24-hr event	 44 mm
Peak ground acceleration (PGA) Maximum design earthquake From local blasting	0.04 g Variable
Seismic coefficient – pseudo-static analysis	50% reduction in PGA 20% reduction in strength
Stability factor of safety Static (steady state) Construction conditions Pseudo static	1.5 1.3 1.1

Three-dimensional depositional modelling was used to determine the location and number of outlets required to achieve the final landform.

To achieve the objective of full in-pit disposal for the LOM, the density of the tailings must be maximised to minimise the volume occupied. Additionally, to isolate the tailings mass from the groundwater flows the permeability of the tailings is to be minimised. The water recovery and tailings consolidation is enhanced through the installation of an underlying drainage system with a partial pervious surround and decant structures. The drainage system is underlain with a high density polyethylene (HDPE) liner and low permeability subgrade to minimise flows from the tailings into the aquifer below. The drainage system utilises the scrubber reject waste materials which are highly suited to the drainage.

Layout and capacity assessments

The TSFs have been designed to maximise storage of tailings while maintaining adequate freeboard to accommodate the operating decant pool and design storm event as well as the closure cover allowance. This freeboard is provided to ensure that the outer perimeter or embankments are not overtopped during rainfall events that could compromise their integrity or result in an environmental spill. The full LOM mining plan and tailings production were considered during the feasibility study to ensure that all produced tailings could be stored in- pit at closure.

Deposition modelling using the RIFT™ software package was undertaken to establish the optimal embankment heights and deposition locations, and to identify the tailings footprint for various stages. Existing pit access ramps on the plant side of the pit are typically utilised as deposition locations. The flow of the tailings down the shallow gradient access ramps reduces the velocity of the tailings before it reaches the drainage layer to avoid washout of the sand and confinement layers. These locations also provide suitable access to the deposition point and reasonable pipeline distance from plant to deposition point. Rheological and consolidation testing of the tailings was undertaken; a beaching angle of one per cent and placed dry density varying between 1.3 t/m^3 and 1.5 t/m^3 with depth in the longer term were estimated from the results.

Following eight months of deposition into TSF 3, we evaluated the deposited dry density to confirm the initial estimates. The surface surveys of TSF 3, prior to filling and with deposited tailings were compared to determine the deposited volume of tailings. This was compared to the tailings deposition rates and the dry density was calculated to be 1.30 t/m^3. The fact that the tailings is at an average dry density of 1.3 t/m^3 at this early stage (approximately half of TSF final height) indicates that the predicted range is being realised.

We also evaluated the survey provided for TSF 3 partially backfilled with deposited tailings and calculated an average beach slope of 1.4 per cent, slightly steeper than predicted. For the future TSF design criteria, a steeper beach slope is considered more conservative for capacity assessments; however, it is less conservative when determining downstream freeboard and embankment crest levels. This is due to the fixed maximum deposition height at the upstream (eastern) end of the pit. Therefore, a one per cent beach slope has been considered for the determination of embankment crest levels and a beach angle of 1.4 per cent has been adopted for capacity assessments. If a 1.4 per cent beach slope is obtained as expected, there will be additional freeboard at the downstream embankment. The premining ground level (river base slope) had a similar slope of 1–1.5 per cent, so this range is acceptable for achieving the desired final tailings surface. The layout of TSF 4 prior to deposition with part of the existing TSF 3 is presented in Figure 1.

Embankment design

The waste material produced by the mining operations is suitable for bulk embankment fill and the location of embankments can provide a short haul opportunity for the waste material. The proportion of bulk fill within the embankment was therefore maximised to make use of this material. The embankment fill consists of three materials – a bulk fill waste rock, a transition material and a compacted low permeability liner subgrade layer.

The construction methodology involves placement of waste rock material to form the majority of the embankment volume by truck dumping, dozing and nominal truck/dozer compaction. Materials selected for waste rock fill material for embankment construction must comply with the requirement of a maximum particle size of 2 m. As the waste rock zone is not highly compacted, settlement with increased load was expected to occur. This is monitored during construction of the final layers to ensure the design geometry is achieved. The transition layer and liner subgrade layer have more stringent grading and compaction specifications.

The slope of the embankment face has been proposed as a maximum of 1V:3H. This has been specified in conjunction with the earthworks contractor as the maximum angle that can be constructed with a top down dozing and compaction methodology as was implemented for the TSF 3 embankment.

The pit void for designated TSF 4 intersects two natural drainage paths designated as the Reid Wash and Kuell Wash areas. Both drainage paths require reinstatement by construction of a channel upon the embankments traversing the pit. The channels will convey water collected from clean upstream catchments during flow events and conduct it toward the natural stream without contacting the tailings, thereby preventing contamination. The channels will be protected against erosion with gabion mattresses on top of unwoven geotextile liner. The typical channel sections are shown in Figure 2.

Water management

The water management system is designed to achieve minimal seepage from the TSF, maximum water recovery and manage external seepage entering the pit. The water management system comprises an underdrainage layer, partial pervious surround, collection channels and sumps, decant structures and pumping facilities.

Underdrainage tailings seepage collection system

Release of pore water during tailings consolidation is the main source of potential contaminant release to the receiving environment. Therefore, the TSF design must provide the most effective means of allowing this fluid to be expelled, while ensuring significant capture of the contaminated water.

Consolidation calculations indicate that the fine nature of the tailings will lead to a relatively slow rate of consolidation. Therefore, the proposed design includes a high permeability consolidation seepage collection layer installed at the base of the facility. This drainage layer is designed to allow for active collection and pumping of the pore water released from the base and partially at the sides of the tailings mass during consolidation. To enhance tailings drainage, and to prevent the expelled pore water from entering the environment, an active pumping system will be installed.

A typical section of the underdrainage layer is presented in Figure 3.

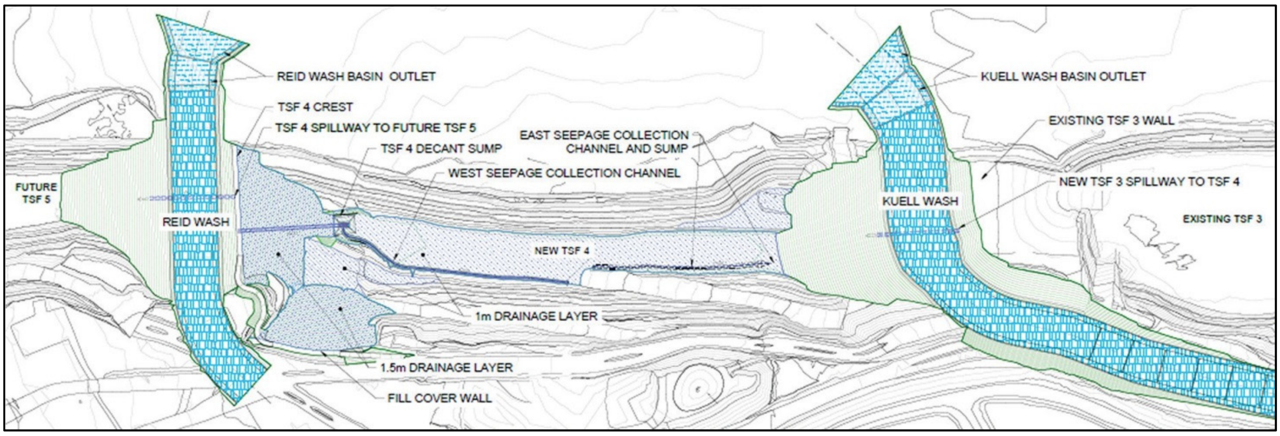

FIG 1 – Tailings Storage Facility 4 layout prior to deposition.

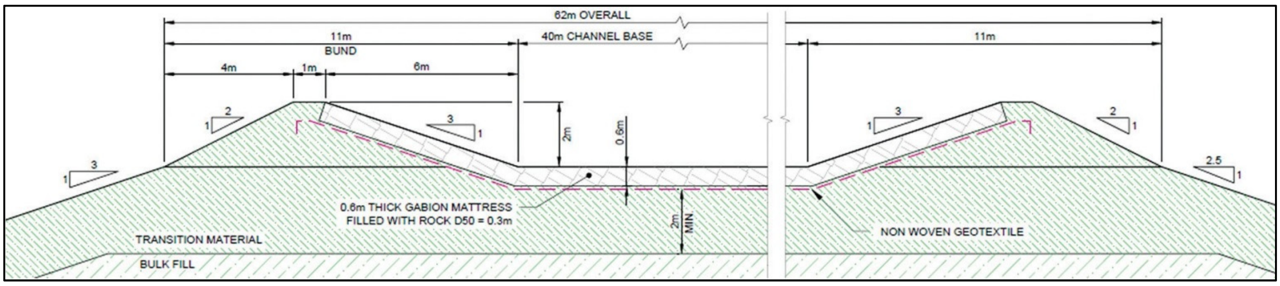

FIG 2 – Typical Reid Wash channel section.

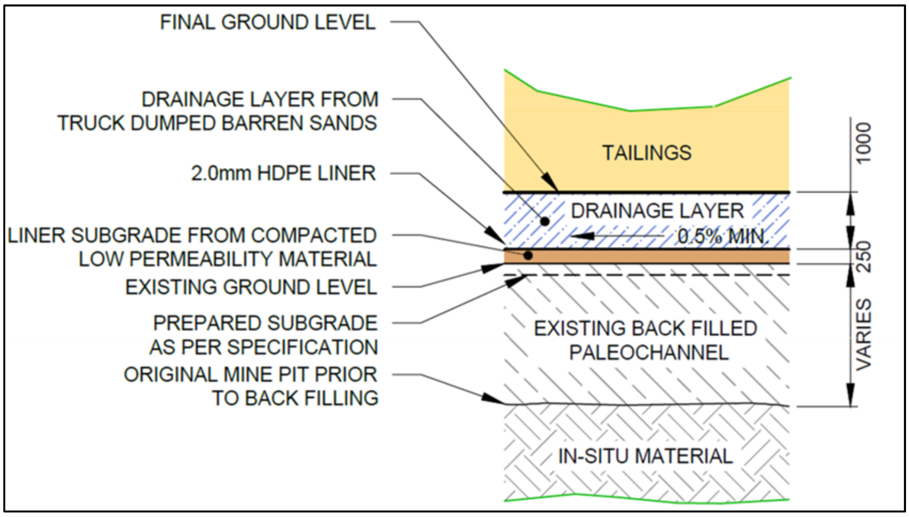

FIG 3 – Typical section of under drainage system (dimensions in mm).

Partial pervious surround

In conjunction with the underdrainage system, a partial pervious surround is be utilised to accelerate the tailings consolidation and reduce groundwater contact with the tailings. This system extends the seepage collection system partially up the pit wall face, typically from the base to the top of the first bench. Additionally, the disturbed zone on the pit wall face (from excavation of the pit) with increased permeability may also act as a natural partial pervious surround for the TSF. Thus, the consolidated tailings acts as a plug, with the groundwater flowing around the tailings mass, through the higher permeability materials rather than through the tailings.

The mined out pit with partial palaeochannel reinstatement is shown in Figure 4.

Influence on groundwater flow

The partial pervious surround will prevent the recovered groundwater system from having significant contact with the consolidated tailings. The partial pervious surround is formed along the edges of the backfilled pit to provide a preferential flow path for groundwater to flow around or under the backfilled pits, and minimise the flow gradient acting on the consolidated tailings.

The portion of groundwater that flows through the surround, rather than the tailings, is determined by the hydraulic conductivity (k) contrast between the surround and the consolidated tailings. The drainage layer and partial pervious surround will be formed of barren sands and have a contrast in permeability to the tailings of approximately six orders of magnitude. Testing of the disturbed zone which forms a natural surround on the pit walls has not been conducted. However, expected permeabilities for the tailings and disturbed zone will provide a contrast of approximately three orders of magnitude.

Impact on tailings consolidation

By constructing the partial pervious surround, the consolidation drainage in the tailings can effectively act in all directions; this can be monitored in the surround itself.

Additionally, decreasing the piezometric levels in the partial pervious surround by means of an active pumping system also allows the tailings to consolidate under full weight, or approximately twice the buoyant weight of the material. By imposing a large gradient between the consolidating tailings and the partial pervious surround, the tailings can be made to over-consolidate, thereby further reducing the final hydraulic conductivity of the material (Matich and Tao, 1986).

Integrated collection system

The partial pervious surround connected to the underdrainage system will be actively pumped to collect pore water expelled from the tailings during consolidation, and induce an inwards groundwater gradient, or hydraulic trap, towards the TSF. It is critically important that the pumping is maintained until a minimal volume of water is retrieved. This pumping will be required beyond the TSF closure as the tailings will continue to consolidate with the placement of the closure cover.

FIG 4 – Photograph of mined out pit with partial palaeochannel reinstatement.

Containment design

For containment, the TSF is lined along the base of the pit and up to the top of the first bench where possible. In some areas of the pit, the first bench is either too high or inaccessible to construct the partial surround system. In areas where this is not possible, 2 m of fill will be placed against the pit wall toe to provide a smooth transition from pit wall to pit base by reducing the angles for the liner. A pseudo-horizontal notch is then cut into the pit wall immediately above this backfill slope. The liner is placed over this fill and anchored into the notch. The key to this system is the tuck-in of the liner into the pit wall notch; this should be at least 0.5 m. The containment system is illustrated in Figures 5 and 6.

Collection

The collected tailings consolidation water and decanted supernatant water report to a collection sump where a pumping system transports the water via the decant structures and pipeline to the surface for reuse in the processing facilities.

The collection sump is formed by excavation within the TSF base. The HDPE containment system layer profile that lines the entire TSF base also lines the sumps. However, as the sumps have larger stones placed within them as a high permeability zone, a non-woven geotextile liner is also installed in the sumps to protect the HDPE liner.

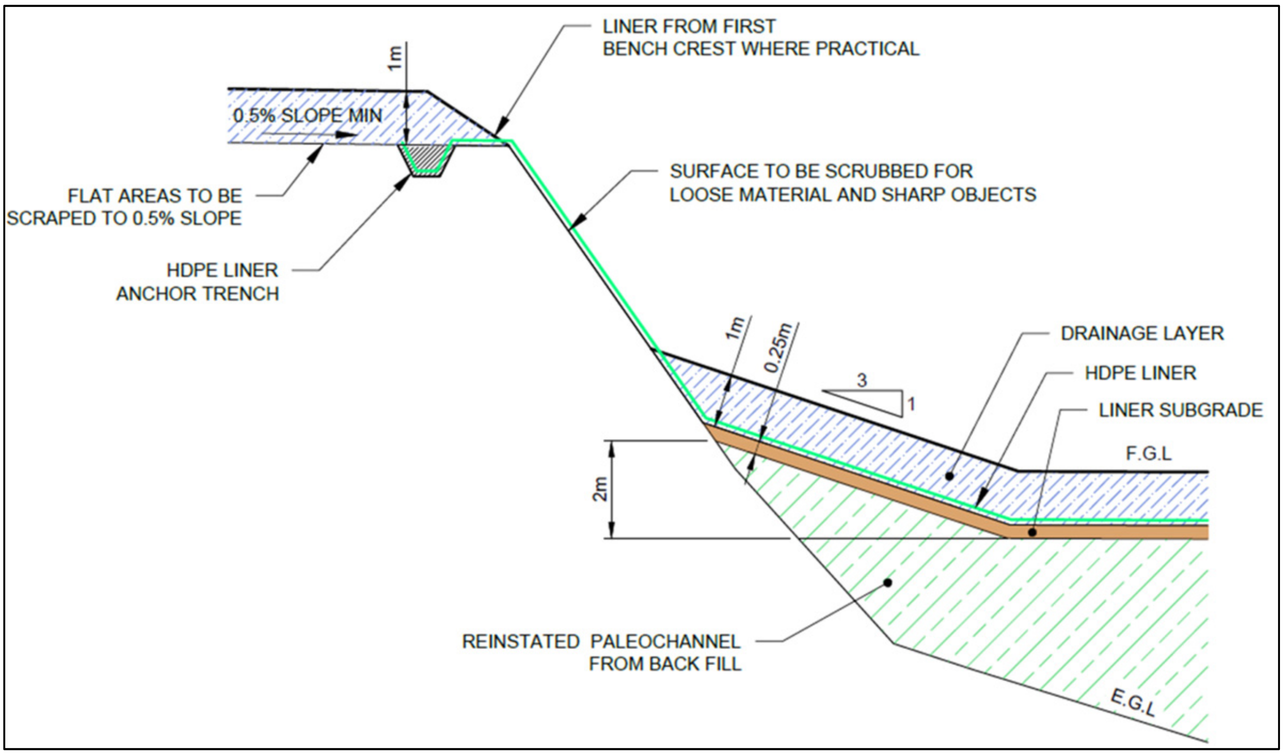

FIG 5 – Optimal tailings storage facility pit base lining design.

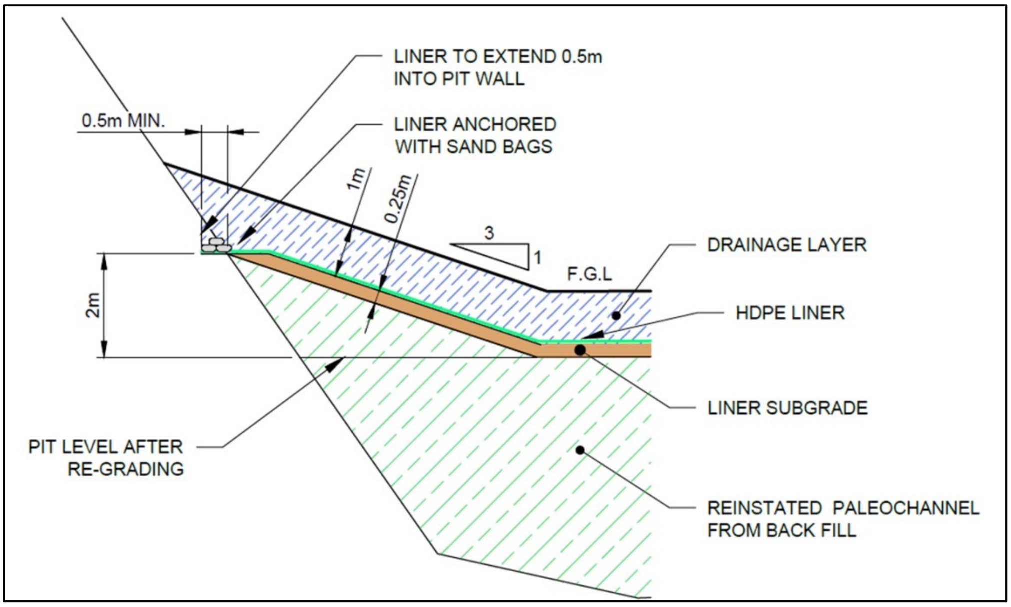

FIG 6 – Default tailings storage facility pit base lining design.

A section of slotted HDPE pipe is placed at the bottom of the collection sump to house the submersible pumping system. The pipe is wrapped in geotextile to prevent the ingress of sand or tailings material. The remaining sump void is filled with high permeability drainage material (coarse rejects) acting as a further filter and connecting the sump to the underdrainage layer. A typical cross-section is presented in Figure 7 and a photograph during construction of TSF 3 is presented in Figure 8.

Decant structures

The collection sumps have two decant structures. The decant structures have two primary purposes; to decant supernatant water from the surface to the collection sump and to provide a casing for the pumping system and pipework to allow for transport of the water from the collection sump to the surface.

The decant structures are formed of a slotted HDPE pipe wrapped in geotextile and surrounded by filter sand. The decant system is extended with a sand drainage layer placed on the upstream face of the embankment connecting to the collection sump. This is to decant any supernatant pond water which forms against the embankment. The decant pipes continue within the collection sumps to provide the housing for the submersible pump. The use of two decant pipes provides a degree of redundancy; should a blockage or issue arise in one pipe, the other can be used. Additionally, should excess pumping capacity be required, a second pump (the spare pump in reserve) can be placed down the second decant, rather than ordering and installing a higher capacity pump which may cause delays.

A vented vibrating wire pressure transducer is located at the base of each decant pipe. This is used to monitor the water level within the sump to provide guidance on the required pumping rate. The submersible pump pipe work and data cable for the pressure transducer are also contained within the decant pipe. The submersible pump is retrieved for maintenance work, as required, and a replacement pump is installed immediately upon removal of the original pump. A typical section of a decant structure is presented in Figure 9.

The decant pipe is supported by the fill embankment. The pipe is also to be covered by a layer of drainage sand which provides protection, filtration, lateral support and protection against buoyancy. Additional support is provided by strips of HDPE around the pipe and welded to the liner at frequent intervals.

The upper section, which extends past the surface of the final tailings level, is free to move in the axial direction to allow for elongation due to temperature effects and any sagging due to settlement. A concrete plinth with attached steel rings provides this support.

Prior to TSF closure, the decant pipes should be extended by welding of an extension piece. This is to raise the inlet level to above the backfilled cover level such that pumping of the underdrainage system can still occur post closure.

External seepage

In some areas of the pit, small sections currently receive contaminated seepage inflow. This is viewed to be localised seepage and is managed by collection and recovery with pumping systems.

Following construction of the TSF in the pit, the seepage is managed with interception, collection and reuse via the seepage collection system to limit the impact to the palaeochannel aquifer. The seepage areas are managed differently, depending if they are above or below the TSF containment system.

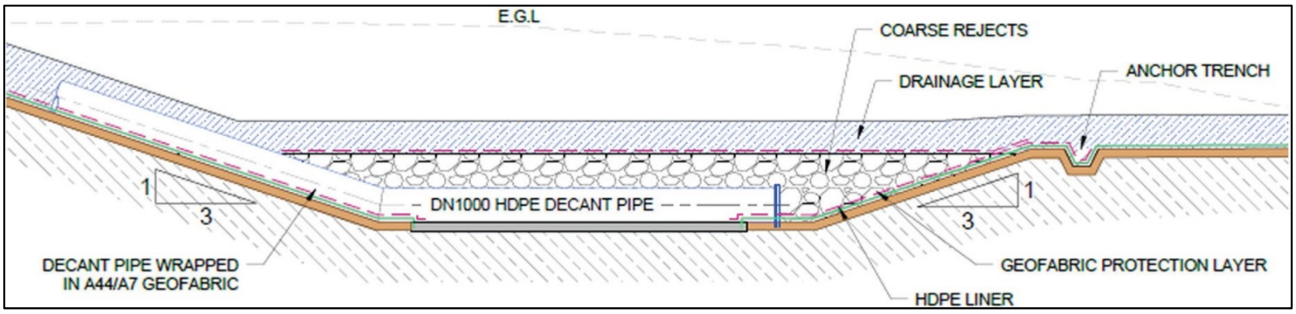

FIG 7 – Collection sump – typical section 1.

FIG 8 – Collection sump during construction.

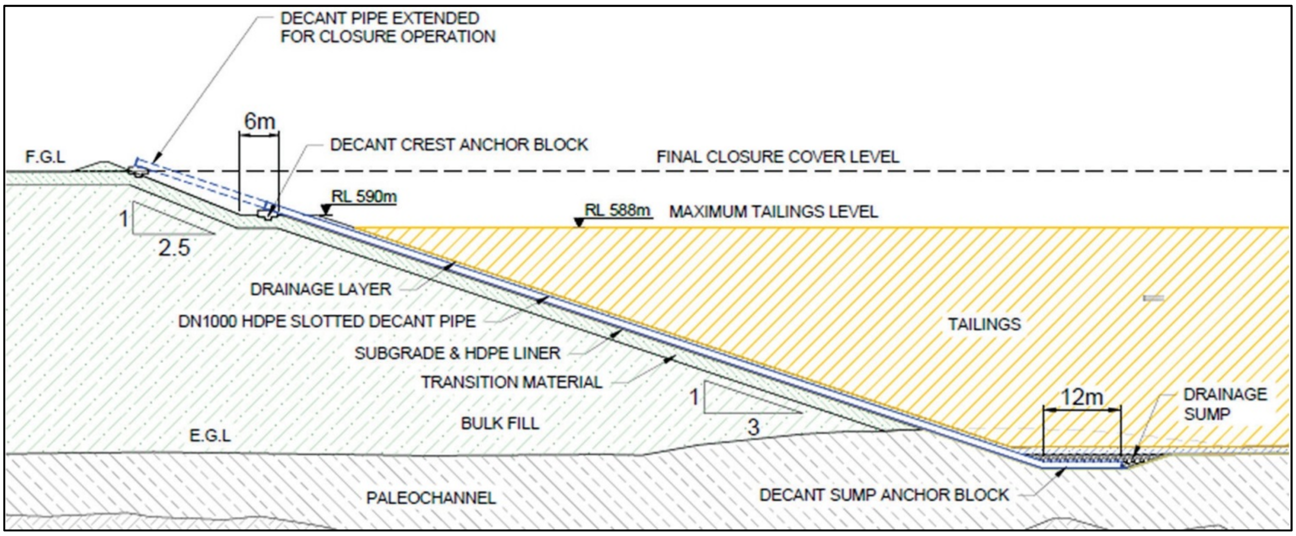

FIG 9 – Decant structure typical section.

The areas of seepage above the TSF base are managed with an interception drain constructed within the TSF containment system to convey the seepage water towards the collection sump. The drain is lined and filled with drainage sand as well as a slotted pipe to provide an efficient flow path for the collected water. The drain terminates in the collection sump. The seepage water is therefore captured and reused along with the collected tailings consolidation water. This system is illustrated in Figure 10.

The areas of seepage below the TSF base are managed similarly with an interception drain. However, this is constructed outside of (below) the TSF containment system. This is required as the seepage daylights in the pit below the level at which the palaeochannel is to be reinstated. This seepage therefore must be isolated from palaeochannel flows. To achieve this, an interception drain as shown in Figure 11 has been designed and constructed. The drain channel is lined and contains a slotted pipe to convey the collected water to a small collection sump located at the base of the upstream embankment. Within and above the drain channel, a zone of drainage sand provides a preferential flow path for the seepage water. This sand zone is lined on top to isolate the seepage from the palaeochannel flows. The palaeochannel reinstatement is constructed above this second liner with a sand protection layer.

A withdrawal pipe is placed against the adjacent embankment and provides access for a small submerged pump to the small seepage collection sump.

Closure

Mining at LHM will require the excavation of all, or some portion, of the shallow Gawib and the deeper palaeochannel aquifer systems. Upon closure, these aquifers will be reconstructed to allow for the re-establishment of natural regional drainage. Therefore, closure design objectives are based on the requirement to prevent or minimise contaminant release to the aquifers after closure.

The primary objectives of closure planning at LHM are the safe containment of the tailings and tailings radiation, the protection of water resources and the re-establishment of the riverine ecosystem.

The current containment philosophy for the in-pit TSFs involves the reinstatement of the palaeochannel, construction of a basal containment system and the pervious surround as discussed previously and closure capping/cover of the tailings mass. The tailings cover is intended to prevent infiltration of surface water to the tailings and hence further seepage flows from the tailings mass. Through these mechanisms, the tailings mass will be effectively sealed and therefore the impacts on the lower aquifer are expected to be negligible.

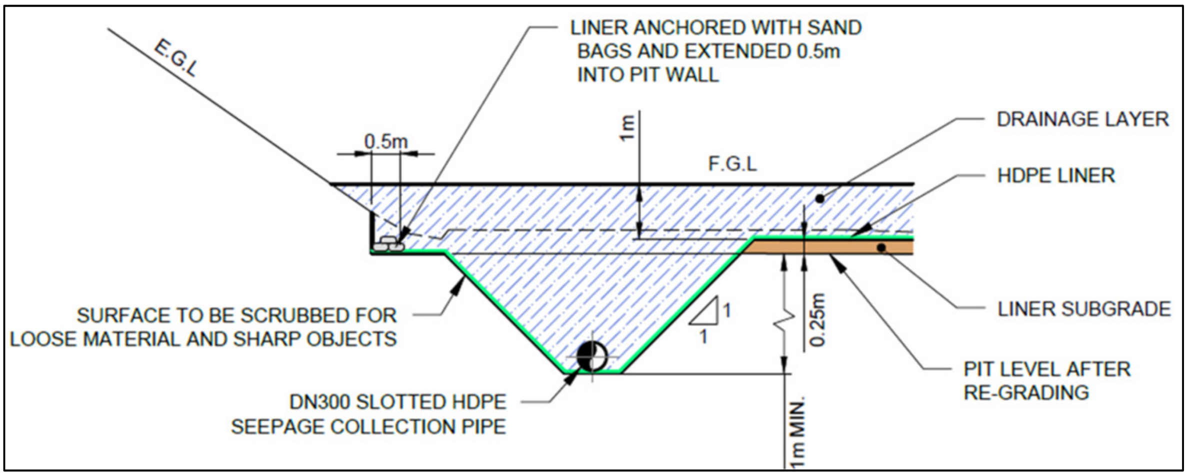

FIG 10 – Within tailings storage facility external seepage collection system.

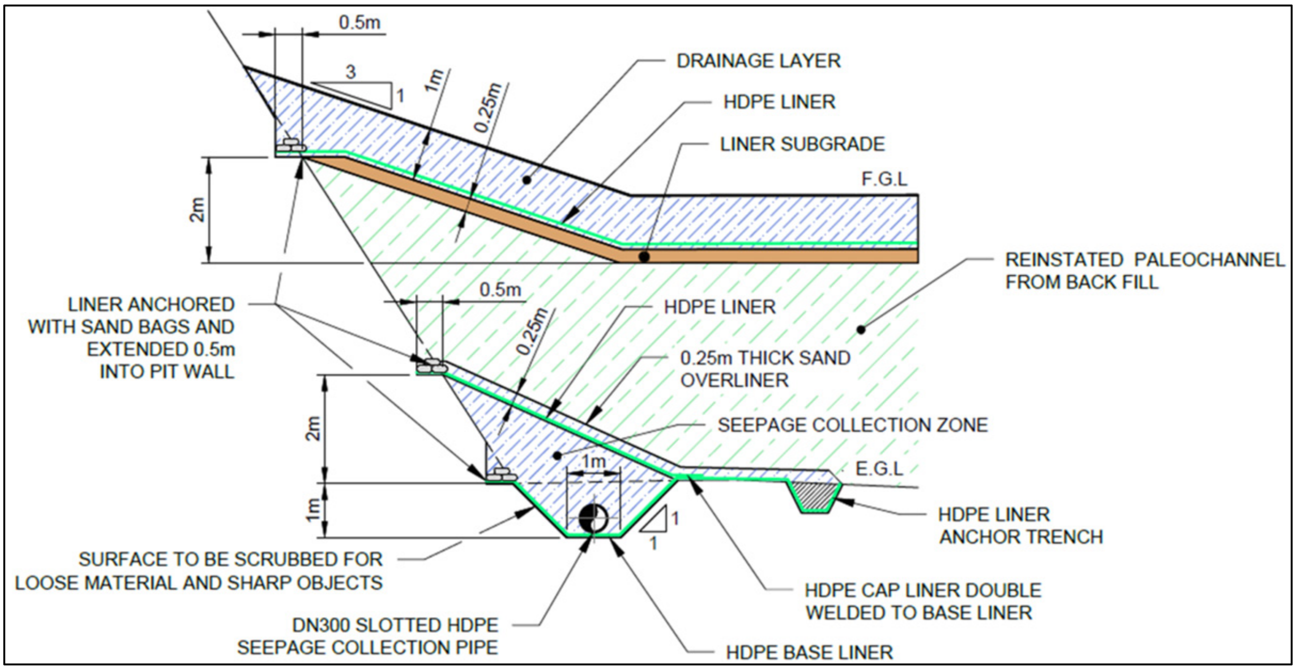

FIG 11 – Below tailings storage facility external seepage collection system.

The specific intent of the cover system is to prevent seepage ingress into the tailings body, prevent radiation/radon from escaping the tailings and to sustainably reinstate the riverbed, preventing large-scale erosion and scouring.

The tailings cover system will be formed of the following two components:

1. lower layer – radiation/radon barrier and low permeability layer to prevent radiation/radon from entering the riverine ecosystem and prevent water ingress to the tailings mass
2. upper layer – river gravels will be backfilled to allow upper aquifer reinstatement and the river to flow; this layer must resist excessive erosion or scouring to provide a protective barrier for the lower cover layer, which could otherwise expose the tailings material.

The configuration of the upper layer will be determined based on river flow modelling, with the lower layer profile determined based on in situ measurement of radiation levels during field trials.

Conclusion

The full in-pit disposal for the life-of-mine tailings disposal and storage methodology designed for the LHM has been successfully commenced. The site conditions present a unique set of challenges to ensuring that the objectives of the TSF are met during operations and for closure. The use of a pervious surround, basal containment, reinstatement of the lower aquifer and allowance for closure capping has achieved these objectives. Containment embankments have been constructed to facilitate the staging of the pit development in sequence with the mining operations. The TSFs are equipped with decant structures and an underdrainage system to improve water recovery, enhance consolidation and increase tailings density. The designs have allowed the operation to significantly reduce environmental impacts post closure as no pits or above ground facilities will remain. Costs have also been minimised by the use of the pits for containment and construction of the embankments and drainage systems with waste materials liberated during the mining of the pits. The designs and construction to date have achieved re- establishment of hydraulic continuity of the local aquifers both above and below the stored tailings mass. It is hoped that the successful demonstration of this tailings disposal method in such a unique hydrogeological environment will allow further in-pit TSFs to be developed and the environmental impacts of tailings disposal to be reduced.

Acknowledgements

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