FEEDLOT DESIGN AND CONSTRUCTION

12. Holding pond design

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Introduction

Stormwater runoff from the controlled drainage area of a feedlot is normally characterised by high concentrations of organic matter. Even though it has passed through a sedimentation system, it still contains substantial levels of organic matter, nutrients and salts. This runoff should not be allowed to flow uncontrolled into the external environment and should be captured by the holding pond(s).

A holding pond is located at the lower end of the controlled drainage area, immediately below the sediment removal system. It is designed to capture and store the runoff from the controlled drainage area until it can be sustainably utilised.

Applying holding pond wastewater to land where it is sustainably utilised by crops and soil is generally the preferred form of wastewater management. Sometimes in arid areas, without access to other irrigation water and where cropping is not sustainable, evaporation of the wastewater may be acceptable. However, regulatory authorities will generally require feedlot operators to demonstrate that the saline residue remaining after evaporation can be safely utilised or disposed of. Where evaporation is the sole or primary disposal mechanism for wastewater and where captured effluent is not normally applied to land, these ponds are typically referred to as evaporation ponds.

Design objectives

Holding ponds are designed to

- store stormwater until the collected wastewater is either applied to land or evaporated
- be large enough to temporarily store effluent from major storms and/or extended wet periods which limit irrigation or evaporation of effluent, and have sufficient capacity for safe storage of the captured wastewater, limiting overtopping to an acceptable and approved frequency
- be constructed so that their base and internal embankments have a low permeability, thereby minimising the risk of groundwater contamination by leaching of effluent
- be structurally stable, thereby limiting the probability of embankment failure with uncontrolled release of large quantities of effluent and resultant surface water and/or groundwater contamination
- minimise odour emissions, with suitable management.

Mandatory requirements

Compliance with

- Relevant Commonwealth, state and local authority codes, regulations and relevant Australian standards as applicable to feedlot development.
- National Beef Cattle Feedlot Environmental Code of Practice (MLA, 2012b).
- National Guidelines for Beef Cattle Feedlots in Australia - 3rd Edition. (MLA, 2012a). These guidelines state that holding ponds should have sufficient storage capacity so that

- Normal holding ponds (i.e. those from which wastewater is routinely extracted for land application) spill no more frequently than an average of one in 10 years.
- Evaporation ponds (i.e. those from which there is normally no land application of captured wastewater) spill no more frequently than an average of one in 20 years.
- The holding pond should have a spillway or bywash capable of discharging the peak flow from the controlled drainage area from a 50-year ARI design storm.
- A minimum freeboard of at least 0.9 m should be provided between the crest of the discharge weir and the crest of the holding pond embankment.
- The holding pond should be underlain by a minimum of 300 mm clay or other suitable compactable soil, or by a synthetic liner able to provide a design permeability of <1 x 10^{-9} m/s (~ 0.1 mm/d).

Design choices

Siting

The holding pond must be sited and constructed to protect groundwater, surface water quality, riverine ecosystems and community amenity. The following criteria can be used as a guide

- Holding ponds should not be sited in a location that is inundated by floodwater, on average more frequently than once in every 100 years.
- Suitable soil material for construction should be available either at or near the construction site.
- The holding pond bywash should not discharge into an adjoining drainage line unless thorough investigation is carried out to demonstrate that the receiving drainage line can safely carry the resulting increased peak flow rates.
- Discharge from the holding pond bywash should be returned to the original drainage line before it leaves the feedlot property.
- The bywash should not directly discharge water to an adjoining landowner's property.
- Holding ponds should not be constructed in areas where seasonal water tables are less than 2 metres below the base of the pond, or in areas where natural groundwater discharges (springs) occur.
- Sufficient area should be allowed between the pen area and holding pond to enable future expansion.
- Holding ponds should comply with relevant national, state and local authority guidelines, codes, and standards.

Properties of materials used

Clay lining material for the holding pond will either be sourced from the site or be brought to the site to ensure sufficient suitable material is available. Suitable clay for lining must conform to the particle size distribution and plasticity limits in Table 1. The clay lining material shall be classified as CL, CI, CH, SC or GC,

Holding pond located outside of the 1-in-100 year floodplain

The siting of this holding pond allows for expansion and its geometry suits the topography of site.

This holding pond was located a sufficient distance away from the closest two rows of production pens to allow for future expansion of the feedlot.

representing clays having low, intermediate and high plasticity, clayey sands and clayey gravels respectively (Table 2). Note that the lining materials used for manure composting and/or stockpiling areas have similar properties.

Table 1. Specifications for clay liner materials

Soil characteristic	Acceptability criterion	Test method
Percentage Fines	More than 25% passing a 75µm sieve More than 15% passing a 2µm sieve	AS 1289.3.6
Liquid Limit	Less than 70	AS 1289.3.1.1
Plasticity Index	More than 15	AS 1289.3.3.1
Emerson Class Number	5 to 6	AS 1289.3.8.1

Table 2. Description, identification and classification of soils (AS 1726-1993)

Group symbol	Major division	Typical names	Particle size	Field identification Sand and Gravels
CL, CI	Silts and clays (liquid limit <50%)	Inorganic clays of low to medium plasticity, gravelly slays, sandy clays, silty clays, lean clays	Fine grained soils	Dry strength –medium to high Dilatancy – none to very slow Toughness – medium
CH	Silts and clays (liquid limit >50%)	Inorganic clays of high plasticity, fat clays		Dry strength – high to very high Dilatancy – none Toughness – high
SC	Sands (more than half of coarse fraction is smaller than 2.36 mm)	Clayey sands, sand-clay mixtures	Fine, 0.075 mm	'Dirty' materials with excess of plastic fines, medium to high dry strength
GC	Gravels (more than half of coarse fraction is larger than 2.36 mm)	Clayey gravels, gravel-sand-clay mixture	Fine, 2.36 mm	'Dirty' materials with excess of plastic fines, medium to high strength

Sizing

Holding ponds should be large enough to temporarily store wastewater from major storms and/or when extended wet periods prevent irrigation of wastewater. The holding ponds should have sufficient capacity such that pond overflows are limited to an acceptable and approved frequency.

Modelling the volume of effluent held in storage with event-driven inflows and extractions through evaporation from a variable pond surface area and application of wastewater to an utilisation area is a relatively complex task.

Small catchment daily time-step hydrology models may be used in the design of a feedlot holding pond. Provided these models are recognised by regulatory authorities, or sufficient information can be provided on the computations and assumptions, these types of models should generally be acceptable for preparing applications for new developments. For example in Queensland – MEDLI model (Gardner et al 1996), RUSTIC (DPI-DAFF, 1994) and ERIM are small catchment models.

The MEDLI model simultaneously models the daily water balance and crop production in the wastewater utilisation area to determine a sustainable irrigation area and acceptable wet weather holding pond capacity based on nutrient loading.

This holding pond is designed to fit the topography between the feedlot pens and a local drainage line.

The pond capacity in the water balance will have to be adjusted until a pond capacity is determined that notionally spills at the required frequency (one in 10 years or one in 20 years, in the case of an evaporation pond). The meteorological data set used should be representative of the site, and cover a period of at least 100 years (i.e. a data set covering ≥ 36,525 days). If historical records covering a 100-year period are not available at some sites, interpolated meteorological data can downloaded through the SILO program.

Typically, small catchment daily time-step hydrology models use the relatively simple (but still robust) United States Department of Agriculture and Soil Conservation Service (USDA SCS) rainfall runoff models (USDA, 2004a and USDA, 2004b) to estimate runoff from the controlled drainage area. In the USDA rainfall runoff model, different values of the catchment index, K1, K2 and K3, are applied to represent respectively dry, normal, or wet soil/manure moisture conditions. Table 3 shows K values typically applicable to feedlot catchments.

Table 3. Suggested values for K1, K2 and K3 in the USDA rainfall runoff model (Source Skerman, 2000)

Catchment	K_1	K_2	K_3
Pens	92	93	95
Hard catchment	96	96	96
Soft catchment	57	75	88

A simple water balance approach may be acceptable as an alternative to the more complex daily time-step hydrology models in some states. In this approach, a simple water budget is based on monthly precipitation and evaporation data.

Modelling based on monthly data is typically more conservative than daily time-step models (Department of Environment and Conservation NSW 2004) and may offer more robustness and flexibility to system operators. Birchall (2008) provides a comprehensive description of a monthly water balance procedure based on the 90th percentile rainfall rather than on mean rainfall.

Design storm methods

Historically, feedlot holding ponds were designed on the basis of a major storm event (e.g. able to contain runoff from a 20-year ARI 24-hour design storm). The 24-hour design storm represents the largest amount of rainfall expected over a 24-hour period. The size of the catchment multiplied by a runoff coefficient and the 20-year, 24-hour storm volume rate is the basis for planning and designing stormwater management facilities (MLA, 2012a).

The intent of this approach was that the designed holding pond should overtop only at a frequency less than one in 10 years (not necessarily only one in 20 years). In practice, however, overtopping events from holding ponds designed on this basis were found to occur at a frequency much greater than an average of one in 10 years (MLA, 2012a).

Overtopping will most likely occur after a prolonged period of wet weather (such as in winter periods in southern areas of Australia) or closely spaced relatively unexceptional rainfall events, as the soils in the effluent utilisation area limit or prevent the application of wastewater.

Well-maintained embankment batters with sufficient freeboard

Large rectangular holding pond

Holding pond shaped to suit the site and topography

Hence, the design storm method fails to account for the cumulative impact of a series of wet weather events such as might be experienced in a wetter than average season. In most Australian states the design storm approach is no longer considered acceptable and alternative design methods should be adopted (MLA, 2012a).

Effluent irrigation pumping site on holding pond embankment.

Alternative methods

State agencies regulating feedlot development may also nominate other acceptable methods such as the Standard tabulated method (Skerman, 2000) which is provided as an option for use in Queensland. However, many of the methods that do not use site-specific daily-step hydrological modelling are better suited to smaller developments. Larger feedlots or those located in sensitive sites will need to undertake more robust modelling approaches.

Freeboard

Freeboard is defined as the vertical height between the crest of a holding pond embankment and the full supply level. Full supply level is the maximum operating level in the holding pond, which is equivalent to the bywash level. When the storage volume increases above this level, the holding pond commences overflowing through the bywash.

Freeboard protects the structural integrity of holding pond embankments from overtopping during bywash overflow events and by wind-induced wave action. Holding ponds that have embankments above the original natural surface level are more susceptible to breaching and failure on overtopping than are below ground holding ponds.

Holding pond with well-grassed batters (to resist erosion) and with sufficient freeboard.

Protection of the internal embankment batters may need to be provided within the freeboard zone to control erosion that may occur even without overtopping. This could be established by good grass vegetation or an engineered solution such as rock rip rap.

Provision of appropriate freeboard can significantly enhance the overall holding pond safety. A minimum freeboard of 0.9 m should be provided between the base of the bywash and the crest of the holding pond embankment.

Overtopping frequency

The *National Guidelines for Beef Cattle Feedlots in Australia - 3rd Edition* (MLA, 2012a) state that overtopping frequency criteria applied to holding ponds are

- for holding ponds from which wastewater is routinely extracted for land application, the spill frequency should not exceed an average of one spill in 10 years.
- for holding ponds from which there is normally no land application (evaporation ponds) the spill frequency should not exceed an average of one spill in 20 years.

In water balance modelling, once a pond has 'spilled' the likelihood of another modelled spill occurring with the next few days is quite high. The National Guidelines define one spill as one or more modelled spill events within 30 days of one another.

Allowance for sludge accumulation

When suspended solids from the wastewater settle, a layer of sediment material known as sludge is deposited on the base of the holding pond. The distribution of this sludge is rarely uniform and varies from pond to pond. Sludge should be removed periodically, although weather conditions may delay removal.

Sludge accumulation is known to have an impact on a range of hydraulic processes including short-circuiting, lag time and recirculation which impact on treatment efficiency. Over time the accumulated sludge reduces the effective storage volume of the pond.

With a well designed and maintained sedimentation and holding pond system, sludge accumulation in the holding pond(s) should be minimal. However, an allowance of at least an additional 10% of pond storage capacity should be made to accommodate sludge that may otherwise progressively build up in the pond.

Bywash

Even though holding ponds should overtop only infrequently, a correctly designed bywash is essential. Bywashes are constructed on holding ponds to divert excess water during and following storm events which result in the pond filling to a level above the full supply level (i.e. overtopping events). Holding pond embankments may fail due to inadequate design or construction of the bywash. The bywash must be large enough to handle flood flows without water overtopping the embankment and such flows should not cause erosion of the bywash return slope.

The holding pond should have a bywash capable of discharging the peak flow from the controlled drainage area from a 50-year ARI design storm (National Guidelines for Beef Cattle Feedlots in Australia MLA, 2012a).

There are various configurations of bywash. In a conventional bywash, the floor, known as a spillway, is horizontal (flat). Figure 1 shows a cross section through a typical conventional bywash. Note that the floor of the bywash is level at top water level of the pond.

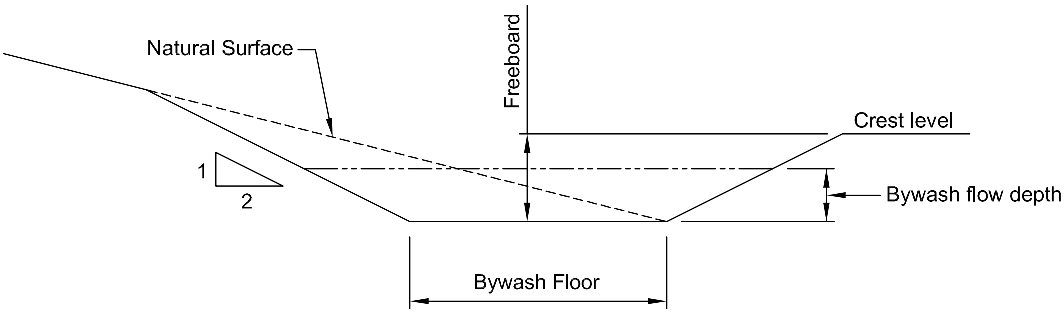

Figure 1. Cross section of a typical bywash

Bywash widths

The bywash inlet width is designed to carry the peak runoff discharge safely around the end of the embankment. The peak runoff discharge (m^3/s) can be calculated using the Rational Method, which is outlined in *Section 10 – Pen and drainage systems.*

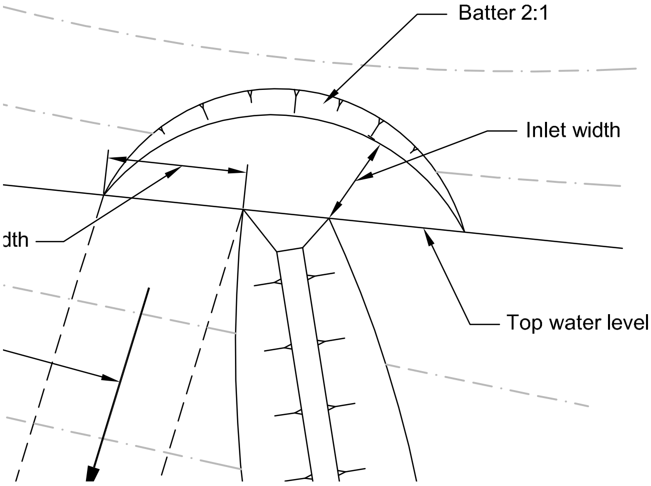

Figure 2. Plan of a typical conventional bywash

The bywash inlet width can be calculated using the broad-crested weir formula. The flow over a broad-crested weir with horizontal crest and 2:1 battered abutments, is given by

$$Q = 1.55LH^{1.5} + 2.47H^{2.5}$$

where

Q = peak runoff discharge (m^3/s)

L = bywash inlet base width (m)

H = depth of flow, or surcharge (m)

Figure 3 illustrates the total depth of water over the bywash at various flow rates and bywash widths for a broad-crested weir.

Typically, bywashes are designed to carry a maximum flow depth of 0.5 m. This provides a flow rate of about 1 m^3/s for each 1 m bywash width. The flow velocity should be kept to a maximum value of approximately 1.8 m/s to minimise erosion of the bywash width.

The bywash outlet width should be designed to keep flow velocities on the return slope below 2.5 m/s to minimise the risk of erosion of grass-lined return slopes. As shown in Figure 2, effluent discharged from the bywash flows down the return slope before returning to the original drainage line that carried local runoff prior to the construction of the feedlot.

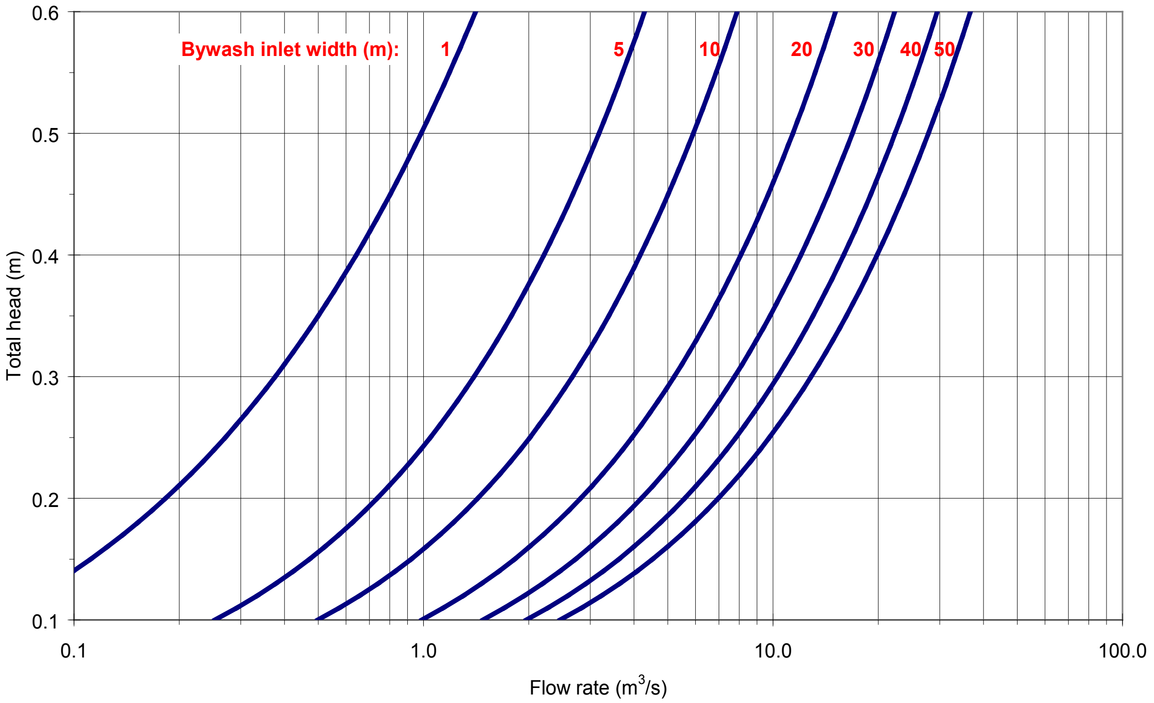

Figure 3. Bywash flow depth for varying flow rates and inlet width (Horton & Jobling, 1992)

Ideally, return slopes should be natural, gently sloping areas supporting a good grass cover in most seasons. The bywash return slope is a critical component of the bywash system and the flattest possible return slope should be adopted.

The location of the return slope should ensure that bywash flows do not erode the external toe of the holding pond embankment.

The bywash outlet width is determined from Figure 4, based on the gradient of the return slope which may be obtained from either contour information or surveyed levels. The bywash inlet width should be at least two thirds the outlet width, to ensure that bywash flows spread uniformly over the outlet reducing the risk of erosion.

A well-grassed bywash return slope should be maintained to prevent erosion. Grass species suited for this purpose include kikuyu, African star grass and para grass.

Alternative designs

Channel bywash

Some holding pond embankment sites have very steep side slopes requiring sizeable excavation to obtain a horizontal spillway floor of the required width. In these situations, a channel bywash may be more suitable. A channel bywash is deeper and narrower than a conventional bywash, although they are difficult to design properly and often require a concrete lip along the outlet width to prevent erosion resulting from the increased flow velocities.

Full concrete bywash

A full concrete bywash is designed and constructed to handle far higher discharge capacities than a grass-lined bywash. However, a full concrete bywash has a higher construction cost than a grass-lined bywash.

A well-grassed embankment will resist erosion.

Lack of vegetative cover and a highly dispersive soil allow wave action to erode this internal batter.

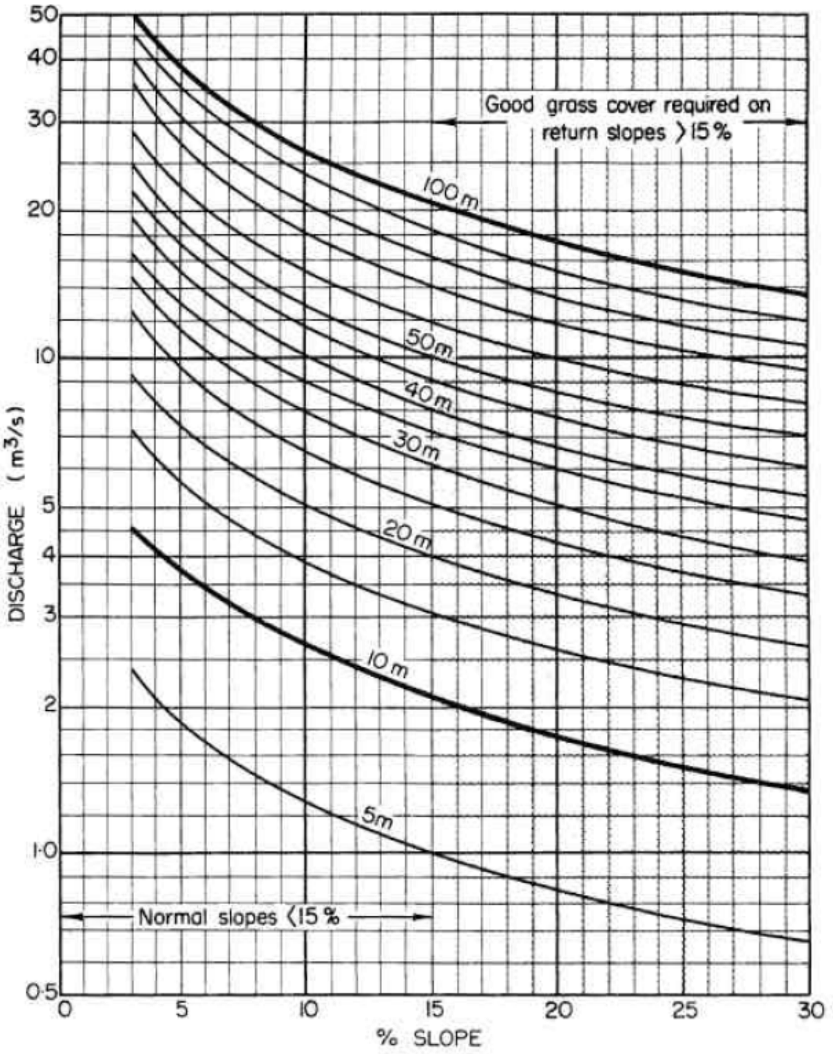

Figure 4. Bywash outlet width for poorly grassed slopes (Horton & Jobling, 1992)

Bywash outlet level

On a flat site, the holding pond storage capacity may be obtained by excavation below ground level. In this situation the bywash outlet will be at the original natural surface, so the entire feedlot drainage system, commencing at the pens, must drain by gravity to this point. If the proposed holding pond bywash site results in excessive earthworks throughout the feedlot system, the designer may need to consider relocating the holding pond if practically possible.

Shape

The topography, site constraints, environmental impacts (e.g. odour), desludging method, lining and wastewater disposal method will influence the holding pond shape.

If the pond is to be lined with HDPE, matching the geometry of the pond to multiples of the roll width of the HDPE liner will minimise liner installation costs.

Efficiency of earthworks can be expressed as the storage to excavation ratio (S:E) i.e. the cubic metres of wastewater stored per cubic metre of earthworks required to create the storage. The S:E ratio is 1 or less for below ground excavated storages and 2 to 5 for hillside storages, whereas gully dams on flat sites have the best S:E ratios ranging from 5 to over 20.

Most feedlot holding ponds are effectively hillside or below ground storages.

A large surface area in relation to depth will increase the effects of evaporation. A deeper pond will reduce the surface area in relation to depth and reduce the effects of evaporation, but will generally be more expensive to construct.

When deciding on the size and shape of the holding pond, consideration should be given to how the holding pond will be desludged. The pond may be periodically emptied and dried and desludged using mechanical means. The holding pond should be designed to allow access for desludging; in the case of large holding ponds access from a number of locations may be required. If the pond cannot be emptied, desludging can only be achieved using a pump with the outflow going back into the sedimentation system. For HDPE-lined ponds, care must be taken to avoid liner damage if mechanical desludging equipment is used within the holding pond.

Odour

Stable, properly functioning holding ponds do not produce a lot of odour. Producing minimal odour whilst maximising the hydraulic efficiency of the holding pond system is an important design consideration.

The factors which influence holding pond odour emissions include

- climate i.e. frequency and volume of runoff events
- the elapsed time since the last major inflow
- the relative volume of fresh inflow to the volume of effluent already present in the pond and the number of days since the rain event
- pond chemistry in terms of electrical conductivity and/or pond pH
- pond microbiology i.e. populations of microorganisms involved in the breaking down of organic matter
- surface area – a holding pond with less surface area can be an option to minimise odour, however, deeper ponds reduce the potential amount of evaporation.

Additional holding pond capacity may be provided to retain some effluent e.g. a depth of 0.3 m to maintain an active microbiological population. The retained microorganisms can then immediately start breaking down organic material in subsequent inflows. Helping a more rapidly stabilising pond microbiology may reduce the levels and duration of odour emissions.

Pond permeability

The general method of protecting groundwater is to ensure that there is a low-permeability barrier between the stored effluent and any underlying groundwater resources.

The holding pond base and embankment should be underlain by a minimum of either 300 mm clay (or other suitable soil) or by a synthetic liner able to provide a design permeability of $<1 \times 10^{-9}$ m/s (~ 0.1 mm/d).

The installation of piezometers to monitor leakage would be done only if it is a licence requirement. Specialist advice should be sought if leakage detection is to be undertaken.

Clay liner compaction

The density of the clay liner is increased with mechanical compaction to reduce air voids and to fit the clay particles tightly together. This increases the load bearing capacity of the soil, prevents settlement, minimises seasonal movement from moisture changes and prevents leaching.

The effect of compaction can be quantitatively described in terms of increased dry density. Hydraulic conductivity is the key design parameter when evaluating the acceptability of a liner material.

Each layer of clay material shall be compacted to produce a field dry density of at least 95% of the standard maximum laboratory dry density determined in accordance with Method 5.4.1 of AS 1289 (Standards Australia 2007) or a Hilf density ratio of at least 95% when tested in accordance with Methods 5.7.1 of AS 1289 (Standards Australia 2006).

An alternative method of compaction involves rolling each layer of material, placed at the correct moisture content, with at least eight passes of a sheepsfoot roller (described below). As a guide, clay is compacted sufficiently when there is a clearance of 100 mm between the drum of the roller and the compacted material (DAFF 2011).

Clay liners should be compacted with at least eight passes of a sheepsfoot roller.

The specifications of the sheepsfoot roller are

- drum diameter of at least 1 m
- drum length 1.2 times the drum diameter
- the feet should extend approximately 175 mm radially from the drum and be of the taper-foot type, with a cross sectional area close to the outer end of not less than 3200 mm^2 and not more than 4500 mm^2
- the number of feet should be such that their total area close to the outer ends should be 5–8% of the area of the cylinder that would enclose all the feet
- the ballasted weight of the roller should be such that the bearing pressure should not be less than 1750 kPa.

Construction

Construction phase activities include the clearing of vegetation, cut and fill, construction of embankments, drainage and other earthworks. Disturbing the soil surface will increase the potential for erosion and transport of sediment to receiving waters. Earthen embankment slopes and holding pond bywash returns should therefore be stabilised as soon as possible after construction.

Quick tips

- Site and construct holding ponds to protect groundwater, surface water quality, riverine ecosystems and community amenity.
- Undertake daily-step hydrological modelling of the controlled drainage area and holding pond to determine the required capacity of the holding pond having a spill frequency of less than one in 10 years, on average (or one in 20 years, in the case of an evaporation pond).
- One spill is defined as one or more modelled spill events, within 30 days of one another.
- Increase the pond storage capacity by at least 10% to accommodate sludge that will progressively build up.
- The level of the bywash outlet constitutes the starting level from which to grade the drainage system (sedimentation system, drains and pens).
- Effluent discharged from the holding pond bywash should be returned to natural drainage lines before leaving the feedlot property. Effluent should not be discharged directly onto an adjoining landowner's property.

Further reading

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