Practical Considerations for the Design and Construction of a HDPE-Lined Tailings Storage Facility

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Abstract

In recent years, the requirements for a barrier system between a tailings storage facility (TSF) and the natural ground surface have significantly changed. In most cases the requirements have specified the need for a high-density polyethylene (HDPE) geomembrane as part of the barrier system design. HDPE geomembrane lining systems can reduce the amount of groundwater contamination if designed and installed correctly however, it does increase the complexity of designing, constructing, and operating a TSF. Historically the South African legislation did not explicitly require the classification of tailings as a hazardous waste product but now does, which essentially requires some form of barrier system, which includes a HDPE geomembrane. This has consequently resulted in limited practical experience, amongst tailings engineering practitioners, in the design and construction of HDPE-lined TSFs. The purpose of this paper is to provide guidance on design complexity, detail specifications, construction sequencing, stormwater management and other practical considerations from experience gained whilst performing quality control and quality assurance on the construction of a new HDPE-lined TSF.

Keywords: *HDPE, liner, geomembrane, tailings, guideline, design, construction*

1 Introduction

Government Notice R635, 2013, requires the classification of mine tailings according to the chemical properties and the properties of the leachate originating from the tailings. Classification as a Type 1 to Type 4 waste requires the construction of a Class A to D landfill containment barrier, respectively, as specified in Government Notice R635, 2013. A Class A to Class C landfill containment barrier specifies the need for a high-density polyethylene (HDPE) geomembrane as part of the barrier system design.

The requirements set out in Government Notice R635, 2013, and Government Notice R636, 2013, are recent requirements from a tailings management perspective. There is therefore limited practical experience in the design and construction of a HDPE-lined tailings storage facility (TSF) in South Africa. The purpose of this paper is to provide examples, based on the author's own practical experience, of how the approach towards design and construction should be adapted to cater for barrier systems which include geomembranes. The considerations discussed should provide guidance on how the design and construction methods can be adapted and simplified for optimal execution of the works. Although the considerations identified in this paper are specific to a Class C Landfill, the fundamental basis behind these considerations remain applicable to other landfill classifications.

2 Characteristics of a HDPE-Lined TSF

2.1 Barrier System Requirements

Waste material classified as a Type 3 waste (Government Notice R635, 2013) requires the construction of a Class C Landfill barrier system (Government Notice R636, 2013). Figure 1 below presents an extract from the Waste Act presenting the minimum requirements for a Class C Landfill barrier system.

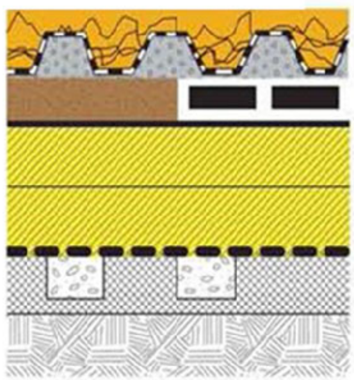

Figure 1. Requirements for a Class C Landfill barrier component (Government Notice R636, 2013)

There are four major components which comprise a Class C Landfill barrier system, namely:

- An under-liner drainage and monitoring system,
- a barrier component consisting of a geomembrane and constructed/in-situ compacted clay,
- a protection component, and
- an above liner drainage system.

The barrier component is required to have a low transmissivity. The result of this is a build-up of positive pore pressures above the barrier component and negative pressures below the barrier. This increases the possibility of localized seepage through the barrier. The purpose of the above-liner drainage systems is to maintain the pressures around the barrier system as close to atmospheric pressure as possible by reducing the hydraulic head above the barrier system. The under-liner drainage system serves to capture flow originating from rising groundwater conditions, reducing pressure on the barrier system from subsurface water.

For the purposes of this paper the barrier system has been altered to represent that of a typical TSF. The above-liner drains have been adapted to a herringbone drainage structure with the addition of larger drains to draw down the phreatic surface, assisting stability requirements. The thickness of the geomembrane has been increased, eliminating the requirement for an additional clay barrier beneath the geomembrane while having a similar performance. A bedding layer has been included which allows the geomembrane to be placed on material which would not compromise the integrity of the geomembrane.

2.2 Drainage Elements

Drainage elements are essential to draw down the phreatic surface in a TSF and to ultimately provide stability to a TSF. Figure 2 below presents a simplified drainage layout of a ring-dyke TSF configuration which consists of the following drains:

- A blanket drain and a toe drain to draw down the phreatic surface in the outer wedge of the TSF,
- chimney drains which convey flow from the curtain drain, constructed as part of operations, to the outlets,
- basin drains, to reduce the hydraulic head on the geomembrane, and
- an arterial drain, to convey flow captured in the basin drains to the outlets.

The layout of the drainage system is such that all drains convey flow to a single outlet located at the lowest point of the TSF.

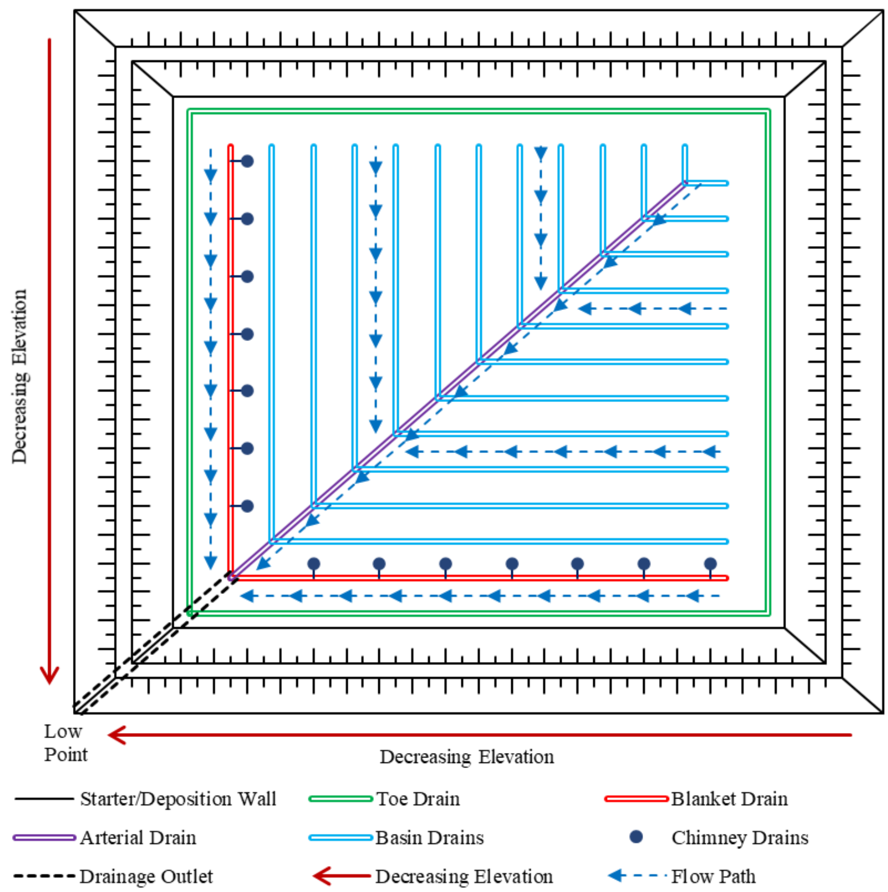

Figure 2. Typical above-liner drainage layout of a HDPE-lined TSF

3 Design Considerations

This section offers some considerations on how the design of a barrier system can be adapted to ease the construction of these elements. It will also evaluate some specific elements which can assist the reader in better understanding the practical aspects of lining.

3.1 Stormwater Management

Stormwater management is essential for the success of a project when working with a geomembrane. By placing an impermeable layer on the natural ground, it is essentially removing the possibility of infiltration through the foundation materials. This will result in a greater buildup of stormwater than that of an unlined facility. Consequently, water will build up on the geomembrane and migrate towards the nearest drainage location along its flow path. Higher volumes of flow will be concentrated towards a specific location, flowing over a smooth surface at a higher velocity than what would be expected in an unlined facility. The resulting effects could be catastrophic if proper consideration has not been given to stormwater management.

3.2 Stormwater Protection Bunds

As the purpose of a drainage system in a TSF is to drain water, it is specifically designed to capture and convey flow out of the TSF. While the drains are exposed, during construction and early deposition, stormwater captured in the basin will migrate towards the drains, eroding any exposed drainage material. To avoid unnecessary reworks, it is essential to protect the drainage material from stormwater. This section will explore the option of constructing stormwater protection bunds on the upstream and downstream side of the drains to divert flow to run along the outside of the drains, without compromising the integrity of the drains.

Figure 3 presents a typical section through a stormwater protection bund constructed on the upstream side of a drain. The stormwater protection bund is located proud of the natural ground level (NGL), upstream of the drain. The barrier components of the barrier system are specifically designed to extend over the bunds as this has the added benefit that the geomembrane will prevent stormwater run-off from eroding the bunds. The protection layer above the geomembrane can either be mechanically placed or placed through selective deposition. If selective deposition is used, the geomembrane will remain exposed until deposition commences. Drainage layers typically consist of a conveyance layer, which conveys flow from the drains, and filter layers, which prevents the migration of fines into the conveyance layer.

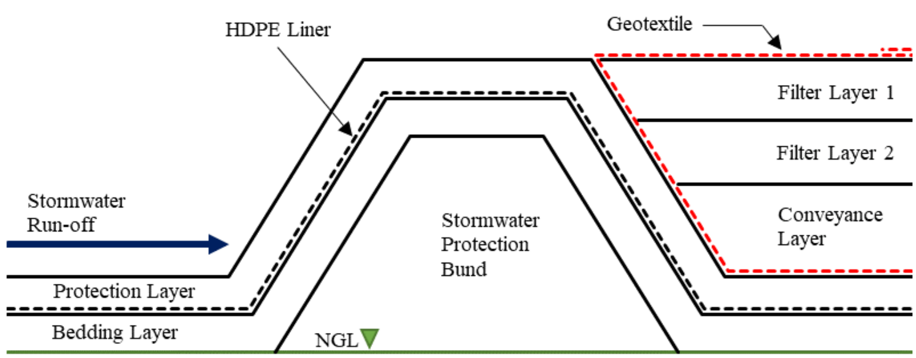

Figure 3. Section through a typical drain and stormwater protection bund

Wrapping the drainage materials in a temporary geotextile will be beneficial in protecting the drains from stormwater damage. The geotextile layer will provide some integrity to the drainage materials and will prevent foreign materials from contaminating the drains. The combination of a temporary geotextile along with stability bunds will provide direct protection to the drainage materials from run-off originating on the drainage surface area. The geotextile layer will also prevent the ingress of fines from the geomembrane protection layer into the drainage materials. Immediately prior to deposition, the geotextile layer is removed from the top filter layer to expose the drainage materials.

By including stormwater bunds along the edges of a drain, stormwater, which would previously have migrated towards the drains from an upstream location, will be diverted to follow an alternative flow path. The altered flow path can be manipulated so that stormwater run-off is diverted towards the arterial drains or main conveyance drains, as indicated in Figure 2. It is not required of arterial drains to capture flow but rather convey flow from the basin drains. It is therefore preferable to divert stormwater run-off towards arterial drains while they are exposed as they contain predominantly gravely material, which is less susceptible to erosion and wash away.

3.3 Basin Complexity

The addition of a barrier system beneath a TSF significantly increases the complexity of the basin topography for construction. As infiltration into the natural ground is prevented, an increase in drainage elements in the basin is required to draw down the phreatic surface in the TSF. With additional drainage requirements it is essential that the complexity of the drainage layout be minimized to simplify construction and liner deployment in the TSF. An example of a complex drainage layout is presented in Figure 4.

To interpret Figure 4, flow is conveyed through a chimney drain which is then conveyed to an outlet pipe which exits through the base of the chimney drains. The chimney drain outlet pipe is located in a channel which then connects to the blanket drain. Flow captured in the chimney drain and blanket drain is then conveyed to an outlet channel from which flow exits the facility. There are multiple aspects presented in Figure 4 which will complicate geomembrane deployment, namely:

- The chimney drain outlet channels runs directly onto the chimney drain base. The geomembrane will have to be battened to the base at a 90-degree angle to the horizontal and will have to extend up the slope of the sides of the channel.
- The misalignment between the outlet channel and the chimney drain outlet channel will lead to unnecessarily having to trim and cut geomembrane to required lengths, leading to excessive wastage.
- The connection between the outlet channels and the blanket drain bunds will require a complicated panel layout to adhere to requirements stated in SANS 10409.
- Access is limited to the blanket drain, complicating deployment of geomembrane in the drain.
- Complex slope changes will require high-quality lining to adhere to the requirements of SANS 10409 which prohibits horizontal welds on slopes steeper than 1(V):5(H).

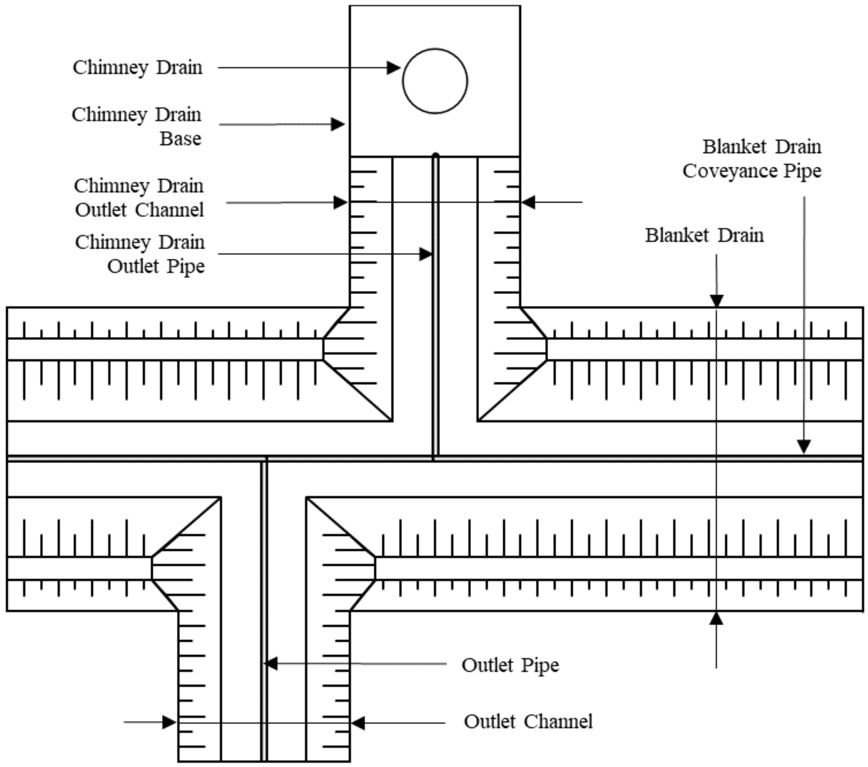

Figure 4. Complex chimney and blanket drain system

The layout presented in Figure 4 can be simplified for construction by considering the following adjustments:

- Aligning the chimney drain outlet channel and the outlet channel.
- Decoupling the chimney drain and the blanket drain allowing the chimney drain outlet to exit the TSF independently.
- Removing the outlet channels, allowing the blanket drains to run continuously, and allowing the outlet pipes to penetrate through the geomembrane where it intercepts the berms. A pipe boot can be used to connect the geomembrane to the outlet which would require less complicated procedures to construct.

3.4 Detail Specifications

This section serves to provide some examples of where the detailed specifications should be specified in such a way that accounts for the installation process of a geomembrane. Specific emphasis will be placed on drain sizing, pipe penetrations, geomembrane-structure anchorage, and temperature effects.

When sizing a drain, the way the geomembrane is manufactured and installed is often overlooked. Geomembranes are typically delivered in rolls of a specific width and length, depending on the type of geomembrane specified. During installation the rolls must be rolled out and placed in position. Multiple rolls are welded together to create a continuous surface over the desired area. If it is required for a drain to be lined, the width of the geomembrane rolls should dictate the width of the drain. The reason for this is the requirement from SANS

10409 which prohibits horizontal welds on slopes steeper than 1(V):5(H). An allowable weld on these slopes would be at a minimum angle of 45 degrees to the horizontal. The drains must therefore be sized in such a manner that welds between panels can be created on flat surfaces. The total width of the stormwater bunds should be less than a single panel width, with a 500 mm allowance for welding on either side of the bund. If the width of the drain, including the bunds, is greater than two panel widths, the inner base width of the drain should be wide enough to accommodate a single roll of geomembrane, or alternatively half a roll, to avoid excessive wastage. The deployment rate of lining a drain longitudinally is faster than lining the drain laterally across the drain.

When it is required for a pipe to penetrate through the geomembrane, a pipe boot would typically be used for this transition. A pipe boot typically consists of a HDPE pipe which has been manufactured with a HDPE plate welded to the pipe. During construction the pipe boot is initially joined to the penetrating pipe either through welding or flanges. The area behind the plate is backfilled to create a bedding layer for the plate. The surrounding geomembrane is then extrusion welded to the pipe boot plate resulting in an airtight seam. When specifying the dimensions of the pipe boot to the manufacturer, special attention should be given to the angle at which the plate needs to be welded to the pipe. The thickness of the plate should be sufficient to support the geomembrane to which it will be welded. In the case of multiple penetrating pipes at a single location, multiple pipes should be joined to a single plate. In this case it is recommended that the dimensions and spacing of the pipes be measured after installation to avoid misalignment. The size of the plate should be sufficient to allow for welding equipment to access the location where the plate will be welded to the surrounding geomembrane. The overlap between the end of the pipe and the edge of the plate, and between pipes should be at least 500 mm to allow for access of the welding equipment.

The design of a TSF requires various infrastructures which need to be connected to the lining system. These can include chimney drains, chimney drain bases, penstock outfall pipelines, etc. Tie-ins are required to join the lining system to the structures. There are two options, namely; casting a HDPE profile into concrete structures, or mechanically anchoring the geomembrane to structures. When working with a HDPE profile it is required to cast the HDPE profile into the structure as concrete is being poured. This requires special attention as the addition of a HDPE profile during concrete pouring can easily be overlooked. Mechanical anchorage has the added benefit of being applied at any stage after the structure has been constructed. A HDPE profile requires that the surrounding geomembrane be extrusion welded to the HDPE profile. Extrusion welds can provide sufficient tensile strength for the connection however, the quality and uniformity of the weld is entirely dependent on the skill level of the welding technician. Mechanical anchorage consists of bolting the geomembrane between the structure and a steel plate which provides a uniform connection between the structure and the geomembrane as the frequency of bolting and applied torque can be controlled.

HDPE is highly susceptible to temperature effects being a flexible material. The geomembrane is constantly undergoing an expansion and contraction cycle. It is therefore essential to account for temperature effects when designing a HDPE-lined TSF. According to SANS 10409, only the number of panels which can be welded in a day may be deployed. Panels deployed on consecutive days must undergo a complete expansion and contraction cycle before they can be welded together. Closure welds are used between panels deployed on consecutive days and in locations where there is a sudden change in slope. Closure welds reduce the possibility of trampolining and wrinkle formation on the geomembrane.

Due to the differential settlement occurring between structures and the surrounding soils, a slack should be specified in the geomembrane at these locations. However, specifying slack is not a simple task and is sensitive to varying temperature effects. To account for this, tie-ins should only be done at temperatures lower than what would be expected at the base of a TSF. If tie-ins are done at higher temperatures, the geomembrane will contract during operation, separating from the bedding layer and causing loads to be applied directly to the geomembrane.

4 Construction Considerations

4.1 Protecting the Works

Protecting the works during the deployment of geomembrane and drain construction is crucial to the success of a project. It is more feasible to assess how the works can be protected as deployment progresses as there are too many variables which can influence a planned procedure. There are two aspects to consider regarding stormwater management during deployment, specifically relating to the origin of stormwater run-off which can either accumulate upstream or on the deployed geomembrane. Reference to a typical flow path is presented in Figure 2.

With stormwater run-off originating from a location upstream of the deployment area the major risk is that flow will infiltrate beneath the geomembrane. This will result in the integrity of the bedding layer being compromised. Flowing water beneath the geomembrane will erode the bedding layer as well as introduce foreign materials into the bedding layer. As a result, the geomembrane, overlaying the affected area, must be removed to repair the bedding layer. This will lead to an unnecessary waste of liner to repair the area where the geomembrane had to be removed, not to mention a delay in the construction schedule. To prevent this from happening the following measures can be implemented:

1. Ensuring that the geomembrane has been welded and sealed along all critical flow paths. Openings along flow paths will result in stormwater infiltrating through the geomembrane and into the bedding material.
2. Anchoring the upstream edges of the geomembrane by placing the leading edges into a small trench and backfilling the trench to the same level as the geomembrane. This will allow stormwater to flow directly onto the geomembrane.
3. Constructing a diversion berm along the upstream leading edge of the geomembrane to divert stormwater run-off towards a less critical area.

Stormwater run-off originating from the deployed geomembrane surface poses a risk to all elements constructed downstream of the geomembrane. An impermeable geomembrane removes the possibility of infiltration into the natural ground and has a significantly lower roughness coefficient than the natural ground. This results firstly, into higher volumes of stormwater accumulating on the geomembrane and secondly into a greater flow velocity over the geomembrane. High flow velocities will cause devastation to any exposed elements constructed along flow paths downstream of the geomembrane. The provision of berms will not be as effective for downstream protection as the high flow velocity will eventually erode the berm. To prevent damage to downstream components it will require planning deployment operations to commence at the low points of the TSF basin. Deployment should start at the areas where drainage out of the basin is provided and extend to cover the low points, ensuring that the geomembrane has been sealed to prevent stormwater penetrating to the supporting layers. Priority should also be given to areas where high flow is expected.

4.2 Construction Sequencing

Construction activities for the barrier system cannot be performed concurrently as each component (excluding the below geomembrane drainage system) requires the completion of the previous component to commence. Common activities which can be expected for the construction of a barrier system include the following

1. Removing topsoil from the basin area, shaping and preparing the basin, excavating the trenches required for the under-liner drainage system.
2. Constructing under-liner drains with specified drainage and filter materials.
3. Constructing above-liner drain berms and excavating to the required drainage depth.
4. Placing a bedding layer of specified material over the area to be lined or compacting the in-situ material accordingly.
5. Lining the specified area, ensuring the geomembrane has been sealed and approved.
6. Placing a protective layer over the geomembrane.
7. Constructing the above-liner drainage system.

With multiple concurrent activities it is essential that proper planning be given towards the sequencing and timing of these activities. Items 1 to 4 need to be completed before lining operations can commence. Items 6 and 7 can only commence once the desired location has been lined. If there is a delay in production of one of these items, it will have an impact on all succeeding activities. The following aspects should be kept in consideration when planning the sequence in which construction activities will be completed:

- Achievable production rate, including quality control checks, with available resources, for each activity (the production rate which can be obtained for the various activities i.e. geomembrane deployment, drain construction, surface preparation, etc.). The production rate for the entire barrier system will essentially be dictated by the lowest achievable production rate.
- The required production rate which needs to be achieved to meet the deadline of the project. The required production rate will dictate what the production rate for each of the activities should be to meet the deadline.

Production tracking is essential to a successful project and should be used as a guide to determine where improvements can be made to aid production of the entire site.

Access must be provided for the construction of each of the drainage aspects. A good example of where access is limited is during the construction of the above-liner drains over the geomembrane. Heavy vehicle traffic is prohibited on a geomembrane as it could diminish the integrity of the geomembrane (SANS 10409). This creates a dilemma when trying to transport and place material for the drains. To allow for access of heavy vehicles, one side of the drain needs to remain unlined. Halting lining operations for drain construction will inevitably impact production. To mitigate a delay in production it would be beneficial to have a second, independent, area prepared for lining. This complicates the sequence of construction activities.

Planning the sequence of construction of a barrier system must consider two major aspects namely, production and access. The following suggestions can be used in preparing a construction sequence:

- Dividing the basin into sections to define the order in which the barrier system in different each area will be constructed. These sections should be divisions of the flat areas between drains. The sequence of lining the drains should also be included in the planning process.

- Starting construction of the barrier system in the lowest areas of the basin and moving outwards. These areas will typically run along the starter wall. It could be beneficial to perform lining operations along lines running parallel with the starter wall, and the drains, as this will provide access for future lining and drain construction and has the added benefit of having multiple areas available for deployment.
- Multiple areas should be available for lining at any given time. This will mitigate any delays caused by operations which occur after the placement of geomembrane

5 Conclusion

Stormwater management and protecting the works are some of the most important aspects which need to be considered for the construction of a TSF. Failure to do so will have a negative impact on the project and could lead to major reworks. Minor details such as detail specifications construction sequencing can benefit a project greatly if they are implemented properly.

Although the requirement for a barrier system is beneficial from an environmental perspective, it does increase the complexity of designing and constructing a TSF. The aspects discussed in this paper are based on the author's own experience and presents ways in which aspects can be improved from the author's perspective. The information presented should not be used as a template for future designs but should provide guidance on how the design and construction of a HDPE-lined TSF can be approached for optimal performance. A mind shift in the right direction can have a major impact on the success of a project.

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