Design of Anaerobic Lagoons for Animal Waste Management

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1 Purpose and scope

1.1 This Engineering Practice describes the minimum criteria for design and operation of anaerobic animal waste lagoons located in predominantly rural or agricultural areas.

2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this Engineering Practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Engineering Practice are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of current valid standards.

ANSI/ASAE EP470 DEC97, Manure Storage Safety
ANSI/ASAE EP403.3 JUL99, Design of Anaerobic Lagoons for Animal Waste
ASAE EP250.2 DEC98, Specifications for Farm Fence Construction
ASAE D384.1 DEC98, Manure Production and Characteristics
ASAE EP470 DEC97, Manure Storage Safety
ANSI Z535.2, Environmental and Facility Safety Signs

3 Definitions

3.1 Anaerobic lagoons: Waste treatment impoundments made by constructing an excavated pit, dam, embankment, levee, or by a combination of these procedures. Livestock waste is mixed with sufficient soil, or another acceptable method or material that will provide a suitable membrane such as synthetic liners, incorporation of bentonite with in-situ mix air. Trees should be kept away from embankments to the extent that they will not compromise embankments.

3.2 Waste storage ponds: Similar to anaerobic lagoons but are used to store livestock waste for limited periods. They are then normally emptied at least annually and are not designed to provide treatment. Because ponds do not require a treatment volume they are normally smaller than anaerobic lagoons.

4 Laws and regulations

4.1 All federal, state, and local laws, rules, and regulations governing the use of animal waste management lagoons shall be followed. Necessary approvals and permits for location, design, construction, and operation shall be secured from accountable authorities. Federal regulations require a permit to make routine intentional point releases of pollutants from an animal waste management system to a water body. However, unintentional releases that may occur during a catastrophic storm (those exceeding the 25y/24h storm event) do not require a permit. Anaerobic animal waste lagoons are customarily designed to preclude the need for a permit for a point discharge by recycling the residual of the treated waste through land application for final aerobic treatment and crop uptake of nutrients rather than discharge to a water body.

5 Design criteria

5.1 The design required for an anaerobic lagoon to operate successfully varies widely because of differences in climatic and site conditions. Design requirements may also vary because of the operational objective being stressed, such as maximizing pollutant reduction, reducing odors, or minimizing sludge production. In addition, there are differences in opinion as to what constitutes acceptable design criteria. For these reasons, the criteria of this should be considered as recommendations and should be compared with locally accepted design criteria. Figure 1 illustrates the various features of an anaerobic lagoon.

5.2 Siting. Siting of an anaerobic lagoon shall give consideration to its potential for producing undesirable odors, and for contamination of ground water. Siting shall also give consideration to operational aspects of the lagoon.

5.2.1 Odors. Following are recommendations for lagoon siting to minimize the impacts of odor that include the lagoon’s proximity to residences and measures that encourage odor dispersal. Additional recommendations can be found in ANSI/ASAE EP379.

5.2.1.1 Proximity to residences. Lagoons should be located at least 400 m (1300 ft) from residences or other places of occupancy off the premises. This minimum separation may need to be extended to as much as 760 m (2500 ft) in populous and other odor sensitive areas.

5.2.1.2 Relationship to wind, vegetation, and topography. Lagoons should be located so prevailing winds will tend to disperse and transport lagoon odors up and away from residences. Topography, such as ravines, valleys, and other natural depressions, which may carry odors during atmospheric inversions, should be avoided. Lagoons should be sited to take advantage of trees and natural barriers that tend to lift and mix air. Trees should be kept away from embankments to the extent that roots will not compromise embankments.

5.2.2 Ground water protection. A lagoon’s proximity to wells and other ground water supplies, and the soils and foundation in which it is constructed, shall be such that the potential for ground water contamination is abated.

5.2.2.1 Proximity to water supplies. Separation distances specified by applicable state or local regulations shall be followed. As a minimum, the nearest liquid edge of lagoons should be a minimum of 90 m (300 ft) from wells and other ground water supplies.

5.2.2.2 Soils and foundation. A thorough site investigation shall be made to determine the physical characteristics and suitability of the soil and foundation for a lagoon. Lagoons should be located in soils of low permeability. More permeable soil types may require an impermeable membrane such as synthetic liners, incorporation of bentonite with in-situ soil, or another acceptable method or material that will provide a suitable seal.

NOTE—It would be desirable to state a design infiltration rate for the movement of liquids through the bottom and sidewalls. However, state-of-the-art has not developed to the point that there is a universally accepted rate. The USDA Natural Resources Conservation Service has published in-situ soil properties for which a liner should be considered in its Agricultural Waste Management Field Handbook available from the Consolidated Forms and Publications Distribution Center, Landover, Maryland.
5.2.3 Operational siting considerations. For convenience, lagoons should be located as near to the source of the waste as possible.

5.3 Total lagoon volume (TLV). The total volume for anaerobic lagoons is the sum of the treatment volume plus the volumes of manure, wastewater, and both contaminated and uncontaminated runoff produced during the period between drawdown events plus an allowance for sludge accumulation.

\[
TLV = TV + LWV + WWV + ROV + SV
\]

where:
- **TLV** is total lagoon volume, \(m^3 \text{ (ft}^3\text{)}\)
- **TV** is treatment volume, \(m^3 \text{ (ft}^3\text{)}\)
- **LWV** is livestock waste volume, \(m^3 \text{ (ft}^3\text{)}\)
- **WWV** is wastewater volume, \(m^3 \text{ (ft}^3\text{)}\)
- **ROV** is runoff volume, \(m^3 \text{ (ft}^3\text{)}\)
- **SV** is sludge volume accumulation, \(m^3 \text{ (ft}^3\text{)}\).

The elements of the equation above are described in the following subsections.

5.3.1 Treatment volume (TV). The treatment volume is sized on the basis of waste load (volatile solids) added per unit of volume and climatic region. Figure 2 shows recommended maximum lagoon loading rates for the contiguous US based on average monthly temperature and corresponding biological activity. The loading rates given are expressed in terms of mass of volatile solids, VS, per day per unit of treatment volume. The figure is intended to show the effect of temperature on loading rate. Where specific local geographic and climatic information is available, it should be used in preference to the values shown in figure 2. If odors are of concern, consideration should be given to reducing the VS loading to below those shown in figure 2. Consideration may be given to increasing loading rates for covered lagoons proposed for methane production. ASAE D384 lists the daily VS production for various animal species, but local data should be used where available. The equation for the treatment volume is:

\[
TV = \frac{LAW \cdot VS}{TDVSL}
\]

where:
- **TV** is treatment volume, \(m^3 \text{ (ft}^3\text{)}\)
- **LAW** is live animal weight (average weight over design period), kg (lb)
- **VS** is volatile solids produced, kg/1000 kg (lb/1000 lb) LAW per day
- **TDVSL** is VS per day per unit of lagoon volume, kg/d \(\cdot 1000 \text{ m}^3 \text{ (lb/d} \cdot 1000 \text{ ft}^3\text{)}\) (see figure 2).

5.3.2 Livestock waste volume (LWV). It is recommended that the volume of waste produced in one year be used. As a minimum, this waste volume should be the volume of livestock manure and other solid waste, such as bedding and spilled feed, produced between drawdown events. The equation for the livestock waste volume is:

\[
LWV = (LAW \cdot VM \cdot P) + (OS \cdot P)
\]

where:
- **LWV** is livestock waste volume, \(m^3 \text{ (ft}^3\text{)}\)
- **LAW** is live animal weight, kg (lb)
- **VM** is volume of manure, \(m^3 \text{ (ft}^3\text{)}\) of LAW per day
- **P** is design period, days
- **OS** is other solids, \(m^3/d \text{ (ft}^3/d\text{)}\).

5.3.3 Wastewater volume (WWV). The wastewater volume is contaminated water, such as milkhouse wastewater and washdown...
water, and unrecycled flush water produced between drawdown events. This volume is determined by observation and measurement of the livestock facility’s miscellaneous wastewater sources.

5.3.4 Runoff volume (ROV). Runoff volume includes all runoff, contaminated or uncontaminated, and precipitation that will contribute to the lagoon. The volume is based on the normal runoff volume for the period between drawdown events plus the runoff volume of the 25y/24h storm event. This volume should also provide for the normal (mean) precipitation between drawdown events and the 25y/24h storm precipitation on the lagoon surface. To the extent possible, uncontaminated runoff water should be excluded from the lagoon except when needed for dilution or other purposes.

5.3.5 Sludge volume accumulation (SV). An allowance is provided for an accumulation of fixed solids or non-volatile solids, and non-biodegradable materials contained in livestock feed that settle to the bottom of the lagoon. This volume may be calculated as follows:

\[ \text{SV} = \text{TAW} \times \text{TS} \times \text{FA} \times \text{DA} \]  

where:

- **SV** = Allowance for sludge accumulation, m³ (ft³)
- **TAW** = Average animal weight for the sludge accumulation period, kg (lb)
- **TS** = Total solids produced per day per 1000 units of live animal weight, kg/day · 1000 kg live weight (lb/day · 1000 lb); see table 1 in ASAE D384
- **FA** = Fraction of TS that accumulates as sludge; see table 1
- **DA** = Days of accumulation; either life of lagoon or days between sludge removal events.

The volume allowance for sludge accumulation can be reduced if it is anticipated that a portion of the sludge will be removed during periodic drawdown events. The volume allowance for sludge should be increased if bedding is discharged into the lagoon. The volume allowance may be decreased if the influent is treated with solids separation prior to discharge into the lagoon.

5.4 Depth

5.4.1 The lagoon design should provide for a 2.0 m (6.6 ft) minimum depth when the lagoon is filled to its treatment volume elevation (figure 1). The elevation at the treatment volume should be at least 0.3 m (1 ft) above the highest ground water table elevation.

5.4.2 The total depth of the lagoon should be as deep as practical to reduce surface area and convection heat loss, enhance internal mixing, reduce odor emissions, promote anaerobic conditions, minimize shoreline weed growth problems, and reduce mosquito production. Where soil and ground water conditions permit, depths of 6 m (20 ft) may be used. Special attention shall be given to sealing and drawdown management when lagoons shall be constructed in areas subject to high water tables. Consideration should be given to the lagoon depth in regard

### Table 1 – Sludge accumulation (for mature lagoons subject to moderate loading rates)

<table>
<thead>
<tr>
<th></th>
<th>m³/kg TS added</th>
<th>ft³/lb TS added</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer</td>
<td>0.00184</td>
<td>0.0285</td>
</tr>
<tr>
<td>Pullet</td>
<td>0.00284</td>
<td>0.0455</td>
</tr>
<tr>
<td>Swine</td>
<td>0.00303</td>
<td>0.0486</td>
</tr>
<tr>
<td>Dairy</td>
<td>0.00455</td>
<td>0.0729</td>
</tr>
</tbody>
</table>

*There is no value for beef. However one might expect it to be close to or slightly less than the dairy value due to the lower fiber percentage of most diets.*
to the cold temperatures in northern climates as to the freezing of inlet and outlet pipes, sealing, and the effect of depth on cooling and warming of the lagoon contents.

5.5 Shape. Desirable length to width ratio varies according to detention time of the lagoon. Lagoons that are nearly round or square are favored for detention times of 1 year or more, or when lagoons are drawn down annually. Length to width ratios up to 4 to 1 may be used where detention time is 50 days or less and there is daily overflow to another lagoon cell or other treatment facility.

5.6 Detention time. Detention time (hydraulic retention time) determines the extent of treatment provided the waste and as such should be as long as regulations or practicality permits. A minimum detention time of 50 days is recommended for the primary lagoon.

5.7 Multiple cell lagoons. Multiple cell lagoons may be used when allowed by local conditions and/or regulation.

5.7.1 When multiple cells are operated in series, the volume of the primary cell should not be less than the sum of the treatment volume and sludge accumulation volume as described in clauses 5.3.1 and 5.3.5.

5.7.2 When multiple cells are operated in parallel, each cell's volume should be determined according to clause 5.3 based on anticipated loadings.

5.8 Earth embankment and excavation

5.8.1 Embankment top width. The minimum embankment top width should be 2.5 m (8 ft).

5.8.2 Side slopes. The combined wet and dry side slopes of settled embankments should not be less than 5:1, and neither slope should be steeper than 2:1. Excavated cut slope should not be steeper than 2:1. Soil stability and the method to be used in maintaining embankment vegetation should be considered in determining the appropriate side slopes. At least in one place, and perhaps more on lagoons with large surface areas, a flatter slope, approximately 10:1, should be provided to allow equipment access for operations such as agitation and drawdown.

At this location the top width should be at least 4 m (13 ft). Consideration should be given to armoring (such as with riprap, concrete, or geotextiles) this area for protection from erosion due to equipment and agitation.

5.8.3 Embankment settlement. The embankment top elevation should be increased by at least 5% during construction to allow for settlement.

5.8.4 Freeboard. For lagoons that collect runoff, the top of the settled embankment should be at least 0.6 m (2 ft) above the total lagoon volume (see clause 5.3). When inflow to the lagoon is always controlled, such as with a pump system, freeboard can be reduced to 0.3 m (1 ft).

5.8.5 Embankment protection. Some means, such as vegetation or armoring (eg, riprap, concrete, or geotextiles) should be considered for protecting the embankment from erosion. If vegetative means are used, suitable topsoil should be placed on the top and dry slope of embankment to a depth of 15 to 30 cm (6 to 12 in.) to promote vegetation establishment. Species selection should favor low-growing, sod-forming grasses and avoid use of vegetation having long tap roots. For lagoons having a surface area greater than 2 ha (5 acres), consideration should be given to providing embankment protection from wave action.

5.9 Inlet and outlet

5.9.1 Inlet. Inlet devices should discharge the waste into the lagoon beyond the toe of the embankment or excavation cut slope. Pipes or open channels may be used. The minimum diameter or least dimension of the inlet should be 150 mm (6 in.) for nondairy waste and at least 200 mm (8 in.) for dairy waste. Inlets may be located either above or below the lagoon's water surface. Gravity pipelines should have a gradient between 4% and 15% with a preferred gradient of 7% to 8%. If the inlet discharges below the lagoon's water surface and originates within a building, it should be trapped and vented so gases are released outside the building. The discharge end should include erosion prevention measures when appropriate.

5.9.2 Outlet. An automatic overflow device, such as an earthen spillway or pipeline, should be installed that will begin discharging when the lagoon level reaches or exceeds the elevation of the total lagoon volume. This outlet should be designed for the 25y/24h storm event with consideration given to its operating head requirements in relationship to maintaining adequate freeboard (see clause 5.8.4). No outlet, however, should be installed to automatically discharge when the lagoon level is below the total lagoon volume unless the discharge is to another lagoon cell or to a storage facility. Outlets for this purpose should have a minimum capacity of 1.5 times the peak daily inflow rate if the overflow is to be contained in another lagoon cell or other treatment facility. It should be installed in a manner that allows the effluent to be taken at an elevation at or above the treatment volume elevation (see figure 1). The discharge end of an outlet should include erosion prevention measures.

5.10 Effluent utilization. Effluent from an anaerobic lagoon shall not be discharged to streams, lakes, or other waterways, or be allowed to run off the owner's property except during storms that equal or exceed the 25y/24h event. Effluent from lagoons is typically land applied. Supernatant and sludge application should result in annual nutrient applications that approximate crop need and not cause undesirable levels of nutrients or toxic material to accumulate in soil, plants, soil water, ground water or runoff. Application frequency should consider labor availability, cropping schedules, rainfall, and soil conditions.

5.11 Water supply. Adequate water should be available for start-up (see clause 6.1) and to maintain the treatment volume. A water supply may also be necessary to dilute lagoon contents and reduce salt concentrations.

5.12 Safety. A fence should enclose the lagoon to reduce the opportunity for entrance of livestock, children, pets, and others. Fences should be constructed to protect the embankment and to permit access for lagoon maintenance (see ASAE EP250). Safety signs in accordance with ANSI Z535.2 should be posted to warn of the hazards of the lagoon.

5.13 Protection. Embankments and disturbed areas surrounding the lagoon should be treated to control erosion.

5.14 Visual appearance. Consideration should be given to using vegetation and natural or constructed barriers to improve appearance of the lagoon and/or to screen it from view.

6 Operation and maintenance

6.1 Start-up. The lagoon is considered in start-up at any time the lagoon is empty, such as following construction or during maintenance. At start-up the primary lagoon should be filled with clean water to at least 60% of the lagoon's treatment volume prior to discharging waste into the lagoon. Surface water may be diverted into the lagoon for this purpose. However, this diversion should cease when the treatment volume is filled. Where possible, waste should be added slowly at first and increased over a period of 2 to 4 months to the design loading rate. Start-up in warm weather should be preferred to cold weather.

6.2 Operational depth and loading. The minimum depth at which the lagoon should operate is at its treatment volume elevation (see figure 1). Daily loading of waste should be preferred to less frequent loading. Drawdown (see 5.10) should begin prior to or when the supernatant elevation reaches the TLV elevation less the contribution of the 25y/24h precipitation on the lagoon surface and the 25y/24h storm portion of the runoff volume (figure 1).

6.3 Crust. Thin crusts, which may form from floating solids, especially when forage is fed, should be maintained for their benefits of reducing odor emissions, maintaining anaerobic conditions, and maintaining a constant temperature. Crusts should be broken and removed, however, when their thickness exceeds 0.3 m (1 ft). When lagoons with crusts are drawn down, additional odors may be released. It is important to time drawdowns when the impact of odor will be least.

6.4 Salt build-up. Lagoons with long detention times or those that are used to recycle flush water may require dilution to reduce the concentration of dissolved salts. These salts along with antibiotics may inhibit bacterial action. When the total salt concentration of the supernatant is in the range of 2500 to 5000 mg/L, the lagoon should be drawn down and diluted with fresh water. Generally, drawdown to the
treatment volume elevation and maximizing dilution water discharged into
the lagoon will solve the salt problem.

6.5 Inlets. Submerged inlets may plug unless flushed with clean water
at least daily. Trickle flows should be eliminated during freezing weather.

6.6 Sludge removal. Removal of sludge after several years of
operation should be anticipated. Procedures and equipment for
management of sludge removal are beyond the scope of this document.
However, complete planning should include contingencies for
management of the nutrients contained in the sludge.

6.7 Inspection. Lagoons should be under continual surveillance,
particularly in regard to operating level and control of overflow. They
should be inspected at least annually for structural integrity, and
maintenance requirements should be noted. Maintenance may be
necessary on liners and safety features, and to control rodent damage
and the growth of vegetation on embankments, lagoon crusts, and
surrounding areas.