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Performance of a Flow Through Tailings Dam

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ABSTRACT

The water quality and ecology in the Savage River located on the north west coast of Tasmania has previously suffered due to historical mining operations from past operators as a result of legacy mine waste rock and tailings storage facilities contributing significant acid and metalliferous drainage to the receiving environment. A series of projects jointly run by the current owners Grange Resources and the government have resulted in synergies and net positive benefits using the current mine operations to manage and remediate legacy mining issues. One such positive example of this synergy is the South Deposit Tailings Storage Facility (SDTSF). The 140m high facility will provide storage for approximately 37 Mm3 of tailings, equating to approximately 20 years' tailings storage. The SDTSF embankment is constructed entirely of waste rock won from mining operations and provides Grange with an economical storage solution for waste management (both tailings and waste rock) minimising the sites environmental footprint. The embankment features a permeable filter face which is sufficiently fine to retain tailings and allows passing of normal catchment flows, while larger flood events are stored within the facility and slowly released. Outflows from the filter face are passed to a 'flow-through' drain constructed from alkaline, waste rock. The outflows discharged through the 'flow-through' will provide a long term source of alkalinity to Main Creek, subsequently feeding into the Savage River. The facility is showing the first signs of environmental benefits to the downstream ecology that has long been degraded due to the effects of legacy acid and metalliferous drainage (AMD), caused by historical mining operations. Based on initial monitoring following commissioning of the facility in 2017, the filter performance compared with design, along with water quality from the 'flow-through' drain.

Introduction

The Savage River open-cut magnetite mine is situated on Tasmania's west coast, approximately 100 km southwest of the coastal port of Burnie. The area is characterised by high rainfall and steep topography, making water management critical to enable safe, stable storage of tailings and waste rock.

The site comprises open cut pits on both the north and south sides of the Savage River. The mine facilities, workshops and primary crusher are located on the north side of the river, with ore fed to the concentrator plant on the south side of the river via a 1.3km long conveyor. The concentrator plant produces approximately 2.9Mtpa of magnetite concentrate. The concentrate is transported in a slurry pipeline, 83km north to be further refined at Granges' Port Latta pellet plant on the north coast of Tasmania, prior to the pellets being transported by ship for use in steel production. The residual material (tailings) from the ore passed through the concentrator plant consists of sand and silt sized particles in a slurry, which require safe disposal in a tailings storage facility (TSF).

The site has acid forming historic tailings as well as some potentially acid forming (PAF) waste rock production, which make risk reduction for generating acid and metalliferous drainage (AMD) from new mining activities a priority. The mine's previous storage, Main Creek Tailings Dam (MCTD) has reached its final filling capacity, thus a new facility, the South Deposit Tailings Storage Facility (SDTSF), has been designed and constructed.

The mine operator, together with the state government, jointly manage legacy AMD issues through the Savage River Rehabilitation Project (SRRP). The AMD is caused by historic waste rock dumps (WRDs) constructed by previous owners, which have previously caused extensive damage to the downstream ecology of Savage River. The Mine operator through the SRRP has been able to significantly reduce this impact and largely remediate the ecology of Savage River since resuming operations. These legacy issues are now largely contained to the Main Creek catchment on which the SDTSF is located, prior to Main Creek entering the Savage River.

The SDTSF embankment is a significant structure totalling approximately 140m in height, constructed in a 3 year period and commissioned in 2017. The facility will provide approximately 20 years of tailings storage (~37 Mm3) and is constructed entirely of waste rock from mining operations, providing storage for approximately 15 Mm3 of waste rock within the embankment construction. The use of waste rock generated from the adjacent mining occurring at the South Deposit Pit as an embankment construction material has made for an economical integrated waste management solution for the mine.

This paper describes the key features of the design, namely the alkaline 'flow-through' rock drain designed to pass regular inflows entering the TSF and provide a long term source of alkalinity to Main Creek, assisting in improving the water quality in the historically degraded environment.

The SDTSF design is unique in adopting a permeable rockfill 'filter face' on the upstream face of the embankment, designed to prevent ingress of tailings into the 'flow-through' and downstream environment.

The SDTSF provides environmental benefits particularly for Main Creek, whilst offering a safe and economical storage of tailings during its operational life, and offers long term closure benefits in enabling capture and transfer of AMD seeps from legacy WRD's and TSF's for transfer to the South Deposit Pit for treatment.

Future construction work on SDTSF is required to complete a remaining portion of the embankment to RL300m, construct the clay core and filters on the uppermost section and cut the closure spillway in natural ground on the right abutment with capacity to safely pass a Probable Maximum Flood.

Key features

Location

The SDTSF is sited downstream of the existing Main Creek Tailings Dam (MCTD), also within the Main Creek catchment. It is situated approximately 1 km from the South Deposit pit, the source of waste rock for the embankment construction.

A general arrangement of the site is provided in Figure 1. This also shows the context of the overall mine site, including the location of the Broderick Creek "flow- through" WRD that is a successful prototype for the proposed operation of the SDTSF (Brett and Hutchison, 2003).

Figure 1 General Arrangement of Site (Google Earth 2023)

General

The SDTSF has been constructed entirely from waste rock materials produced from the mining of South Deposit Pit. Access to the dam site was gained by constructing ramps using waste rock from the pit. The ramps developed tip heads for dumping, working towards the upstream face and filling the valley from the right abutment side (right side of valley when looking downstream).

The design features two significant innovative engineering elements:

– A “flow-through” rock drain to be constructed of coarse (D50 ~200 mm), alkaline A Type waste rock, designed to pass regular inflows entering the TSF storage, utilising designs and performance data from the Broderick Creek flow-through project. The facility has been designed to store flood inflows temporarily, before releasing water through the “flow-through” drain.

– A ‘Filter Face’ on the upstream face of the embankment. This has been designed to prevent ingress of tailings into the “flow-through” and downstream environment, whilst filtering water flows into the flow-through drain.

The two zones were constructed utilising tip-head placement techniques, whereby large mining dump trucks place waste from a minimum height of 20 m at the angle of repose for the rock. This effectively causes segregation in the mine waste, which results in the coarsest rock being placed in the creek bed forming the “flow-through” drain. Examples of the segregated particle size distributions are provided in Figure 2Figure 2.

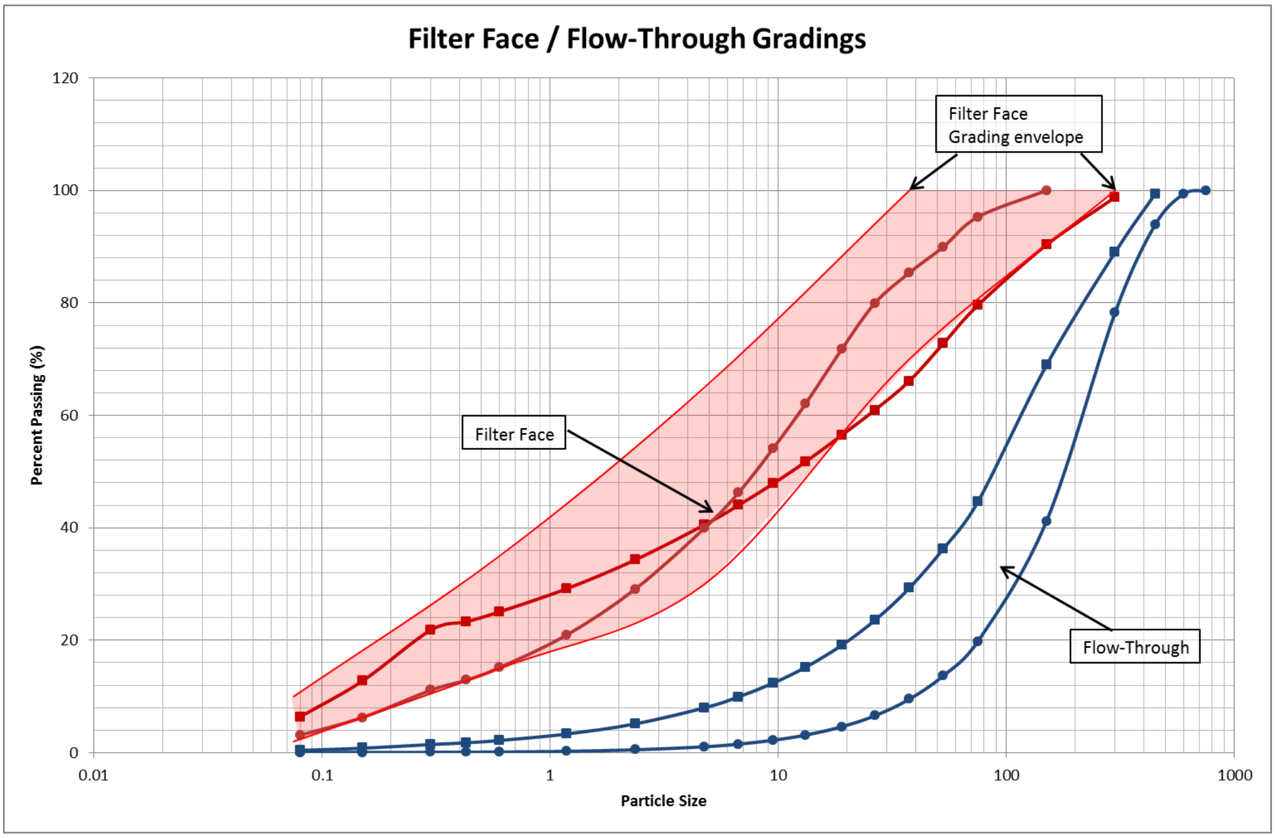


Figure 2 *Filter Face / Flow-Through Grading Examples*

The remainder of the embankment has been be constructed from waste rock (Type A and B), through a combination of paddock dumping in maximum 2m lifts (Consolidation Section in Figure 3), and tip-head placement in 10 - 20m lifts (D/S Shell in Figure 4). The paddock dumping and compaction in lifts within the consolidation zone is to limit settlement of the section supporting the filter face and the closure section.

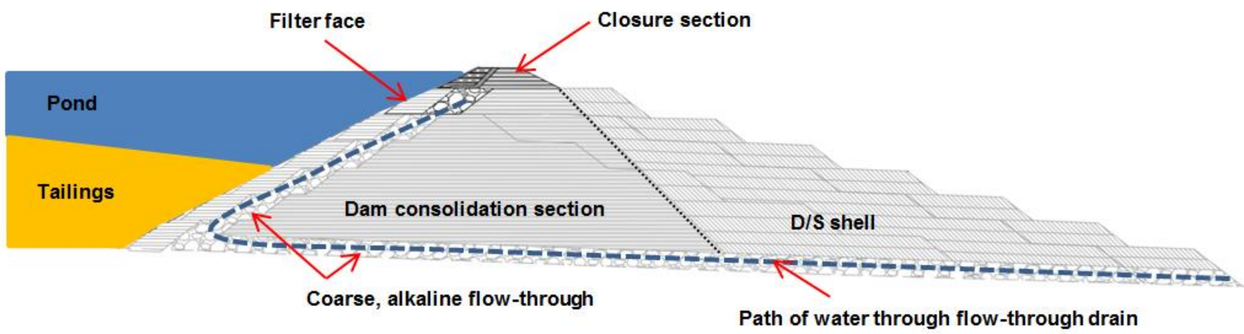


Figure 3 *Embankment Cross Section*

The embankment was constructed using a conventional 'downstream construction' methodology; i.e. stages of the embankment will be constructed in the downstream side of the embankment crest on natural ground.

The SDTSF is unique for a large, water retaining embankment as it does not feature a conventional clay core. It is intended that the pond level will be controlled by the tailings stored – as the tailings level builds up against the filter face, they block off the lower levels of the filter face and create a low permeability barrier along the face of the embankment and foundations. The level of the pond will rise as the tailings level rises.

This type of permeable embankment is similar to that used in management of coal wastes, whereby coarse coal rejects are used to construct permeable embankments that retain the fines, while allowing water to pass. However, the authors are not aware of an application for tailings retention with a filter face and flow through drain of the scale of the SDTSF in a wet climate such as the Savage River mine.

The final stage of the embankment which is yet to be constructed has been designed as a conventional water retaining embankment, with a clay core and engineered filter zones, in order to maintain a full water cover over the tailings in perpetuity.

Flow-Through Rock Drain

A key design element of the SDTSF is the flow-through rock drain. This was constructed from coarse alkaline A-Type waste rock. Constructing a flow-through drain has a number of benefits, including:

- Water flowing through the spillway will pick up alkalinity, improving the water quality as per the Brodericks Creek flow-through drain. As the TSF is constructed on Main Creek which has previously been contaminated with historic AMD issues), this is beneficial to the existing water quality.
- The TSF was able to be continuously constructed, without the need for cutting staged spillways into natural ground. Due to the naturally steep topography of the area, cutting spillways would result in significant cost.

The flow-through rock drain has been designed to cater for regular flows. The embankment has been designed with enough dry freeboard (approximately 30 m) to allow for storage of the 72 hour Probable Maximum Precipitation (PMP) flood event, estimated to be approximately 5.8 Mm^3. The flow capacity during flood events of the flow-through drain is expected to be between 2–3 cumecs; however, the flow will be controlled by the capacity of the Filter Face, which is not expected to exceed 2 cumecs (GHD, 2013). Having the inflow limited by the Filter Face limits the risk of developing a high phreatic surface within and on the downstream face of the TSF. The store and release methodology for dealing with large flood events, results in elevated ponding above normal operating levels. The worst case scenario allows passing of a PMF event within 30 days.

The ‘tip-head’ construction method causes segregation of the A-Type waste rock and is an essential methodology for construction of the flow-through drain. Grange have many years experience in carrying out this type of construction. The drain was developed along the left abutment of the TSF from valley floor to the crest, and along the front face behind the ‘Filter Face’ zone to create the necessary flow paths.

The ‘tip-head’ construction methodology requires a minimum height of 20 m to achieve segregation of the rockfill, based on historical and current site experience at Savage River in the construction of waste rock dumps, and the flow-through drain at Broderick Creek Waste Rock Dump (Brett and Hutchison, 2003). The height of the flow-through will necessarily be 20 m below the crest height on the left abutment until the final stage of construction when the water retaining closure embankment section is constructed (see Figure 4).

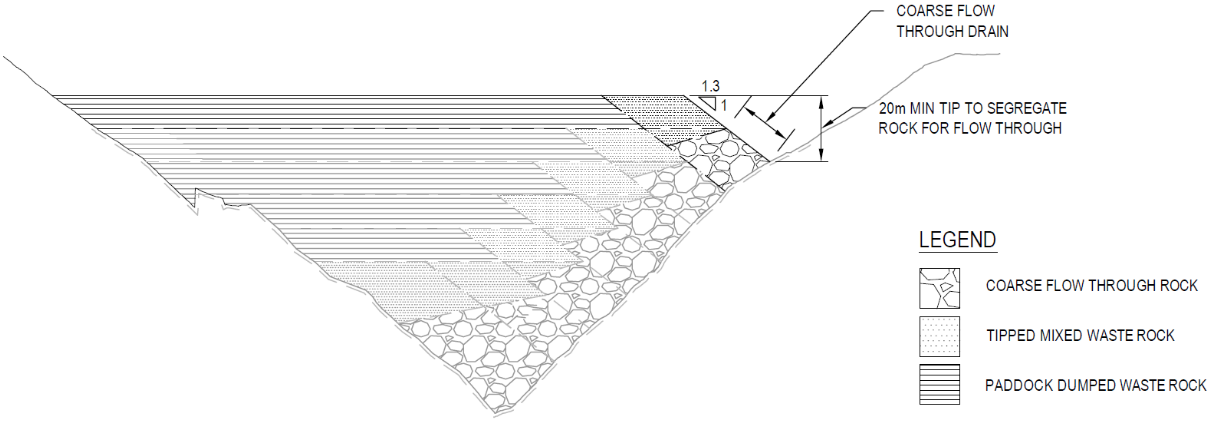


Figure 4 ***Section across valley***

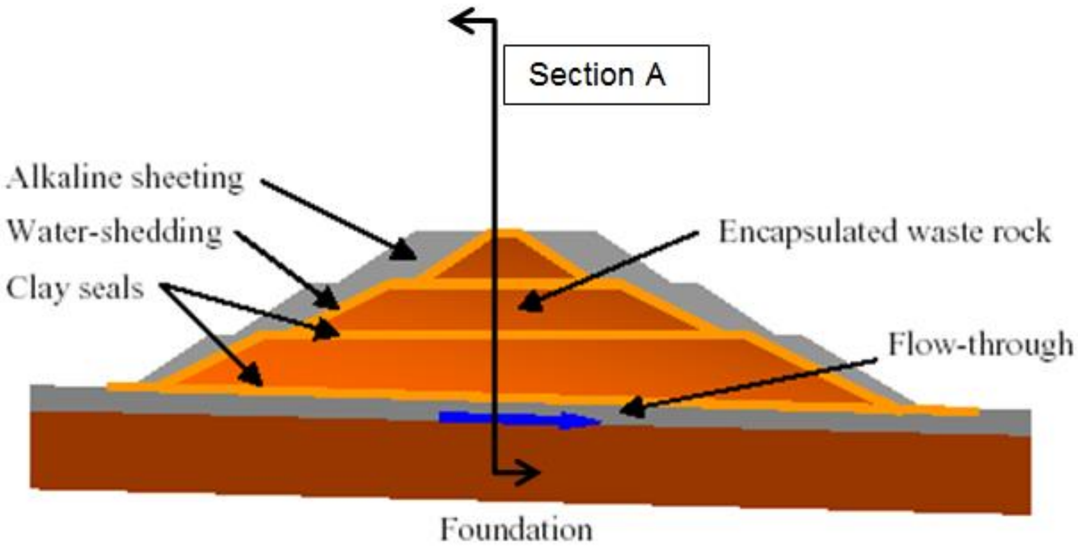
Design Precedent – Broderick's Creek Waste Rock Dump

The Broderick Creek WRD is a successful example of 'flow through' rock drain construction at Savage River, and serves as basis for performance monitored design parameters used in the SDTSF flow through design.

The Broderick Creek WRD consists of an initial flow-through spillway structure comprised of a permeable zone constructed within a 'dam' of dumped rock. The permeable zone consists of selected hard rock with open grading produced by segregation during placement. Outflow is limited by the cross section area of the drain. A long section and cross section of Broderick Creek is shown in Figure 5. The flow-through was designed to pass normal creek flows, with a pond building up under flood conditions. The storage area upstream of the waste rock dump has the capacity to store in excess of the Probable Maximum Flood (PMF) event. The pond also acts as a silt trap with sediment being deposited upstream of the waste rock dump, thus mitigating the risk of blocking the permeable zone.

Based on monitoring data maintained by Grange, the characteristic permeability of the flow-through has been calculated to be 0.26 m/s, which is within the predicted range in the original design (0.2 – 0.4 m/s).

The success of the original Broderick Creek 'flow-through' concept has allowed the development of an extended flow-through zone under expanded dumps, which now spans the complete length of Broderick Creek in excess of 4 km. As the Broderick Creek flow-through has catered for the majority of planned waste rock disposal for the life of mine since the mid 1990's, it has effectively made the mine viable (Brett & Hutchison, 2003).



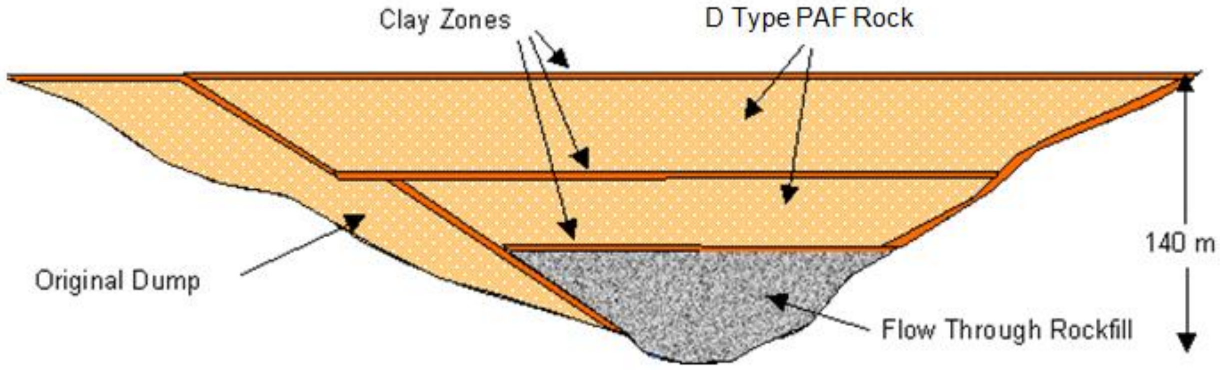


Figure 5 ***Broderick Creek Long Section & Cross Section***

Filter Face

The ‘filter face’ located on the front face of the embankment has been designed for the following purposes:

– To prevent migration of tailings into the flow-through rock drain and subsequent possible release to the downstream environment; and
– To be permeable enough so that water in the storage does not build up during normal operations and overtop the flow-through drain.

The SDTSF Filter Face does not perform some of the functions that a traditional filter might in other embankment dams, that is:

– There is no soil zone within the embankment that it is designed to protect from internal erosion (piping failure); and
– It is not required to act as a drain for the TSF/WRD, as the zone immediately downstream of the filter is the flow-through rock.

As such, the filter face has been classified as a non-critical filter (Fell, 2005).

Prevention of Tailings Migration

The following design criteria have been adopted to prevent migration of tailings into the flow-through:

– D15F (i.e. particle size of the filter material for which 15% by weight is finer) ≤ 0.7mm. This is the D15F design criterion for a Type 2 soil (Sherard and Dunnigan, 1989). The D15F criterion is used to achieve a partial size distribution in the filter so that the voids are sufficiently small to prevent migration of the base soil, which in this case is the tailings slimes. Testing on MCTD slimes have found the fines component (<75 μm) to be approximately 77%, and are therefore classified as a ‘Type 2’ soil.
– D15F/D85B < 5 (where ‘F’ is the filter and ‘B’ is the tailings slimes). This is a criterion used as a measure of whether fines will be trapped within the filter; i.e. the soil is considered self-filtering if this criterion is met (Schuler and Brauns, 1993).
– Filter to be of sufficient width to negate the effects of segregation during construction (segregation in this case would be defined as coarse particles aligning in the filter resulting in a conduit within the filter). The filter face has been designed to be of 10 m minimum thickness.
– Filter to be constructed of well graded rockfill with a maximum size of 150 mm (as per requirements for a non-critical filter).

QA/QC monitoring during construction was undertaken to confirm the filter face placement specification was achieved.

Permeability

The permeability of the filter face is a critical element of the design, as the SDTSF does not feature a conventional decant structure. Therefore, the filter face has been designed to be permeable enough to allow the flow of water into the flow-through drain, so as to prevent water from backing up significantly within the storage causing potential for overtopping of the flow-through down the left abutment. The SDTSF upstream face, pond and beached tailings can be seen in Figure 6.

A further consideration is that if a significantly large pond was maintained due to the filter face not being permeable enough, then it may affect the storage capacity as beach development would be hindered due to lower tailings density.

The design permeability of the Filter Face has been estimated using three methods:

– Empirical estimation of the permeability (k), based on the soil type. Based on the geotechnical investigations, the soil has been classified as generally well-graded gravel with some fines. As such, it is expected that the permeability should be in the range of 1 x 10-2 and 1 x 10-4 m/s.
– Using Hazen’s Formula: k = C(D10)2, where the D10 value has been estimated from the grading curves, and the factor C has been assigned a value of 0.004 (considered conservative). This gives a permeability of 1.6 x 10-4 m/s.

– Field permeability testing: four permeability tests were conducted on A Type rockfill materials within the MCTD embankment (during geotechnical investigations), constructed out of materials that are considered to be similar to those that will be used for the Filter Face. The tests were conducted using a 100mm diameter hand auger and as such are not considered to be representative of the overall permeability of the material; however, they do give an indication. The results of the permeability tests ranged from 2.0 x 10-6 to 4.4 x 10-4 m/s.
– Larger scale permeability testing on a trial embankment. A mini storage was constructed with a plastic lining, and tailings sluiced into it. Permeability was measured using the Darcy's formula Q= kiA, where Q (m3/s) was determined through the rate the water level in the storage dropped, A was the cross-sectional area of the upstream face, and i was estimated based on seepage location. The permeability obtained ranged from approximately 2 x 10-5 to 1 x 10-4 m/s.

From these observations and calculations, it is determined that the permeability would be approximately between 1 x 10-5 to 1 x 10-4 m/s.

Based on measuring the flow-through drain outflows and back calculating the wetted area of the filter face the an indicative permeability of the filter face has been calculated in the order of 5x10-4 m/s which is within the design range.

Despite the abovementioned theoretical and field test work showing reasonable correlation of expected performance, there are contingency plans in place should adjustment to the filter face be deemed necessary, to ensure optimal permeability. Contingency scenarios which can be adopted during operations include:

– If the filter face is lower permeability than design, the storage will fill with water more rapidly, as excess water above the design permeability will accumulate within the storage. This will cause less beaching of tailings, resulting in reduced storage capacity due to a lower tailings density. If construction monitoring showed this to be the case, the compaction of the filter face was proposed be reduced to increase its permeability.
– If the filter face is higher permeability than design, it can be more heavily compacted or can be partially sealed with clay post construction.

Hence, the filter face design, construction and operations have in-built flexibility and contingency to allow for the observational design approach.

Figure 6 SDTSF storage and upstream face

Environmental benefits

The flow-through drain consists entirely of A-Type alkaline waste rock. All water entering the catchment of the SDTSF reports to the flow-through, introducing a long-term source of alkalinity to Main Creek downstream of the embankment, which feeds into the historically degraded Savage River which has been impacted by acid and metalliferous drainage. SDTSF is providing a source for improving the overall water quality of Savage River, in addition to other improvement programs provided by the mine operator and state government.

The Savage River Rehabilitation Project has been monitoring water quality for over two decades at the site. Based on monitoring directly below the SDTSF outflow (MCbSD) the SDTSF is considered effective at neutralising and retaining metals contained in the mine tailings, legacy B Dump seepage and in the discharge from the MCTD. Several metals/metalloids and other parameters are consistently at or near the minimum level of laboratory reporting (arsenic, cadmium, chromium, lead, molybdenum and selenium) downstream of SDTSF. Key metals of concern are shown in Figure 7 to be trending down and have reduced since 2014 by approximately two orders of magnitude. Key changes in the graph represent when SDTSF construction commenced in 2014 which introduced a mechanism to capture and neutralise legacy AMD. Secondly further reduction was realised once SDTSF was commissioned to receive tailings in 2018 which introduced further alkalinity to SDTSF from the tailings process water.

On the balance of evidence, the SRRP is presently achieving its goal of establishing a modified but healthy ecosystem in the Savage River. Main Creek has also shown a marked improvement, with both rivers shifting towards reference condition as compared to previous monitoring. The improved environmental condition parallels the decrease in metals in the river (Koehnken, 2022).

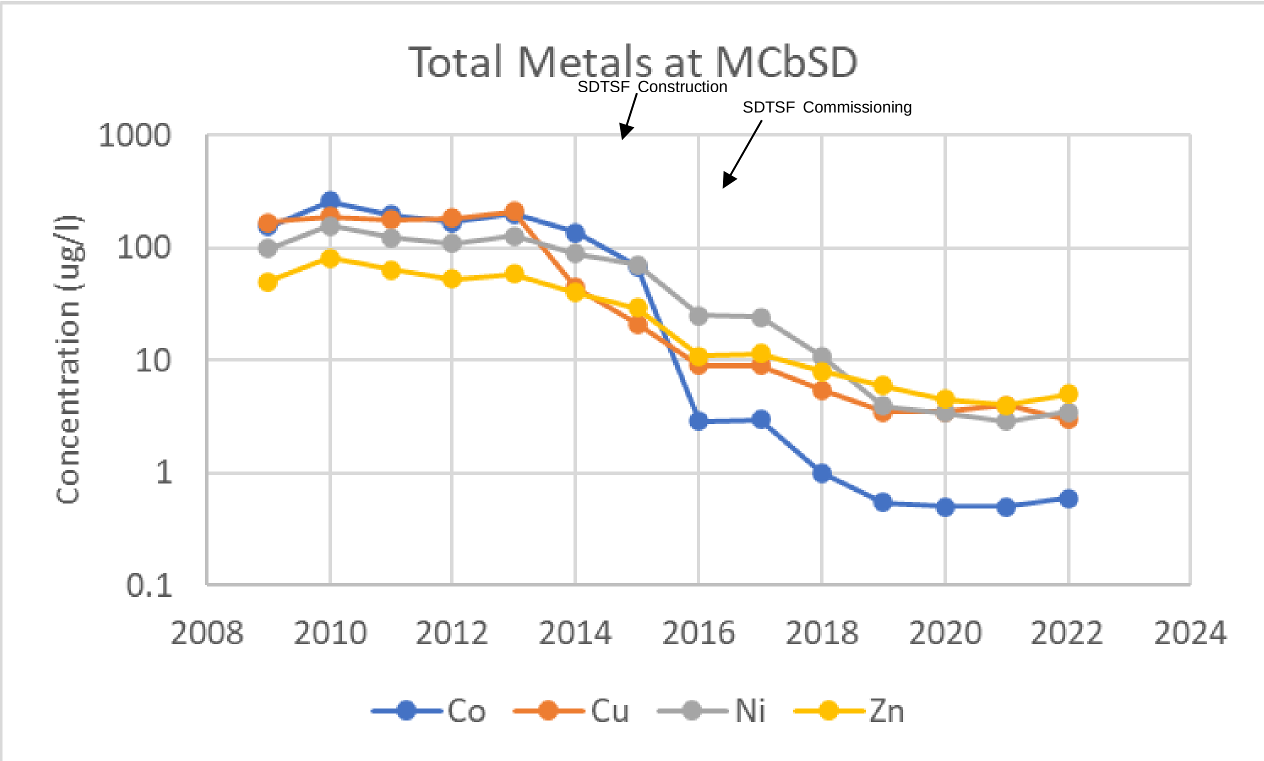


Figure 7 *Total Metals Monitoring below SDTSF*

Conclusions

The design of the SDTSF aimed to integrate waste management at the Savage River mine site, by utilising waste rock in the construction of the dam embankment, thereby creating a storage for both tailings and waste rock. This integration is effective in both limiting the site's environmental footprint, as well as reducing costs associated with waste management.

The innovative flow-through drain and filter face allow for cost savings associated with water management, as the facility does not require infrastructure such as staged spillways and decant structures. In addition, the alkalinity introduced to the downstream environment through the flow-through drain has been shown to provide environmental benefits to the downstream ecology in the long-term since construction.

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