2.5 Pond design and construction

Earthen pond design and construction must be based on the results of thorough soil and site assessments; see chapter 2.4 'Pond site investigation' for details. The design and construction of dairy effluent ponds should minimise the likelihood of seepage and pollution of groundwater or surface waters. Well defined standards of soil assessment and pond construction are necessary to ensure that the structural integrity of embankments, clay liners and associated pond features provide the level of security necessary.

Pond design and specifications

Pond sizing, shape and depth

For pond shape and depth, see chapter 2.3 'Anaerobic, aerobic and facultative ponds'. For storage requirements, see chapter 2.6 'Effluent storage requirement'.

Freeboard

Freeboard is the elevation difference between the full pond and the crest of the bank. Freeboard protects the bank from wave action, rilling, bywash flows and overtopping under high-intensity rainfall and fast filling. The freeboard of a pond needs to be specified for each situation to minimise the risk of overtopping. A minimum freeboard depth of 600 mm is mandated in SA (Environment Protection Authority 2003). Allow for 10% consolidation and compaction under stock or vehicle traffic.

Soil parameters

The propensity for seepage losses from earthen ponds is dictated by soil physical and chemical characteristics and the resulting hydraulic properties of the material forming the embankment, walls and floor of the pond. The soil characteristics of a site govern pond design and dictate the need for soil ameliorants and synthetic liners. Cohesionless soils provide poor embankment strength and cannot impound effluent. Heavy clays make suitable embankments and effluent storages but can crack when drying and are difficult to work when either wet or dry. Details of soil analyses and parameter thresholds are provided in chapter 2.4 'Pond site investigation'. Although not definitive, an indication of soil suitability is provided in Table 1. This is based on US Bureau of Reclamation (1977) and the Unified Soil Classification System (USCS) as per Standards Australia (1993).

Selective material placement

The various components of a pond and embankment should be zoned to allow appropriate materials to be used to the best advantage, providing for placement of specific soil layers in various zones of the pond. For example, dispersive soil layers could be confined to the floor, and layers consisting of natural lime or gypsum, which can enhance soil stability, could be used on the inner embankment.

Table 1. Rating of materials for embankments and pond floors.

Rating	Description	Percentage clay and silt and USCS rating	Linear shrinkage (%)	Emerson class No.
1 (Very good)	Very well graded coarse mixtures of sand, gravel and fines, D85 coarser than 50 mm, D50 coarser than 6 mm. If fines are cohesionless, not more than 20% finer than the No. 200 sieve.	Clay 10%–25%, silt + clay 20%–40%. These coarse-grained soils are generally suitable for use in earthworks. Such soils with a classification of GM of SM are not suitable for homogeneous or impervious zones of water storages. Soils are susceptible to tunnelling.	0–12	3, 7, 8
2 (Good)	(i) Well graded mixture of sand, gravel and clayey fines. D85 coarser than 25 mm. Fines consisting of inorganic clay (CL) with PI > 12. (ii) Highly plastic tough clay (CH) with PI > 20.	Clay 25%–40%. These generally fine-grained soils are suitable for most soil conservation earthworks. Pay attention to susceptibility to tunnelling and cracking.	12–15	2
3 (Fair)	Fairly well graded, gravelly, medium-to-coarse sand with cohesionless fines. D85 coarser than 6 mm; 0.5 mm < D50 < 3.0 mm. Not more than 25% finer than the No. 200 sieve.	Clay 10%–25%, silt + clay > 45%. These fine-grained silty soils have variable permeability and are likely to be erodible. Generally suitable only for upstream and downstream zones of a zoned embankment or in a modified homogeneous embankment with a filter zone.	17–22	4, 5
4 (Poor)	(i) Clay of low plasticity (CE and CL-ML) with little coarse fraction. PI 5–8. Liquid limit >25. (ii) Silts of medium to high plasticity (ML or MH) with little coarse fraction. PI > 10. (iii) Medium sand with cohesionless lines.	Clay > 40%. These fine-grained soils may leak if well aggregated, or may crack on drying if they have high-volume expansion or linear shrinkage values.	>22	6
5 (Very poor)	(i) Fine, uniform, cohesionless silty sand. C55 < 0.3 mm. (ii) Silt from medium plasticity to cohesionless (ML). PI < 10.	Clay < 10%, silt + clay < 20%. These coarse-grained soils are pervious and are not recommended for general use in homogeneous or impervious zones of water storages. Soils with a USCS rating of GC or SC may be suitable for water storage when well compacted at the optimum moisture content. A filter zone would be required.	None	Only clay soils can be dis-persive. Class 1 (Clay)

Source: US Bureau of Reclamation (1977).
PI: plasticity index.

Embankments

Pond embankments need to be constructed from appropriate material (see previous section) and appropriately compacted (see 'Compaction' below). Subsurface soil and geological conditions, identified in the site investigation, will dictate cut-off trench depth under an embankment. Although a minimum of 300 mm is recommended (NSW Dairy Effluent Subcommittee 1999), depths could range up to 2000 mm or, in special cases, more. The depth is dictated by the depth and thickness of pervious strata underlying the proposed site.

Batter slope

The maximum batter slope should be 2.5:1 for internal and external walls and embankments where a bulldozer is used; 3:1 where a compacting roller is used (NSW Dairy Effluent Subcommittee 1999); and not steeper than 2:1 (DPI 2004). Flatter batters better maintain embankment stability, facilitate compaction, protect against wave run-up and improve safety in pond construction and maintenance.

Crest width

The embankment crest width should be a minimum of 3.0 m (DPI 2004); 3.0 to 4.0 m is preferable to allow vehicle access for construction and maintenance (Bradshaw 2002a, Bradshaw 2002b, DairyCatch 2006, NSW Dairy Effluent Subcommittee 1999). Crest width must allow for desludging activities, which generally require heavy machinery (EPA 2004). Some contractors prefer at least one of the long sides to be 6 m wide and to have approach and departure ramps with a slope of 1:10 to provide access for machinery during desludging.

Pond construction

In preparing a site for pond construction, before any land disturbance, put in place erosion and sedimentation controls to limit any off-site impacts. Strip and stockpile topsoil only immediately before construction. Consider and minimise any potential adverse impacts on adjoining sites from noise or dust.

During excavation, be alert for any material substantially different from that revealed in the pond site investigation and soil geotechnical analysis. If encountered, the differing material will need to be assessed, and pond design or construction practices must be adjusted. For example, the presence of excessively silty or sandy soil layers may require the construction of a compacted clay liner.

Although not mandatory and dependent on project scale, supervision of construction by a geotechnical engineer is recommended for quality control.

The objective of construction is not just to provide a hole. If a ramp or shallow batter can be installed as well, it will assist desludging and pumping out and improve escape prospects for stock and humans, reducing OH&S risks.

Floor and lining

The floor of a pond needs to be constructed from appropriate material and to be appropriately compacted (see next section). The soil geotechnical analysis will identify soils that crack excessively or contain <20% clay, and areas of exposed rock or sand, all of which will require lining. Where it cannot be demonstrated that, with conventional compaction, the *in situ* soil material can achieve a permeability of $<1.0 \times 10^{-9}$ m·s^{-1}, a clay or synthetic liner must be installed on the floor and internal embankments. Documentation of permeability may be required (Environment Protection Authority 2003). A NATA-accredited laboratory should conduct these tests.

Pond lining—clay liners

Although it is impossible to achieve zero leaching through a compacted soil layer, leaching should be minimised to achieve a permeability of $<1.0 \times 10^{-9}$ m·s^{-1}. Within effluent ponds, clay lining is typically required to achieve this. George *et al.* (1999) state that, in general, most studies show that the initial leakage rate of a storage pond is high, but over time it is reduced as a result of sealing due to physical, chemical and biological processes within the pond. The flux of leachate through a pond liner is typically calculated by applying Darcy's Law under the assumption of saturated conditions (Tyner and Lee 2004). Ham (2002) found in a study of 20 animal effluent ponds that the hydraulic conductivity of compacted soil liners averaged 1.8 × 10^{-9} m·s^{-1}, and found evidence that organic sludge moderated seepage rates. Cihan *et al.* (2006) developed a model to predict the formation of a seal by animal effluents through compacted soil liners, and found that over time, as the seal forms, infiltration rates are further reduced.

Where soil geotechnical results show that a clay liner needs to be laid on the pond floor and internal embankments, the following criteria apply:

- Permeability must be ≤1.0 × 10^{-9} m·s^{-1}.
- The material used should be classified as CL, CI, CH, SC or GC under the USCS (Skerman *et al.* 2004).
- Clay-dominant material should have a Liquid Limit between 30% and 60% and a Plasticity Index of >10% (Skerman *et al.* 2004).
- Clays with a liquid limit between 60% and 80% may be used as lining material provided the liner is protected from drying out by a minimum thickness of 100 mm of compacted gravel (Skerman *et al.* 2004).
- The liner must be 300 mm thick for a 2-m liquid depth and 450 mm for >2 m (Skerman *et al.* 2004).
- The pond should be filled with at least 500 mm of water upon completion to prevent the liner from drying out (Bradshaw 2002a).

Pond lining—synthetic liners

Where a synthetic liner is required, the following criteria apply:

- The liner must have permeability of ≤0.1 mm·day^{-1} and be installed to the manufacturer's specifications (Environment Protection Authority 2003).
- Seepage losses are usually associated with the joining of membranes, so take care with overlapping and welding of the liners.
- Protect the liner from desludging operations; for example, with a layer of used tyres (Bradshaw 2002a). Alternatively, use an agitator and pump for desludging ponds.
- Do not use synthetic liner where the water table is high: High water tables can place upward pressure on linings and cause damage.

Compaction

To attain sufficient compaction, specific geotechnical recommendations, based on soil geotechnical results, may be provided. If not, the following criteria will help to attain sufficient compaction:

- Where a bulldozer or excavator is used for construction, the floors and embankments must be appropriately compacted with a roller (NSW Dairy Effluent Subcommittee 1999).
- Scrapers or sheep's foot rollers give greater compaction rates.
- Compact soil with a moisture content within ±2% of optimum (Skerman *et al.* 2004).
- Where material is too dry to achieve satisfactory compaction, soil will have to be wetted.

- Each lift (a layer of fill generally not exceeding 200 mm) must be compacted to at least 95% of maximum dry density. This is typically achieved through eight passes of a sheep's foot roller (Skerman *et al.* 2004). Tamping foot and vibrating rollers can also be used.
- The lift thickness must not exceed 150 mm after compaction (Skerman *et al.* 2004).
- Construct liners with a minimum of two compacted lifts for optimum performance (Reinsch 2001).

Sealing

The sealing of a pond floor is aided by clogging by microbes and particulate matter (Magesan *et al.* 1999) and the formation of a sludge blanket (Silver *et al.* 2000). Pond design should be conducive to these processes.

Spillways, pipes and cut-off collars

In addition to stormwater diversion, ponds may require an emergency spillway for protection from severe storms; general dam design procedures may be used to determine the necessary dimensions.

Typically the weakest point in a pond is where pipes perforate embankments, so pipes through embankments should be avoided. However, a piped outlet to facilitate reuse is typically required; this should have seepage cut-off collars of 1200 mm × 1200 mm × 150 mm (Bradshaw 2002a, NSW Dairy Effluent Subcommittee 1999). Where concrete seepage cut-off collars are used, they should be reinforced with F81 mesh (NSW Dairy Effluent Subcommittee 1999). Where a suction pipe is used, this should be placed through the embankment berm at a height to assist pump priming (DairyCatch 2006). HDPE pipes should be used and be fitted with HDPE collars. Bentonite wafer collars can also be used.

Topsoiling

Topsoil should be stripped and stockpiled before construction, placed on external embankments after construction to a depth of between 200 and 300 mm (NSW Dairy Effluent Subcommittee 1999), and then grassed (Lower Murray Irrigation Action Group 1994) to stabilise embankments.

Pond monitoring

The water level in storage ponds should be monitored regularly, along with groundwater heights and sludge depths. To monitor groundwater, a shallow (0–3 m) slotted PVC pipe in which depth is measured is all that is required. Water table heights must not come within 1 m of the compacted lining of the storage, or the compacted clay layer can become damaged, and effluent from the pond can enter groundwater. Monitoring of effluent levels allows any seepage losses to be readily detected and corrected. If water tables become close to levels within storage ponds, synthetic linings must not become damaged, and groundwater must not overtop the pond. Monitor these levels monthly during wet periods, when water tables are likely to rise.

Monitoring sludge depths is critical to ensuring sufficient room in the pond for heavy rain. As sludge accumulates, the capacity for effluent diminishes, so ponds must be regularly desludged (see chapter 2.8 'Desludging and pond closure').

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