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AUSTRALIAN PORK LIMITED

New Design Guidelines for Anaerobic Ponds

2015

This document should be cited as follows:

Project 2013/031 New Design Guidelines for Anaerobic Ponds (2015), Australian Pork Ltd, Barton, ACT, 2600

INTRODUCTION

The main objective of effluent treatment is to remove organic matter and nutrients from raw piggery effluent. Most primary effluent treatment ponds at piggeries are anaerobic, because the high organic loading that they experience consumes any dissolved oxygen to exhaustion. Anaerobic ponds are a popular treatment option as they are simple to build and operate, and provide for effluent and sludge storage. Well-designed, properly-managed anaerobic ponds also provide good effluent treatment without odour nuisance or adverse impacts to water resources.

Until fairly recently, most anaerobic ponds at Australian piggeries were designed using the Rational Design Standard (RDS) by Barth (1985). The RDS leads to conservative large pond volumes which are effective at removing organic matter and nutrients from the effluent (Photograph 1). However, large ponds have major drawbacks; they occupy significant land areas with high costs of construction, have large surface areas that release odour and greenhouse gases (GHG) and can be difficult to desludge.

Photograph 1 Very large ponds are designed when using the Rational Design Standard (RDS) by Barth (1985)

Over the past 10 years, Australian Pork Limited (APL) has heavily invested in the development of alternative design and management solutions to overcome these challenges. This booklet provides design guidelines for heavily loaded anaerobic (HLA) ponds.

Principles of Anaerobic Digestion

Anaerobic decomposition is a three-stage natural biological process by which manure is progressively broken down by different micro-organisms in each stage. Firstly, enzymes produced by bacteria break down manure solids into simpler dissolved organics. Secondly, the dissolved organics are fermented into volatile fatty acids (VFAs). Thirdly these are broken down into acetate, hydrogen and carbon dioxide. Finally these are converted into methane and carbon dioxide. The methane forming micro-organisms (methanogens) responsible for the final stage are slow-growing. Methanogens are also most prone to being inhibited by pH changes, chemicals/additives in the piggery effluent or other unfavourable conditions in the anaerobic pond. This is important, because a number of conditions (sudden increase in manure load or too short a hydraulic retention time) can cause an imbalance with too few methanogens and too many fermenting bacteria, which in severe cases lead to pond failure and substantial odour. For this reason, it is important to design and manage ponds to facilitate a balanced microbial community and in this way ensure good treatment of piggery effluent.

A New Design Concept: Heavily Loaded Anaerobic Ponds

Heavily loaded anaerobic (HLA) ponds (Photograph 2) are ponds which have a treatment volume that is about one-tenth to one-sixth the size of RDS-sized ponds, and thus experience a 6-10 times higher volumetric load. For many years, Australian pork producers have suggested that HLA ponds can perform just as well as larger RDS-sized ponds, providing adequate treatment of piggery effluent. For example, in a series of trials, Skerman et al. (2008) investigated the performance of HLA ponds by loading an anaerobic pond at a commercial piggery and a settling tank at a research piggery at 6-10 times the RDS-calculated organic loading rate. They found that HLA ponds:

» achieved similar volatile solids (VS) removal rates than RDS-sized ponds, removing at least 70% of VS

» accumulated sludge at lower rates than what was suggested by Barth (1985)

» developed heavy surface crusts if loading rates exceeded about 600 g VS/m^3/d (but this can assist with odour mitigation)

» emitted lower levels of offensive odour than RDS-sized ponds because of the reduced surface area and the surface crusting.

Photograph 2 HLA pond

Potential advantages of HLA ponds include:

» reduced earthworks costs due to smaller volume, and

» smaller footprint, so

» less expensive and easier to line for groundwater protection, or to cover for biogas capture (if this is desired)

» simpler and cheaper to desludge of sludge

» lower odour emissions

» potential to expand the piggery or develop at sites limited by separation distances to areas of sensitive land use (Tucker et al., 2010).

HLA Ponds: Volume

Like RDS ponds, HLA ponds must provide sufficient volume for effluent treatment, sludge storage and freeboard (Figure 1). Like the RDS-method, the treatment volume of HLA ponds is determined by using a VS loading rate, which for HLA ponds should be less than the maximum value given in Table 1 and adjusted for temperature (Skerman *et al.*, 2008).

FIGURE 1 **The various volumes that contribute to the total volume of an uncovered piggery lagoon**
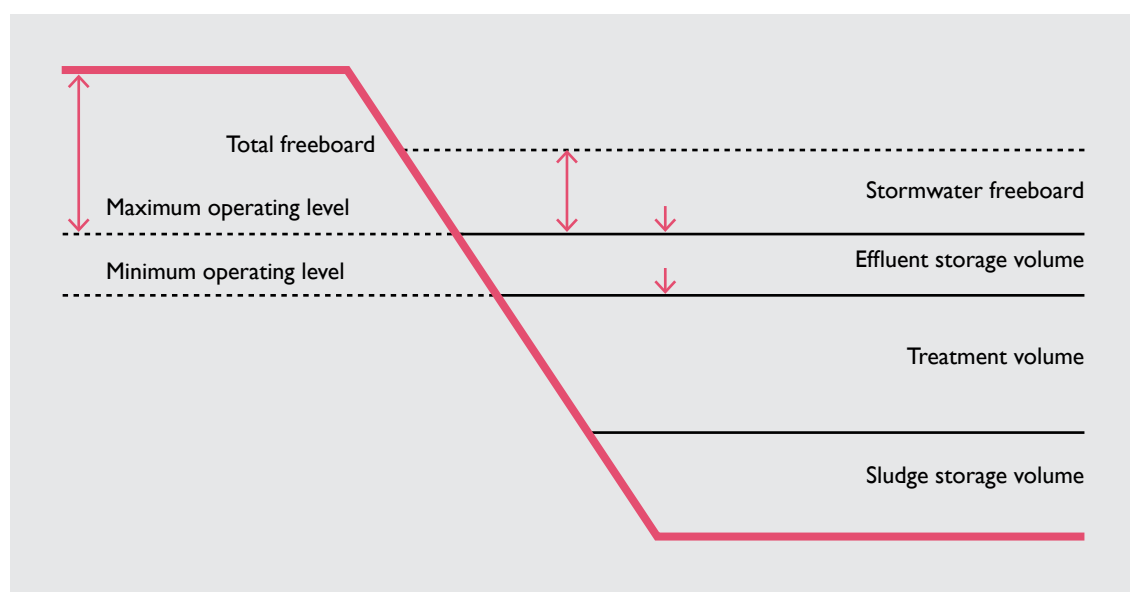

TABLE 1 **Recommended maximum VS loading rates and the minimum treatment volume for HLA ponds**

Climate	Maximum VS loading rate for sizing of treatment volume of HLA ponds (g VS/m³/d)	Minimum treatment volume of HLA ponds (m³/SPU)
Cool	450	0.55
Warm	600	0.41
Hot	750	0.33

Skerman et al. (2008)

From the maximum loading rates, the smallest viable HLA pond volume can be determined. This is done by considering that one standard pig unit (SPU) excretes about 90 kg VS/yr as manure and waste feed (Tucker et al. 2010). So, as an example, the minimum treatment volume (to be added to sludge accumulation volume and required freeboard) at 450 g VS/m^3/d, would be:

= ((90 kg VS/SPU/yr/365 days)/(450 g VS/SPU/d /1000)
= 0.55 m^3/SPU (as in Table 1)

> **Using the maximum VS loading rate to size an anaerobic pond produces the smallest viable treatment volume. Extra volume is needed for sludge storage and to provide for management flexibility.**

Sludge storage volume is estimated by multiplying a sludge accumulation factor by the number of years between planned sludge removals. The American standard ASABE (2011) includes a sludge accumulation factor of 0.00137 m^3/kg TS added to the pond. From this factor, the sludge storage volume can be calculated. One SPU excretes about 108 kg TS/yr which will flow into the pond.

So, as an example, the sludge storage volume for a 5-year desludging cycle would be:

= 108 kg TS/yr × 0.00137 m^3/kg TS ×5 years
= 0.74 m^3/SPU

> **A HLA pond for a 10,000 SPU piggery in a warm climate would need a minimum HLA pond volume of 5,600 m^3 (5.6 ML) consisting of 4,100 m^3 of treatment volume and 1,480 m^3 of sludge storage volume (assuming annual desludging). Additional capacity may be needed to cater for wet weather storage, changing effluent flows and additional freeboard.**

Providing for a greater sludge storage volume to enable less frequent desludging, also has drawbacks in that:

» it requires bigger ponds with higher construction costs

» it increases the pond footprint

» it may make desludging more difficult, because older sludge may settle in more compacted layers with very high solids concentration which may be very difficult to pump. Such a pond may need to be taken off-line for sludge removal using earthmoving or dredging equipment.

» it may result in bigger pond surface areas with greater odour emissions.

Pond sludge is a valuable nutrient resource, being rich in phosphorus and other nutrients. It is common practice to desludge when sludge nutrients are to be spread to crop land. It is recommended that ponds be sized with *no less than* 12 months of sludge accumulation volume, because an active sludge layer is always required in a pond to treat manure effectively. Any additional sludge volume allowance can improve management flexibility.

> **As well as treating the effluent and storing sludge, the pond system must provide adequate wet weather storage. The latest version of the National Environmental Guidelines for Piggeries sets a maximum overtopping (spill) frequency of once every ten years on average. A holding pond will generally be needed to meet this criterion.**

The total pond volume (Figure 1) is then calculated as liquid treatment volume + sludge accumulation volume + effluent storage volume + stormwater storage freeboard

Table 2 provides an example.

HLA Ponds: Dimensions

The footprint of a HLA pond depends on:

»   total volume (see above)

»   total depth

»   batter of internal walls and external banks (batter is the slope of a wall or bank expressed as a ratio of horizontal to vertical distance)

»   length-to-width ratio

»   freeboard.

Deep anaerobic ponds can be preferred as a deep profile:

»   minimises the pond surface area. For uncovered ponds this reduces odour emissions and heat losses, and minimises the rainfall volume to be managed and reduces evaporation which unfortunately concentrates salts. For covered anaerobic ponds (CAPs) it reduces the size and cost of a cover and the cover surface area for which stormwater is to be managed

»   provides a more stable pond temperature, which can improve digestion performance

»   usually ensures there is adequate depth for the treatment volume. Hamilton (2007) recommends maintaining at least 2 m of treatment depth above the design sludge volume.

However, it is important to ensure that:

»   the pond base is 2 m or more above the highest seasonal groundwater table

»   the depth of the pond is practical for desludging.

Steep internal wall batters minimise the pond surface area for a given pond volume. Relatively steep batters are usually possible for plastic-lined ponds. Ponds that are pumped out will be more prone to bank collapse and generally need flatter batters than ponds that are kept full. Skerman et al. (2008) suggests a batter slope no steeper than 2 horizontal to 1 vertical on the internal walls, with some soils needing more gradual batters to ensure structural stability. The batter slope may also be limited by the safe operation of machinery during pond construction, and possibly for later desludging. Batters on the ends of the internal walls should be at least 4 horizontal to 1 vertical to provide for safe access by maintenance machinery.

Photograph 3 shows a lined pond with steep batters on the long sides and flatter batters on the ends.

Photo 3 Plastic lined trapezoidal pond with steep batters on long sides and flatter batters on ends

Long, narrow and deep ponds provide good solids settling for treatment and minimise short-circuiting of the influent flow. Minimum pond length-to-width ratios of 3 – 4:1 are often recommended in effluent pond design manuals to improve contact between the treatment bacteria and the fresh effluent (ASABE 2011, Shilton and Harrison 2003). Desludging will also be much easier and less disruptive if the pond is narrow enough to remove solids from a bank using a pump, vacuum tanker or long reach excavator. Long reach excavators have a maximum range of around 18 m, which limits the maximum pond width at crest to about 30 m.

The pond width at top water level is determined by the base width, the internal batters and the depth. The minimum base width will generally match the width of the construction equipment (typically ~3 m). Example dimensions for a HLA pond for a 10,000 SPU unit with top water level depths of 4, 4.5 and 5 m are provided in Table 2. Figure 2 shows the dimensions schematically.

Freeboard is the height from the top water level of the pond to the bank crest. It is provided to protect the bank from wave action and to allow for imperfections in crest height. A minimum freeboard of 0.5 m is specified in the latest version of the National Environmental Guidelines for Piggeries, although some states may require larger freeboard depths.

"Incorporate sludge removal pipework in the pond during construction."

Producer VIC

TABLE 2   **Example dimensions for HLA ponds for a 10,000 SCU piggery in a warm climate - three top water level (TWL) depths**

Typical design criteria – all ponds (may vary with specific site requirements)			
Treatment and effluent storage volume (m³)	4100		
Sludge storage volume (annual desludging) (m³)	1480		
Total water volume (m³)	5580		
Freeboard (F) (m)	0.5		
Batter on width (H:V)	4:1		
Batter on length (H:V)	2:1		
Dimension			
	TWL Depth (D) 4 m	TWL Depth (D) 4.5 m	TWL Depth (D) 5 m
Width at base (W_B) (m)	3	3	3
Width at top water level (W_{TWL}) (m)	35	39	43
Width at inside crest (W_C)	39	43	47
Length at base (L_B) (m)	63	64	65
Length at TWL (L_{TWL}) (m)	79	82	85
Length at inside crest (L_C) (m)	81	84	87
Batter on length (H:V)	2:1	2:1	2:1

FIGURE 2   **Schematic diagram showing dimensions of HLA pond as given in Table 2**
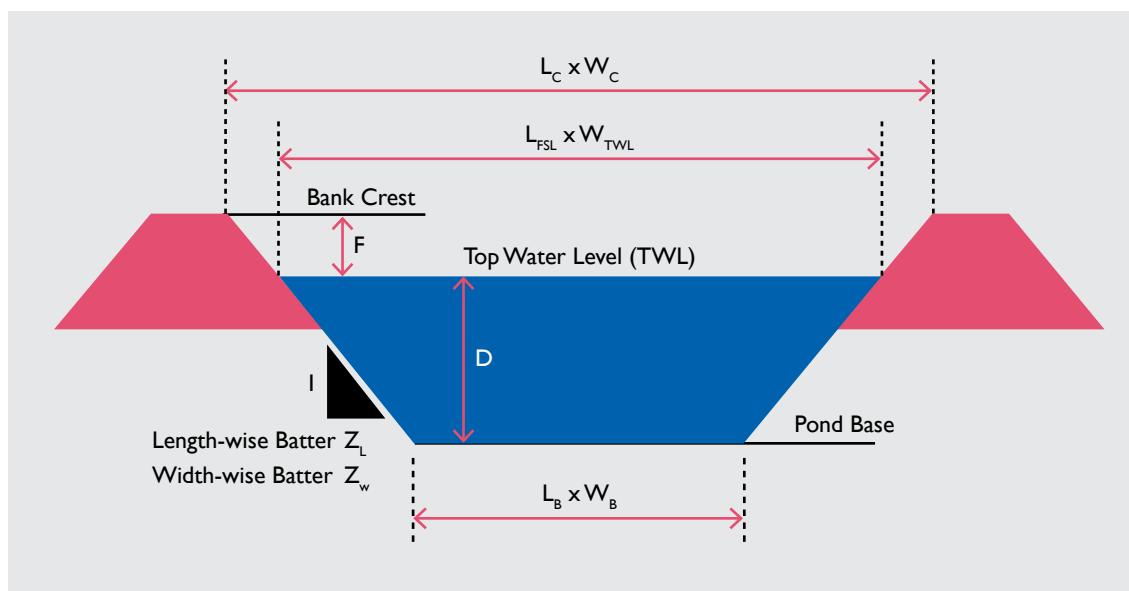
(Skerman et al. 2008)
* FSL = full supply level

Following is a simple method to estimate the dimensions of a trapezoidal pond (i.e. a pond with a rectangular base and surface area) with a required volume and water depth.

Find the dimensions of a pond with a required volume and water depth

A worked example for a pond with a volume of 20 ML, a water depth of 5 m, freeboard of 0.5 m and internal banks with a slope ratio of 3:1 (horizontal to vertical) follows.

To calculate top water level (TWL) length and width:

1. Calculate mid-depth surface area (m^2)

$$= \text{volume } (m^3) / \text{depth (m)}$$
$$= 20,000 \ m^3 / 5 \ m$$
$$= 4000 \ m^2$$

2. Work out some suitable dimensions for this mid-depth surface area.
   e.g. 100 m X 40 m

3. Calculate the top water level (TWL) length and width:

TWL length (m) = mid-depth length (m) + (2 X (slope ratio x ½ water depth))
                = 100 m + (2 X (3 x 2.5 m)
                = 115 m

TWL width (m)   = mid-depth width (m) + (2 X (slope ratio X ½ water depth))
                = 40 m + (2 X (3 X 2.5 m)
                = 55 m

To calculate base and crest dimensions:

4. Calculate the base length and width:

Base length (m) = mid-depth length (m) - (2 X (slope ratio X ½ water depth))
                 = 100 m - (2 X (3 X 2.5 m)
                 = 85 m

Base width (m)   = mid-depth width (m) - (2 X (slope ratio X ½ water depth))
                 = 40 m - (2 X (3 X 2.5 m)
                 = 25 m

5. Calculate the crest length and width:

Crest length (m) = TWL length + (2 X (slope ratio X freeboard depth (m))
                  = 115 m + (2 X (3 X 0. 5 m))
                  = 118

Crest width (m)   = TWL width + (2 X slope ratio X freeboard depth (m))
                  = 55 m + (2 X (3 X 0.5 m)
                  = 58 m

"Using settling ponds allows for greater solids retrieval for reuse in cropping systems."

Producer NSW

Following is a simple method to estimate the volume of a trapezoidal pond with known dimensions.

Calculate the volume of a trapezoidal pond with known dimensions

A worked example for a pond with top water level (TWL) length of 115 m, width of 55 m, depth of 5 m and internal banks with a slope ratio of 3:1 (horizontal to vertical). Note that the TWL should be at least 0.5 m below crest height to allow sufficient freeboard i.e. in this example, assuming 0.5 m freeboard is provided, the pond depth from base to crest is 5.5 m.

1. Determine base length
   Base length   =   TWL length – (slope ratio X TWL depth X 2)
                         =   115 m – (3 X 5 m X 2)
                         =   85 m

2. Determine base width
   Base width   =   TWL width – (slope ratio X TWL depth X 2)
                         =   55 m – (3 X 5 m X 2)
                         =   25 m

3. Calculate the area of the pond base
   Base area   =   base length X base width
                         =   85 m X 25 m
                         =   2125 m^2

4. Calculate the TWL area
   TWL area   =   TWL length X TWL width
                         =   115 m X 55 m
                         =   6325 m^2

5. Multiply the sum of the TWL and base lengths by the sum of the TWL and base widths
                         =   (115 m + 85 m) X (55 m + 25 m)
                         =   200 m X 80 m
                         =   16,000 m^2

6. Sum the answers from steps 3, 4 and 5, multiply by the depth to TWL and divide the answer by 6 to get the volume in m^3
                         =   ((2125 m^2 + 6325 m^2 + 16,000 m^2) X 5 m) / 6
                         =   20,375 m^3 or 20 ML

HLA Ponds: Permeability

Protect groundwater by ensuring that pond bases and walls have a design permeability not exceeding 1×10^{-9} m/s. Department of Agriculture, Fisheries and Forestry (2009) provides practical guidance for achieving this standard during construction.

Sometimes, the in situ clay will be suitable for compacting to the required permeability. Soil testing can confirm whether this is the case. In other cases, clay will need to be imported or a synthetic liner used.

Photograph 3 shows a pond with a synthetic liner. Suitable lining materials include high density polyethylene (HDPE) with a thickness of 1.5-2 mm, or 1-2 mm thick polypropylene (PP) in cases where the effluent does not contain large quantities of fats or oils. Liners can easily be damaged by livestock and machinery movements and bush fires and need to be protected; consider fencing the pond to exclude livestock and wildlife, use equipment carefully, and keep vegetative fuel down near the pond.

HLA Ponds: Banks

To provide for safe access, bank crests must be structurally stable, ideally at least 2.5 m but preferably at least 4 m wide, or 6 m for a covered pond, and flat on top with a slight downward slope towards the outer wall to direct stormwater runoff away from the pond.

Batters of at least 4 horizontal to 1 vertical are recommended for external banks. Earthen ramps, with gradients of 10 horizontal to 1 vertical, on the external end banks, provide safer access.

Grass, compacted gravel or geotextile on a crest or bank can help to minimise erosion. Trees should never be planted on the banks or near a pond. Uncontrolled vegetation in close vicinity to a plastic-lined or covered pond can encourage vermin or have increased fire risks. Topsoil over the crest and outer bank can help prepare for grassing. Ramps should be protected with a layer of compacted gravel.

HLA Ponds: Inlets and Outlets

Effluent may be pumped through pipes to HLA ponds, or may enter under gravity flow via channels or pipes. Table 3 provides guidance on minimum grades for gravity flow inlet pipes of different diameters. Larger diameter pipelines will discharge more quickly and are less likely to block.

Providing multiple inlet points disperses the effluent within the pond which may enhance treatment and allow sludge to deposit more evenly within the pond. All inlet pipes should be well separated from the outlet pipe.

TABLE 3   Minimum slopes for gravity pipes conveying untreated effluent

| Inside diameter (mm)	Minimum slope (%)	Velocity at full flow (m/s)
75	3.3	1
100	2.5	1
125	2.0	1
150	1.7	1

(Birchall et al. 2008).

Since thick crusts may form over HLA ponds, inlet and outlet pipes need to be carefully positioned to prevent blockages. In most cases the ends of the inlet pipes sit above the expected top water level and crust level, and beyond the bank providing for free outfall into the pond (Photograph 4). However, pipes can also be positioned to discharge under the expected minimum liquid levels.

Treated effluent may be removed from the pond using a pipe, a weir or by pumping. If an outlet pipe is used, a tee fitting will exclude the floating crust (see Photograph 5). The base of the vertical pipe should be well below the crust and top water level but above the maximum sludge storage level to ensure only liquid is being extracted. The bottom of the overflow pipeline sits at top water level height with a downwards slope towards the wet weather pond. This keeps the effluent volume in the HLA pond relatively constant and prevents spills.

Photograph 4 Effluent pond inlet pipe discharging above top water level
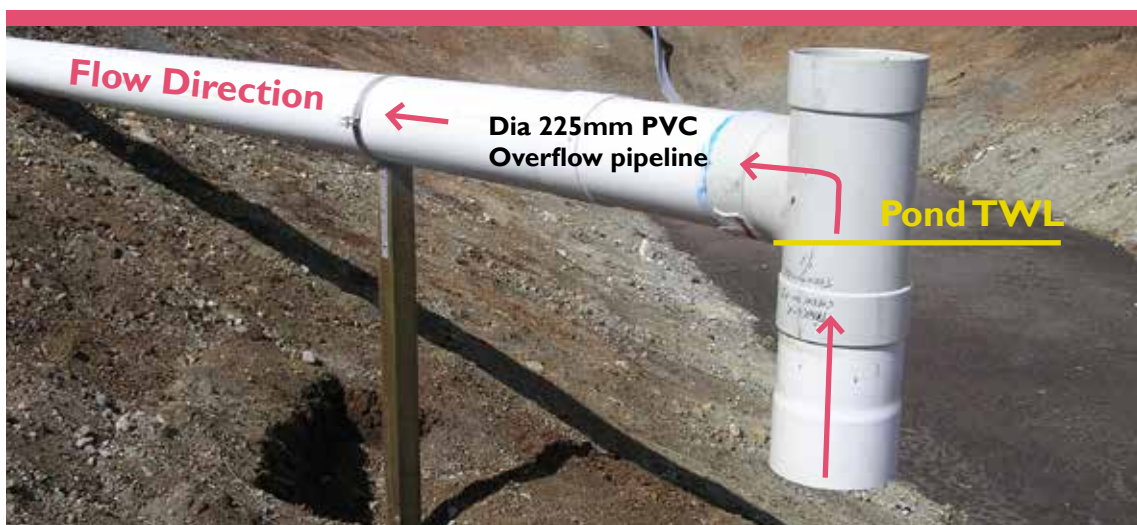
Photograph 5 Tee on overflow pipeline from HLA pond to wet weather pond (Photo courtesy of Alan Skerman)

If a weir will be used, an adjustable type should be considered with horizontal plates placed in a slotted opening. The plates can be inserted or removed to control the overflow level, thus improving management flexibility.

Pipelines for pumping treated effluent for reuse, should have a minimum internal diameter of 75 mm, or larger if the pumping distance exceeds 100 m or there is greater static head or a flatter slope. Table 4 provides diameter-slope recommendations for outlet pipes with different diameters.

TABLE 4   **Minimum slopes for gravity pipes conveying treated effluent**

Inside diameter (mm)	Minimum slope (%)	Velocity at full flow (m/s)
75	0.2	0.29
100	0.1	0.25
125	0.07	0.24
150	0.05	0.23

(Birchall et al. 2008).

Since effluent can be corrosive, sulphate-resistant concrete, unplasticised polyvinyl chloride (uPVC) or HDPE piping is recommended for channels or pipes. Sewer-class pipes should be used to transport effluent under gravity. Rubber-ring-jointed PVC pipe is recommended. HDPE is better able to withstand water hammer than uPVC and may be better for conveying treated effluent to reuse areas (Bradshaw 2002). Seek professional advice during pipe selection.

Trenches for underground pipes should be excavated to provide sufficient cover depth to protect the pipe from stock, vehicles and/or heavy machinery movements. Larger pipes need a greater cover depth. Seek advice on cover depths from the pipe supplier.

HLA Ponds – Sludge removal pipework

HLA ponds may need frequent desludging. Desludging activities can be made simpler by the installation of appropriate extraction pipework. Using a pump or vacuum tanker, or a dredge, allows pond function to be maintained during desludging. While a pond can be desludged using a pump or vacuum tanker fitted with a single pipe over the wall of a pond, good results may be obtained by installing multiple sludge extraction ports along the length of the pond through the pond bank (Photograph 6). Sludge extraction ports typically consist of 300+ mm poly or uPVC pipes permanently installed through the bank. Ports spaced every 10-15 m along the pond length are suggested. Installing these at a 45 degree angle can provide for a better reach.

Where a vacuum tanker is connected directly to the sludge extraction pipework, the pipework will experience a large suction vacuum that it must be able to withstand; for this reason poly pipe may be preferred. Such sludge extraction ports can also provide a guide for a 200 mm pipe attached to a pump or vacuum tanker to be threaded through the port for sludge removal (Photograph 7).

HLA Ponds – Safety

All effluent treatment ponds should be fenced to exclude children and stock. Signs should warn of deep water that may be hidden by a surface crust or cover. Where a significant drowning risk still prevails, a floating device or float-and-retrieval ring should always be available.

Photograph 6 Sludge extraction ports being installed along outer wall of new CAP (Photo courtesy of Tom Smith)

Photograph 7 Pipe threaded through sludge extraction port

"We build 10 year ponds but desludge every 2 years using in-situ pipes."

Producer WA

Notes

NEW DESIGN GUIDELINES FOR ANAEROBIC PONDS

Notes

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"I should have made the primary
pond longer and narrower."

Producer QLD