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Application of filtered tailings storage method at Tüprag Efemçukuru Gold Mine

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Abstract

The filtered mine waste management method is a good alternative for sustainable mining and minimising environmental footprint. This method was applied for the first time at the commercial level in Turkey in 2011 at Tüprag Efemçukuru Gold Mine.

At the Tüprag's Efemçukuru Gold Mine (Efemçukuru), half of the dewatered filter cake is pumped to underground as paste backfill, the other half (filtered tailings) is stored in a surface tailings storage facility (TSF). The tailings material designated for surface is dewatered to approximately 80% solids through the use of thickening and filter presses and turned into a filter cake. The filtered tailings stockpile is a lined facility constructed with a double geosynthetic low permeability base liner system and includes a leakage detection system. Mining Association of Canada's (MAC) Towards Sustainable Mining (TSM) principles and Global Industry Standard on Tailings Management (GISTM) are being applied for the management of the storage facility.

Filtered tailings storage methods have advantages over other tailings deposition methods including increased physical stability of the stored heap due to the decrease in the waste saturation, and mitigation of potential failure mechanisms (e.g. liquefaction) as long as the tailings material is sufficiently compacted. Filtered tailings are also placed at an increased density, which reduces the facility footprint. Furthermore, deposition at a low water content means an active pond is not required within the TSF which allows for progressive reclamation.

In this article, practical experience gained through the design, testing, construction and operation of the Efemçukuru filtered TSF is presented as well as the discussion of the ongoing implementation of Best Available Practices (BAP) and Best Available Technologies (BAT) in the site's mine tailings management practices.

Keywords: *filtered tailings, filtered stack, filtered tailings management, sustainable mining, best available practices, best available techniques*

1 Introduction

The Efemçukuru Gold Mine is in western Turkey, approximately 50 km southwest of the city of İzmir (Figure 1). It is an underground gold mine with a daily ore production rate of 1,500 dry-tonnes. Ore processing results in a tailings slurry with 60–70% water content. Approximately half of the tailings material is used for paste backfill operations within the underground workings. The remaining slurry is pumped to the filter plant (Figure 2) where the filtering process reduces the gravimetric moisture content to less than 20% (W_{water}/W_{solids}).

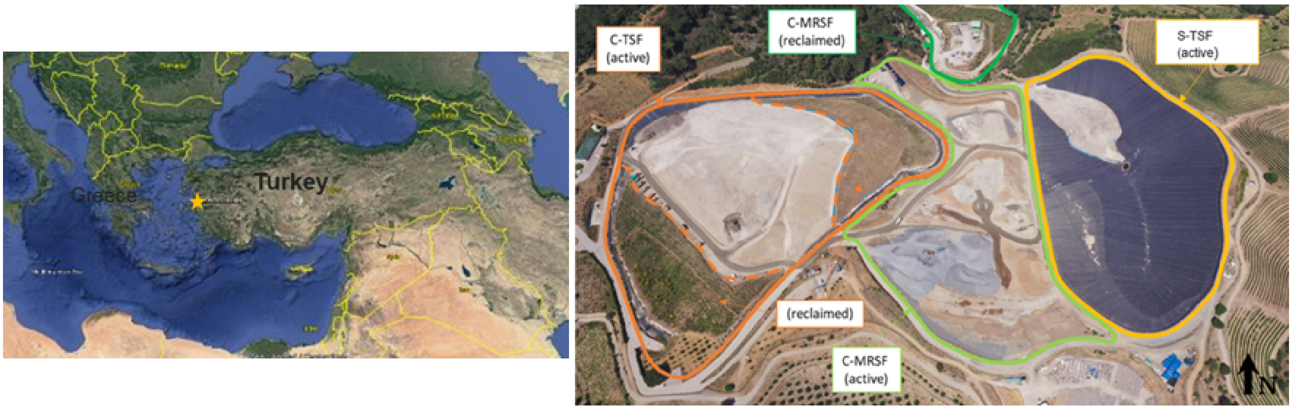

Figure 1 Efemçukuru location and mine waste storage facilities aerial view

Figure 2 Efemçukuru filter and paste plant

Mine waste stored on surface at the Efemçukuru Mine is composed of filtered tailings and mine development rock. Filtered tailings is stored in the Central and South Tailings Storage Facilities (C-TSF and S-TSF; herein referred to as TSFs) while mine rock is stored in the Central Mine Rock Storage Facility (C-MRSF). The mine waste facilities are integrated with the mine rock structures acting to support the tailings storage areas. Key features of the filtered tailings storage facilities include:

- Mine construction began in 2008 and filtered tailings placement started in 2011.
- Articulated haul trucks transport filtered tailings material to the TSFs.
- TSFs have a composite geosynthetic liner system that includes internal leakage detection.
- All contact water (surface and seepage) is collected and treated.
- As of year-end 2021, 1.33 M m^3 of filtered tailings have been placed.

Efemçukuru is the first mine to implement the filtered tailings disposal method in Turkey. Significant experience has been gained during this application. This article discusses the benefits of implementing the filtered tailings storage method and shares practical information obtained as a result of direct operational experience.

2 Selection of the filtered storage method compared to conventional methods

Here we provide an overview of the benefits that may be realised by implementing filtered tailings technology at a mine site. The benefits are presented as a comparison to conventional tailings technology (i.e. slurry tailings). Conventional tailings are considered a high-water content (<60–70% solids) pumpable tailings slurry. This slurry is pumped and discharged into a storage facility requiring containment structures to safely store water and liquefiable tailings. In contrast to these impounded tailings facilities, the benefits of filtered tailings management are as follows:

- Filtered tailings stacking allows increased storage volumes compared to conventional tailings for a comparable footprint. There are two primary reasons: first, the low moisture content material can be stacked and compacted to form a stable pile and second, a filtered tailings stack does not require a supernatant pond. Water from the filter plant is recirculated for mine operations, stormwater runoff is still collected in a sedimentation and treatment pond.
- Increased process water recovery can be achieved at early stages in the tailings management sequence. The water recovered from the filter plant can be returned to the system without losses associated with conventional storage facilities (i.e. evaporation or seepage). This is especially beneficial in geographies with limited sources of water. It can also significantly reduce requirements for pumping and pipelines.
- Improved constructability since a sufficiently compacted stack is self-supporting and water retaining dams are not required. Design and construction of water retaining dams is more complex due to the ongoing storage of large volumes of water (internal seepage controls, material filter compatibility, abutment tie-ins, etc.).
- Filtered tailings stacking can eliminate the risk of a dam breach affecting the downstream communities, environment and infrastructure. This is done by eliminating stored water in the tailings facility and ensuring the as-built stack is non-liquefiable.
- Implementation of the filtered tailings method supports progressive reclamation. This is one of the most important advantages of the system. Reclamation can begin early in the mine life as soon as outer slopes of the filtered tailings are constructed. This reduces environmental exposure, improves public perception and reduces resource demand on the mining company by spreading the work and related costs over a longer period.
- Material handling and transport provide greater flexibility for placement. The dewatered material can be loaded with construction equipment (e.g. loaders) (see Figure 3), transported by truck/belt conveyors, spread by dozers, and effectively compacted to design specification using mechanical compactors.

Figure 3 Filtered tailings loading area

Depending on the production rates for the mine, the capital and sustaining costs required to implement the filtered tailings method may be higher than the conventional slurry tailings handling and storage methods. The cost comparison between different technologies will be project and site-specific. However, operators and stakeholders should consider the overall sustainability of the enterprise. There are significant benefits that should be considered as part of overall project assessment and costing such as reduced structural risk of the facilities due to improved stability (note that critical design and operating parameters must still be satisfied), smaller footprint requirements, improved water recovery, and progressive reclamation. These were key considerations for the selection of filtered tailings as BAT at Efemçukuru given the site had the following constraints:

- Limited project footprint.
- Proximity to the village of Efemçukuru.
- Seasonally limited water supply (distinct wet and dry seasons).
- Sensitivity of the local stakeholders to potential offsite effects.
- A need to demonstrate progressive reclamation of the site.

3 Filtered tailings operational experience at Efemçukuru Mine

3.1 Filtered tailings placement

Filtered tailings at Efemçukuru are transported from the filter plant to the filtered stack using articulated haul trucks of 25 t capacity (Figure 4). Tracked dozers are used to spread the tailings in thin lifts to support drying and compaction and a roller compactor is used to achieve final compaction (Figure 5). The construction method used is bottom-up and the first tailings lift was 50 cm thick to prevent damage to the geosynthetic base liner system where trucks are used. This thickness could vary depending on equipment size. Subsequent layers are up to 30 cm thick as long as moisture contents are adequate for meeting compaction specifications.

Figure 4 Filtered tailings transportation equipment

Figure 5 Filtered tailings spreading and compaction

An improvement to tailings transportation was obtained by coating the truck box with a polymer liner to prevent material from adhering to the box. This reduces the amount of carry-back material and increases truck productivity (Figure 6). Although the climate at Efemçukuru is temperate, it can be beneficial to have snow clearing equipment and a road sanding/salting truck onsite to be used in case of snowfall and road icing during winter months.

Figure 6 Truck box with polymer liner installed

3.2 Field management of tailings moisture content

The moisture content of the filtered tailings produced from the filter plant and the compaction values obtained after spreading and compacting this material at the storage area are continuously monitored. The minimum compaction specification at Efemçukuru is 97% Standard Proctor Maximum Dry Density (SPMDD) based on ASTM D698 (Kwan et al. 2011). This value should be determined for each specific site with the goal of creating non-liquefiable zones of tailings, wherever required in the geotechnical design. Tailings moisture content is important for achieving required compaction. Optimum Moisture Content (OMC) should be determined during the feasibility stage and checked regularly during facility construction. Geotechnical OMC is 15.5 ± 2% for the tailings at Efemçukuru.

The filter plant may not always provide tailings at OMC, or meteorological conditions may affect the amount of moisture in the tailings during placement. If the tailings moisture content is too high, the tailings should be either/or:

- Spread in thin lifts and allowed to dry as needed, if weather conditions are amenable.
- Temporarily stockpiled for future placement.
- Placed in a dedicated wet tailings (off specification) area if sufficient footprint is available.

Stockpiled filtered tailings should be protected from increasing moisture content through use of water management and tarp covers for small areas. If compaction test results do not meet the specification, areas can be disturbed and re-compacted after allowing time to dry (Figures 7 and 8).

Figure 7 Dozer tilling off specification tailings to allow drying

Figure 8 Disturbed area being re-compacted after drying

Stockpiled tailings or placed tailings that do not meet compaction specifications should be excavated, spread in thin lifts in previously well compacted areas, and re-compacted once enough drying has occurred (Figure 9).

Figure 9 Stockpiled filtered tailings re-handling

3.3 Testing and quality control

Efemçukuru established a dedicated, onsite tailings testing laboratory for the determination, evaluation and monitoring of moisture and compaction values. In addition to onsite testing, third-party laboratories complete independent verification tests as well as carrying out tests that the onsite laboratory is unequipped for such as Atterberg limits, hydrometry, specific gravity and strength testing.

During normal operations at Efemçukuru, a Troxler-type device (aka nuclear densometer) is used to measure field compaction values (Figure 10). However, there are stringent requirements related to the use of a radioactive source device with regulations that must be met for the supply, transportation, storage and operation of these devices. Compaction testing to depth is also completed periodically by digging test pits down to depths of 3–4 m and testing at set intervals as an additional check that specifications are being met.

Figure 10 Use of Troxler (nuclear) proctor device on tailings lift

The issue of varying filtered tailings moisture content can be addressed in a number of ways:

- Tailings moisture will not always meet specified values. For this reason, operators working in the field require rapid and accurate data on which material is suitable for spreading and which material needs to be stored in the temporary stockpile area.
- Moisture content will be affected by environmental factors including rain, snow, frost, dew and hot weather. Therefore, to protect the material produced by the filter plant, especially from excessive rainfall, it is beneficial to create a covered area near the filter plant with temporary storage capacity for 1–2 days of production. Dew formation will also create difficulty in working on the stockpile surface. Timely processing of incoming material will reduce this effect. It is also difficult to work at the tailings storage area after snow or frost. After snow, the surface should be cleaned of snow or

frozen material and the working surface should be allowed to dry. After any climatic event (rain, snow, frost, dew) which increases the tailings area surficial moisture, the new tailings spread work should not be started until the surface is allowed to dry. If new spreading is performed on damp surfaces, the underlying damp contact material can form weak zones within the TSFs. In addition, working on slippery surfaces with high moisture can create safety problems for mobile equipment.

- Moisture content increases due to rainfall on the TSFs and stockpiled filter cake. On the other hand, extreme hot climatic conditions can cause moisture content to drop below the lower end of the OMC range. In this case, it will not be possible to sufficiently compact the tailings material. For this reason, it is necessary to spread and compact the material with suitable moisture in the field immediately during hot, dry conditions. Work should be planned with consideration of weather forecasts and site meteorological station data. Relevant information should be shared with technical and operations personnel so that preparations can be made to mitigate the effects of possible adverse climate events.

3.4 Tailings trafficability, surface treatment and dust control

As new lifts are developed on the tailings stack, dedicated access roads are required over the previously placed tailings. Experience with access roads has shown that the placement of crushed mine rock as a roadbed surface improves trafficability and safety. The compacted tailings surface becomes slippery after rainfall, and this can limit access. Therefore, it has become operational practice to cover designated areas with crushed/screened rock to create a suitable surface for trucks entering, manoeuvring and dumping on the tailings stack (Figure 11).

Figure 11 Screened/crushed mine rock used as roadbed in TSF

As noted in the previous section, there are many benefits to compacting the tailings material without delay. Dozer traffic during spreading creates a roughened surface texture caused by the dozer tracks which will allow the material to lose moisture quickly in dry conditions. Alternately, if the weather is rainy, the roughened surface structure will hold water and the TSF surface will become excessively muddy. Compaction of the surface by a smooth roller compactor as soon as possible after dozer spreading has been shown to form a thin crust on the pile surface (Figure 12), limiting moisture loss in hot weather conditions and lowering water retention in rainy conditions. Once created, this surficial crust must be protected; if vehicle traffic is required, it must be ensured that vehicles follow the same track in order to protect the crust (where roadbed material has not been placed).

Figure 12 Creating a smooth surficial crust by roller compaction

Compaction of the surface also has the benefit of minimising dust generation in hot and windy weather conditions. Dust control is an important component of the filtered TSF management and dust that may arise from the working areas must be minimised. The tailings storage area can be a serious source of dust along with the transportation routes to/from the filter plant. Efemçukuru actively controls dust along its access roads and at the tailings stack using several dust suppression techniques, including:

- Truck mounted watering/spraying: A water truck equipped with both a road sprayer (Figure 13) and an overhead water spray system (Figure 14) is used to spray roads and tailings areas that aren't accessible to truck traffic (ex. slopes). The use of lingo-sulphate on stabilised road sections has been shown to be effective in dust suppression.
- Paved access roads: The access road from the filter plant to the tailings area is an asphalt paved road which reduces road dust and increases haul efficiency (Figure 15). The paved road is cleaned regularly of any spilled tailings or other material using a sweeper truck which controls dust and sediment loading from road runoff (Figure 16).
- Fixed sprinkler system: The site has installed a fixed sprinkler network along the haulage road at the perimeter of the tailings storage area to support dust suppression.
- Progressive reclamation: Progressive reclamation of the TSFs is ongoing wherever tailings placement has reached the final design extent. The placement of the final geosynthetic and vegetated cover reduces dust and water erosion (Figure 17).

Figure 13 Access and TSF roads are sprayed by water truck

Figure 14 Watering TSF surface by overhead spraying from water truck

Figure 15 Asphalt paved access road from the filter plant to TSFs

Figure 16 Sweeper truck for paved road cleaning

Figure 17 Reclaimed tailings slope following rehabilitation and revegetation activities

3.5 TSF monitoring

The tailings management plan includes a monitoring system which monitors deformation, piezometric levels, water quality and seepage volumes. Vibrating Wire Piezometers (VWP) and standpipe wells have been installed to measure piezometric levels and to allow for water quality sampling. Potential deformation of the pile is monitored with survey prism stations (Figure 18). Monitoring frequencies are defined in the site's Operations, Maintenance, and Surveillance (OMS) manual and reviewed on an annual basis (Norwest 2018). Additional instrumentation is also installed as the TSFs expand according to the design documents and operational requirements.

Figure 18 Survey prism station for monitoring deformation and settlement

The monitoring program also includes periodic geotechnical site investigations to assess as-built conditions and compare with key design requirements. Site investigations have included SPT (Standard Penetration Test) and CPT (Cone Penetration Test) programs (Figures 19 and 20). The purpose of these investigations is to confirm that as-built conditions satisfy design requirements to eliminate the risk of liquefaction. The first CPT program identified a small zone of saturated tailings at depth in the C-TSF. This zone is from the earliest days of filtering and placement at Efemçukuru. This small, saturated zone does not pose a risk to stability due to the ongoing construction phasing and practices to ensure material is compacted to the required specification. Additional CPT measurements have shown small increases in density at depth with increases in fill height (Norwest 2014). It has been interesting to learn that a strong surficial desiccation crust can form in the compacted tailings during dry periods, and it has become standard practice to strip off this crust prior to drilling or pushing CPT cones (original CPT program was unable to push through this crust).

Figure 19 SPT investigation in C-TSF

Figure 20 CPT investigation in C-TSF

4 Surface and seepage water management

4.1 Non-contact and contact water management system

Design and operational planning for the facility included developing hydrological and water balance models for the TSF and surrounding area (Selim İnci et al. 2020). These models were used to design the water management systems (surface and seepage) based on analyses of regional and site data as well as consideration of future changes in conditions. The system was developed based on separation of contact and non-contact flows to the extent practical since all contact water requires containment and treatment. Water channels, pipes and collection drains were sized with capacity to meet design requirements as well as allow for future expansion of the facility. The system was designed and constructed to not have water stored within the lined TSF area (Figures 21 and 22). Surface runoff and seepage collection are directed through sediment collection sumps downstream of the TSF before being stored in a concrete dam impoundment prior to treatment or being used for process make-up water.

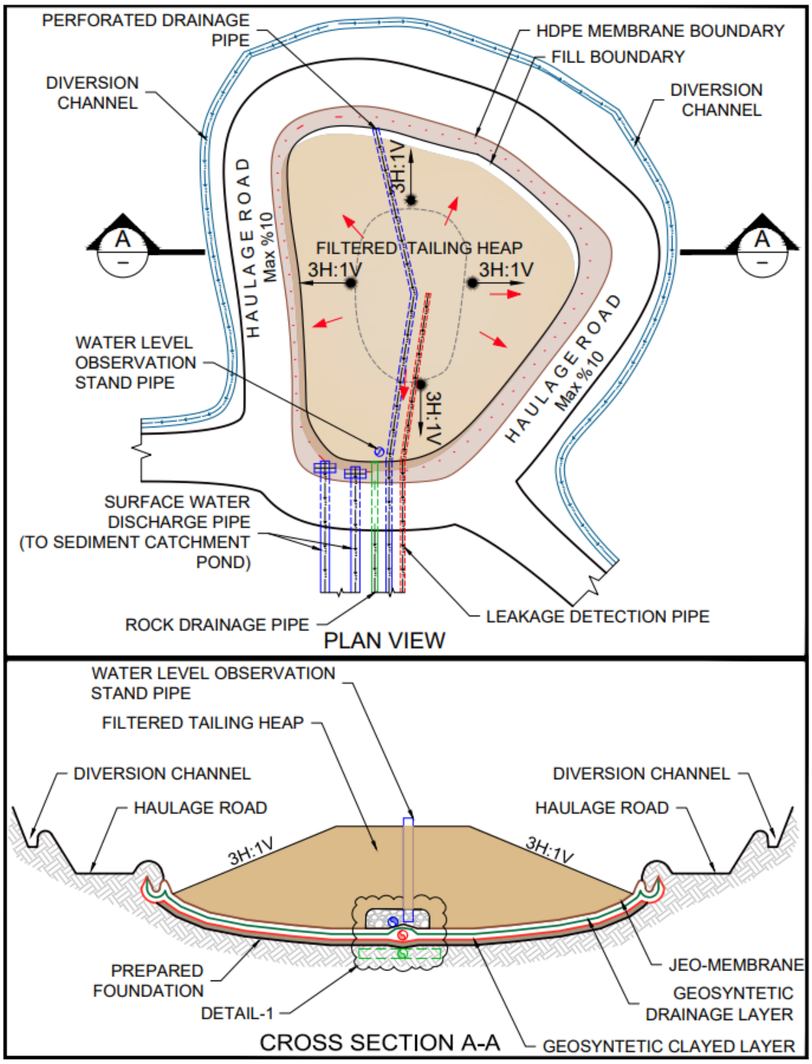

Figure 21 Schematic of tailings storage area water management system including non-contact water channels

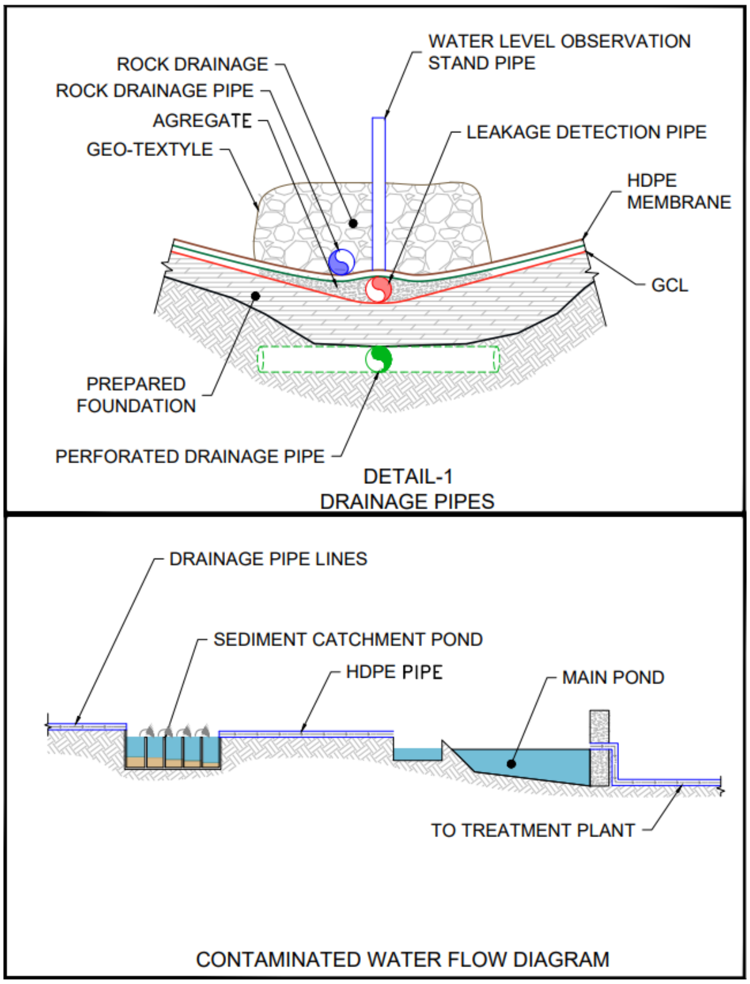

Figure 22 Schematic examples of underdrain system and sediment catchment sumps

Sediment management is a key part of the filtered TSF operation as the fine tailings are susceptible to erosion, both by water and wind (discussed earlier). Filtered TSFs need to be designed and constructed to manage sediment runoff due to erosion caused rainfall events. During runoff events at the mine, even short slope lengths can be prone to erosion which typically manifests as rill formation and conveyance of sediment into the toe drainage channels (Figure 23). These sediment loads would be problematic if allowed to reach the main water impoundment as they would interfere with pumping as well as taking up storage capacity behind the dam. In order to prevent this situation, the site found it beneficial to construct concrete sediment catchment sumps to contain tailings particles. The sediment captured in these sumps can be easily removed using an excavator and trucks (Figure 24) thus avoiding more challenging removal from the main geosynthetic lined impoundment.

Figure 23 TSF erosion after rainfall

Figure 24 Sediment removal from sediment catchment sump

The site has also developed operational practices to mitigate against excessive erosion. During the rainy season, site operations have found it useful to construct small temporary geosynthetic lined channels on the surface of the storage area to reduce slope distances that surface runoff travels which limits the development of higher velocity, concentrated flows which can lead to excessive erosion (Figure 25).

Figure 25 Geomembrane lined channels to reduce erosion and manage runoff

4.2 Piping and seepage collection systems

Separate pipe networks were designed as part of the overall surface and seepage water management systems for the facility. Given the compact footprint of the site, some portions of the surface flow are conveyed from the TSF to the sediment sumps or for non-contact water, to discharge points downstream of the TSF area. Perforated pipes were installed below the lined facility to control natural groundwater levels. The liner system itself incorporates an underdrain system to control water levels above the liner and leakage detection system was also installed to monitor for any leakage through the upper membrane liner. The designed system includes a significant number of buried piping systems. Each buried piping system is surveyed during construction and detailed mapping is created and posted at key pipe outlets (Figure 26). This allows for tracking of where the flows come from, and water quality, sediment content and flow rates can be monitored.

Where contact surface runoff is directed into pipe conveyance, site has developed an inlet configuration to prevent clogging with eroded tailings material. This configuration includes the use of small sumps immediately upstream of the inlets. Each system has multiple (redundant) inlets with openings covered by screens (Figure 27).

Figure 26 Water discharge pipes with detailed map

Figure 27 Surface water runoff collection inlet configuration

5 Integrated tailings and risk management system

Due to the importance of tailings management, Efemçukuru has adopted a continuous improvement approach to the performance level of their TSFs. As part of the goal of following best practices, the mine has adopted the MAC-TSM tailings management protocols (MAC 2019, 2021a) and it is currently looking at aligning MAC practices to GISTM (Global Tailings Review 2020). External evaluations have confirmed that Efemçukuru's tailings management system meets the highest level (AAA) according to the MAC-TSM protocols (Stantec 2022). Key components of the tailings management system at Efemçukuru include:

- Development of consistent policies and commitments to the principles of responsible tailings management.
- A training program for employees, specific to their roles and responsibilities related to tailings management.
- Development of an OMS manual in collaboration with the facility design team. The Efemçukuru OMS was developed following guidelines provided by MAC (MAC 2021b).
- A detailed facility risk assessment (Stantec 2019). This is required for a risk-based management approach and allows for key risks to be identified, and critical controls to be developed. The risk assessment also informs the development of risk-specific Trigger, Action, Response Plans (TARP), as well as the Emergency Preparedness Plan (EPP) and Emergency Response Plan (ERP) (Uzunçelebi et al. 2022).
- Internal audits are completed annually or sooner if a major event or design change occurs. Internal audits documented in an annual review report prepared by the site tailings management team and design engineer of record. This report is submitted and a review meeting is held with company senior-level executives responsible for the TSFs.
- External audits are carried out by an Independent Technical Review Board (ITRB). The ITRB is currently composed of three subject matter experts that are not involved in the ongoing design or operation of the TSF.

6 Conclusion

The adoption of filtered tailings technology is rapidly increasing in the mining industry and is often accepted as BAT for tailings management (understanding each site should be assessed independently). This was the case for the Efemçukuru Mine where the opportunity to reduce the disturbance footprint, minimise impacts to local water sources, mitigate potential downstream risks and demonstrate progressive reclamation made filtered tailings the site-specific BAT.

This paper provided an overview of the operational, design and risk management practices that have allowed the Efemçukuru tailings technical and operational team to be successful in the implementation of the first filtered tailings operation in Turkey. The mine's operational experience since start-up in 2011, as well as a continuing corporate commitment to adopting international best practices and standards have made the site an example for the Turkish mining industry. The benefits of the filtered tailings storage method have exceeded Tüprag's expectations and it is hoped others in the industry are able to benefit from their experience.

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