Engineering

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General Technical Information for Geotechnical Design - Lined Storages

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Only the current revision of this Guideline should be used which is available for download from the SA Water website.

Significant/Major Changes Incorporated in This Edition

This is the first issue of this Technical Guideline under the new numbering format. The original version of the document was last published in 2007 with the name of General Technical Information for Geotechnical Design Part F – Lined Storages (TG 10f). A full version history of this document is given in Document Controls. The major changes in this revision include the following items:

- Minor revision of Section 3 (formerly Section 2 in TG 10f)
- Minor revision of Section 4 (formerly Section 3 in TG 10f)
- Major revision of Section 5 (formerly Section 5 in TG 10f)
- Major revision of Section 6 (formerly Section 4 in TG 10f)

Document Controls

Revision History

Revision	Date	Author	Comments
0	2004	Ed Collingham	First Issue of TG 10f
1	10/1/2007		Nil
2	25/10/2019	Moji Kan	Major Revision, Reformatting to TG 0636

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1 Introduction

SA Water is responsible for operation and maintenance of an extensive amount of engineering infrastructure.

This guideline has been developed to assist in the design, maintenance, construction, and management of this infrastructure.

1.1 Purpose

The purpose of this guideline is to detail minimum requirements to ensure that assets covered by the scope of this guideline are constructed and maintained to consistent standards and attain the required asset life.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
CSS	Cement Stabilized Sand
CTQR	Cement Treated Quarry Rubble
DPTI	Department of Planning and Transport Infrastructure
EPA	Environment Protection Authority
FS	Factor of Safety
I/O	Inlet (Intake) and Outlet (Outtake)
LES	Lined Earth Storage
MDD	Maximum Dry Density
SA Water	South Australian Water Corporation
SPM2/20QGC4	20 mm Class 2, 4% Cement Stabilised Quarried Material
TG	SA Water Technical Guideline
TS	SA Water Technical Standard
TWL	Top Water Level

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
EPA 509/18	Guidelines on Wastewater Lagoon Construction, EPA, October 2018

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
TS 0460	Liners and Floating Covers for Earth Bank Storages for Potable or Recycled Water

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for TG 0636 defined on page 3 (via SA Water's Representative)

2 Scope

The scope of this document is to provide guidelines for the geotechnical aspects of design of the lined storages for SA Water infrastructure.

3 Lined Earth Storages – Design Principles

Lined (and covered) earth storages are one of the popular storage systems in SA Water. This is mainly because they appear to be an economical way of meeting the need to store large volumes of treated water out of contact with the ground and covered from the air. For sites where lined earth storages are appropriate, certain basic design constraints should be observed if their full benefits are to be realised and their shortcomings avoided.

The purpose of these notes is to provide designers with a checklist of the basic design principles for lined earth storages so that design pitfalls can be avoided.

This section shall be read in conjunction with SA Water Technical Standard TS 0460 – Liners and Floating Covers for Earth Bank Storages for Potable or Recycled Water.

Table 1 shows the basic constraints that may favour a lined earth storage over aboveground tank option. General design notes about the lined earth storages are given in Table 2.

Table 1: Basic design constraints of lined earth storage vs aboveground tank

Conditions that favour a Lined Earth Storage	Conditions that favour an aboveground tank
Large storage volume (> 20 ML)	Smaller storage volume (< 20 ML)
Deep soil profile – no rock in the excavation	Rock foundation at shallow depth
Large site – no boundary constraints	Restricted or oddly shaped site
Flat site with balanced cut and fill	Steep slopes acceptable
Internal slopes can be 1V:3H or flatter	Internal slopes of a LES on the site would have had to be steeper than 1V:3H
External slopes can be 1V:3H or flatter	External slopes of a LES on the site would have had to be steeper than 1V:3H
Shallow depth / large area of storage desirable	Tall tank required (surge tank / water tower)
Excavator can reach all of slope from floor/top	LES would have had to be too deep for an excavator to reach all of the slope from floor/top
Floating cover is acceptable	Fixed roof is desirable or needed
Few penetrations (e.g. I/O sumps) through liner	Many penetrations (e.g. column bases) needed
No penetrations on slopes	Penetrations (e.g. column bases) would be required on the slopes
Design TWL at about site natural surface level	Design TWL well above site natural surface
No bushfire and/or no vandal risk	Significant bushfire and/or vandal risk present
Infrequent cleaning required	Frequent cleaning required
Low visual impact desired (low-angle outer slopes can be landscaped to look “natural”)	Visual impact less of an issue (or because of small size the tank can be screened with trees)

Table 2: General considerations in design of lined earth storages

Design Feature	Description
Slopes Angle	**1V:2H (26° or 50%):** Cannot be safely walked on irrespective of their surface finish. Cannot be worked on by construction plant or rollers of any kind. The slope itself may be unstable in some soils or jointed rocks. Ordinary sand (with an angle of friction of say 30°) would be on the verge of stability on this slope – so only stabilised materials could be used to smooth the slope or as a liner-bedding layer, and even these would be difficult to place and compact. It may be difficult to bond/interlock a stabilised material to a slope this steep – it may be necessary to cut key pockets, drape a geogrid down the slope, or use a "structural" liner-bedding layer (e.g. reinforced shotcrete). **Slopes 1V:3H (18° or 33%):** Can just be safely walked on if they have a non-slip finish (e.g. not a wet liner). Can be climbed by some tracked plant if the surface is stable and not slippery. Only towed rollers can be used (not rigid chassis). Ordinary sand (with an angle of friction of say 30°) would have a factor of safety of only 1.7 on this slope. Sand would be easily displaced during construction, and both sand and rubble may become unstable if saturated during operation – it may still be desirable to use stabilised material to smooth the slope or as a liner-bedding layer. **Slopes 1V:4H (14° or 25%)** Can be easily walked up. Can be worked on by most construction plants across the slope as well as up and down. If the surface is stable and not slippery, they can be driven up in a 2WD vehicle. Rigid chassis rollers are allowed. Sand or rubble may be used as the smoothing or liner-bedding layer. The FS for sand with an angle of friction of 30° would be 2.3. **Slopes 1V:5H (11° or 20%)** They have a "natural" landscaped appearance. They can be readily walked up or driven on in a 2WD vehicle. They are relatively resistant to erosion by rain or irrigation runoff and can be mown by most ride-on mowers.
Slope Finish	All pockets/voids in the floor/slopes must be filled and bumps flattened. Excavations in the floor/slopes should be backfilled either with material with a similar compressibility to the surrounding material (e.g. concrete if in rock), and/or a gradual transition detail incorporated.
Liner Bedding Layer	If the floor and/or slopes cannot be trimmed and/or rolled to an acceptably smooth finish, then a liner bedding layer may be required. This may consist of compacted sand or rubble fill, but the stability of such materials on saturation followed by "rapid drawdown" in the storage should be considered.

	An ideal material is cement-stabilised sand as it gives a smooth, tough, slip resistant, bedding layer that will also stabilise the surface beneath. Cement stabilised sand (CSS) is particularly effective at smoothing and locking together the surface of jointed rock cut slopes or rocky fills. If the CSS is made using very clean coarse sand / fine gravel (grit) and 8% cement, and if it is only lightly screeded (not compacted) into place, then not only will the liner bedding layer have good strength, but it will also be very permeable both across its thickness and down the slope. It will therefore act as an excellent underdrainage layer for the slopes and/or floor.
Underdrainage	The design of all water storages should allow for the foundation to become saturated from leakage and/or external groundwater inflow. For lined earth storages an engineered underdrain system will generally be necessary – at least beneath the floor. See liner bedding layer above. The outlet should be brought to the surface so the discharge can be monitored. See TS 0460 for more details about the underdrainage and leakage detection systems.

4 Examples of Lined Storages

This section shows some historical photos of construction of the lined earth storages for SA Water. This section was prepared in January 2003 and is retained here to keep the track record of technical notes on earlier SA Water lined earth storages.

Plaque 1: An irrigation storage in the Clare Valley showing the prepared soil surface. A geotextile underlay is often used where the soil contains sharp rubble, but in this example, there is none.

Plaque 2: The same storage as above about a year later. Internal slopes are about 1 on 4. A low slope such as this makes it easy to compact the surface and to roll-out and weld the liner. It also reduces the tendency of the liner to creep down the slope.

Plaque 3: Another lined irrigation water storage in the Clare Valley. The internal slope on this one appears to be even flatter – about 1 on 5. There is no tension on these liners, so the top edge is simply turned down into a shallow trench and backfilled. Current SA Water standard practice requires that the top of the liner be fixed to a perimetric concrete ring beam all around the storage.

Plaque 4: Another Clare valley irrigation water storage with a very flat internal slope. Note that on this one there is almost zero width at the top of the embankment.

Plaque 5: The treated effluent storage at Christies Beach WWTP. Note the varying freeboard – instead of cutting a bench at a fixed elevation, the liner was continued up the slope to the left until it was convenient to return it into the ground.

Plaque 6: The treated effluent storage at Christies Beach WWTP. The fence has a concrete footing/path and the liner is simply returned into a backfilled trench. It is required to avoid having sharp aggregates anywhere near a liner.

5 Control of Infiltration from Lagoons

5.1 Introduction

A proportion of the water discharged into a disposal basin will be lost by infiltration. The task of the designer is, generally, to minimise the infiltration and to predict its impacts such that the acceptability of operating the basin can be assessed.

The minimisation of infiltration can be achieved by selecting a site underlain by an effective natural aquitard. Infiltration will also be limited where a basin is close to or below the pre-existing water table and distant from any groundwater discharge point such as a river.

The natural attributes of a site can be enhanced by placing a synthetic liner on the floor of the basin, or by surrounding it with ditches, drains, wellpoints or bores and returning the intercepted infiltration to the basin.

5.2 EPA requirements for limiting infiltration from wastewater lagoons

The EPA Guideline 509/18 specifies that the permeability of clay lining of wastewater lagoons must not exceed 1×10^{-9} m/s. A geotechnical professional must confirm the limiting thickness against specifications and finished lining must be tested to ensure that it meets the permeability criterion. Regular maintenance should be undertaken to ensure this permeability is maintained throughout the lifetime of the lagoon.

5.3 Generic specification for the design of infiltration loss control systems for lagoons

Acceptable designs might include any or a combination of the following:

- Reliance on undisturbed natural materials in the floor and side slopes of a lagoon whose properties; lateral extent and depth have been proven by investigation.
- Reliance on a low hydraulic gradient between the lagoon top water level and any receiving surface waters or groundwater.
- The construction of surface or sub-surface interceptor drains with pumping back to the lagoons.
- The construction of a compacted natural clay liner beneath the floor and side slopes of the lagoon (including an overlay of sand or gravel to ballast and mechanically protect the clay and prevent it drying out).
- Fill embankments whose inside face consists of 2 m (measured horizontally) of compacted clay soil.
- A geosynthetic clay liner system such as Bentofix™ or Claymax™ (including an overlay of sand, gravel, quarry rubble or cement treated quarry rubble to ballast and mechanically protect the clay and prevent it drying out).
- A geomembrane liner system.

Where there is more than one lagoon in a group, and a liner system is to be used, each lagoon may be lined individually.

The design of any liner system shall allow the sludge to be removed from the lagoons using wheeled plant without damage occurring to the liner.

6 Clay Liner for Sludge Lagoons

6.1 General

This section with slight modifications was originally developed in December 2003 for design and construction of sludge lagoons using clay liners. This section shall be read in conjunction with further requirements outlined in TS 0460.

6.2 Clay liner placement

The clay liner shall cover the whole floor and all sides of the sludge lagoons up to the top of the embankment fill (i.e. to the underside of the paving). The designers should determine and confirm the required thickness of the liner. However, the total thickness of the clay liner shall not be less than 300 mm. The tolerance on the thickness of the clay liner shall be minus 0 mm to plus 50 mm.

The following method shall be used to ensure that permeability of the clay liner is ≤ $1x10^{-9}$ m/s.

- Percentage of fine shall not be less than 25%.
- The clay shall be non-dispersive of low/moderate plasticity.
- The clay shall not contain more than 20% of fine/medium gravel.
- The clay shall be placed in layers not exceeding 150 mm loose thickness. The placing and compaction procedures shall be carried out in such a way as to prevent the drying out of the clay.
- Each layer shall be compacted to not less than 98% of Standard Maximum Dry Density.
- Prior to placing the clay, the moisture content of the clay shall be within 1% Dry to 3% Wet of Standard Optimum Moisture Content.
- Before placing the new lift, surface of the previously compacted layer shall be scarified to a depth of at least 50 mm. If the surface dried out and/or cracked, it shall be ripped or disc-ploughed to at least 50 mm below the depth of drying or cracking then watered and mixed.
- Each layer shall be placed and compacted over the internal surface of the lagoon before any part of the next layer is started.

6.3 Clay liner protection

The clay liner shall be permanently protected from mechanical damage and drying-out. Minimum thickness of the clay liner protection shall not be less than 250 mm. Three options of liner protection could be used. These options are discussed in following sections.

6.3.1 Sand/Gravel cover

The clay liner shall be permanently protected from mechanical damage and drying-out by a layer of sand/gravel. The sand/gravel layer shall not be susceptible to erosion by water flow. The sand/gravel cover shall be placed in one layer. The sand/gravel shall be compacted to not less than 95% of Standard Maximum Dry Density and shall be placed in layers not exceeding 150 mm thick when compacted, and each layer compacted separately.

6.3.2 Clay cover

As per Section 6.3.1, with exception of the following:

- The clay cover shall be placed in one layer.
- Compaction ratio shall not be less than 92%.

6.3.3 Cement Treated Quarry Rubble (CTQR) cover

This probably would need a synthetic membrane between the clay liner and the CTQR. Allow for the supply, placement and compaction of SPM2/20QGC4, as per DPTI specifications. Place and compact the CTQR within 2 hours of delivery to site. Place and compact the CTQR to 92% of Standard Maximum Dry Density.

6.4 Geosynthetic Clay Liner with CTQR overlay

A geosynthetic clay liner consists of a layer of bentonite clay powder sandwiched between two layers of geotextile filter fabric. It is about 5 mm thick (when dry) and is supplied in rolls. A geosynthetic clay liner can be laid directly on a rough surface (stones protruding up to 20 mm). Following further steps will be needed where a clay liner is used to control the infiltration from sludge lagoons.

6.4.1 Additional excavation

For those parts of the lagoons in excavation, excavate an additional excavation beyond the finished surface.

6.4.2 Reduction in fill

For those parts of the lagoons in embankment, finish the embankment fill short of the finished surface.

6.4.3 Preparation of the cut and fill surfaces

Compact cut and filled surfaces to 95% of Standard MDD to a depth of 150 mm.

6.4.4 Geosynthetic clay liner

Allow for the supply and placement of one layer of geosynthetic clay liner over the floor and all sloping sides of the lagoons.

6.4.5 CTQR overlay

As with a natural clay liner, the geosynthetic clay liner needs to be surcharge loaded and protected from drying-out and mechanical damage by an overlay layer.

Allow for the supply, placement and compaction of a 300 mm thick layer of 4% cement treated quarry rubble (CTQR). Place and compact the CTQR within 2 hours of delivery to site.

Place and compact the CTQR to 96% of Modified MDD in layers not exceeding 150 mm compacted thickness.