Livestock Manure Lagoons Protect Water Quality

Ronald E. Hermanson, P.E.

Lagoons treat livestock manure and store the treated products until final use, generally application to soil for recycling into crop production. Lagoons designed and operated to destroy (break down) manure solids can reduce organic matter and nitrogen by more than 50%. Lagoons can be designed and operated for the individual needs of Washington producers. Designing storage lagoons to fit local weather conditions will provide ample storage of manure and wastewater and will meet the no-discharge requirements of the Washington Department of Ecology (Ecology) and the U.S. Environmental Protection Agency. Additional design considerations fit the storage to cropping and labor cycles of the operation. Adding storage for recycled flush water is popular with many dairy and swine operators. You can trace lagoon failure to improper design, construction and management.

**Advantages**

Properly designed and operated lagoons have many advantages:

- Low cost construction
- Minimum operating cost
- Reduced labor
- Maximum convenience in handling and land spreading of manure
- Compatibility with modern flush cleaning systems and pit overflow systems
- Reduced or eliminated fly problems

**Disadvantages**

- Even a properly functioning anaerobic lagoon can produce disagreeable odors
- Significant loss of manure nitrogen fertilizer
- Need for periodic sludge removal
- Need for final disposal of lagoon contents by irrigation or tank wagon
- May form mosquito habitat
- Cost of equipment and electrical energy if aerators are needed
- There is no economically feasible method of treating livestock manure so that the lagoon contents can be discharged to a watercourse without pollution.

Use lagoons where you need economical manure storage for several months or more, where you use large volumes of water, as in flushing, and where labor is limited. Engineers recommend lagoons only where distances to property lines and residences are adequate. Do not use a lagoon where the subsoil is porous or the water table is shallow unless you create an impermeable barrier.

### Types of Lagoons

The two basic types of lagoons are aerobic (pronounced air-o-bic) and anaerobic. Animal manure contains bacteria, which digest some of the manure as food, thereby making the manure more stable. The manure is not completely destroyed in either type of lagoon, so a large volume of sludge remains for final disposal.

**Aerobic Lagoon.**

Aerobic bacteria require dissolved oxygen in the manure-water mixture. Because oxygen must be absorbed from the air, and sunlight is necessary for the growth of oxygen-producing algae, design aerobic lagoons on the basis of surface area. Some communities use aerobic lagoons for treating their wastewater. Aerobic lagoons are normally not practical for animal manure treatment because they would need such a large surface area. A major advantage is that the aerobic lagoon is odor free. Use mechanical aeration to develop the aerobic process where disagreeable odors are a problem. The most common aerator floats on the lagoon surface, where it pumps wastewater into the air to incorporate oxygen and mix the lagoon contents. A diffused air system can pump air into the manure, but the floating aerator appears to be more economical. The disadvantage of the mechanically aerated lagoon is the electrical expense to run the aerator continuously. Mechanically aerated lagoons should be at least 10 feet deep and can be 20 feet deep if groundwater and foundation conditions permit. Minimum water volumes and aerator sizes for mechanically aerated lagoons are given in Table 1. The aerator size is based on an oxygen transfer rate to the lagoon water of 2 pounds per horsepower-hour and provides oxygen at a rate of 1.5 times the biochemical oxygen demand.

**Anaerobic Lagoon.**

Anaerobic lagoons are the most common and practical for livestock manure because it is not necessary to dissolve oxygen in the wastewater. Anaerobic bacteria can live in water of any depth. Volume of water, rather than the surface area, is the basis of anaerobic lagoon design.

Anaerobic bacteria digest organic matter by liquefying it and then converting it primarily into carbon dioxide, methane, ammonia, and hydrogen sulfide. If grossly overloaded, anaerobic lagoons give off septic odors. Even properly functioning anaerobic lagoons may produce some disagreeable odor, so locate them downwind from residences. Nuisance conditions from livestock manure lagoons have developed in some cases where the design was inadequate or the lagoon was improperly managed. Today engineers can design a lagoon to operate anaerobically.
with a minimum of disagreeable odors, provided it is not overloaded. Lagoon size depends upon number, size, and kind of livestock. Anaerobic lagoon depth can vary from 6 to 20 feet or deeper. Minimum water volumes of anaerobic lagoons for various types of livestock and poultry appear in Table 2.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Volume per pound of livestock (cu. ft.)</th>
<th>Volume per animal (cu. ft.)</th>
<th>Aerator size* (head per horsepower)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry (4-lb. chicken)</td>
<td>0.75</td>
<td>3</td>
<td>2290</td>
</tr>
<tr>
<td>Hog (200-lb hog)</td>
<td>1.00</td>
<td>200</td>
<td>75</td>
</tr>
<tr>
<td>Beef (1000-lb animal)</td>
<td>0.75</td>
<td>750</td>
<td>20</td>
</tr>
<tr>
<td>Dairy (1400-lb cow)</td>
<td>1.25</td>
<td>1750</td>
<td>14</td>
</tr>
</tbody>
</table>

* For maximum mixing and oxygen dispersion, the aerator can be sized to give 1 horsepower per 1000 square feet of lagoon water surface.

Table 2. Minimum design volume of anaerobic storage lagoon.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Volume per pound of animal (cu. ft.)</th>
<th>Volume per animal (cu. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry</td>
<td>3</td>
<td>12 (4-lb chicken)</td>
</tr>
<tr>
<td>Hog</td>
<td>2</td>
<td>400 (200-lb hog)</td>
</tr>
<tr>
<td>Beef</td>
<td>2</td>
<td>2000 (1000-lb animal)</td>
</tr>
<tr>
<td>Dairy</td>
<td>2</td>
<td>2800 (1400-lb cow)</td>
</tr>
</tbody>
</table>

Lagoon Location and Planning

Location.
Construct an anaerobic lagoon near the manure source, yet as far from inhabited dwellings as practical. No minimum distance will fit all circumstances. Acceptable minimum distances vary from 500 feet to 3,750 feet. Build lagoons at least 100 feet from wells that supply water for people. Prevailing summer winds should carry odors away from residences. Visual barriers such as trees and fences around the lagoon will reduce complaints from neighbors.

Lagoons function best when several buildings drain into them, and when the buildings drain on a schedule that approximates continuous loading. Daily and weekly lagoon loading are common and work well.

Reduce the possibility of groundwater pollution by locating the lagoon in impervious soil or soil that can be adequately sealed. Seal porous soils, especially those in regions where fractured rock is overlain with a shallow layer of porous soil, before using the lagoon. You can seal lagoons using soil additives, such as bentonite, 6 to 12 inches of compacted moist soil that is sandy loam or finer in texture, an impermeable membrane, or other sealants. Research indicates that physical and biological sealing reduce seepage 90% to 99%, and that manure is an adequate sealant in soils that are sandy loam or finer in texture. Even loamy sands have sealed in 30 to 60 days under reasonable manure loadings when all manure was put into the
lagoon. If you are unsure of soil suitability at a selected site, consult your county extension agent or Soil Conservation Service representative.

Confinement livestock systems often are expanded. The first lagoon built to serve the system usually occupies the best site. Remember that it is easier and less expensive to build larger lagoons during initial construction when all equipment is on the site, than it is to enlarge them after they are in use. Seriously consider possible expansion of the livestock enterprise before constructing your lagoon. Build the lagoon to accommodate any new buildings planned for the next 4- or 5-year period. Do not drain new buildings into existing lagoons that are not large enough to accommodate the manure.

**Inlets and Outlets**

Locate outlets that connect the primary lagoon to a secondary lagoon across the lagoon from the inlet pipe. A 6-inch pipe will convey the flow from a heavy rainfall on a 1-acre primary lagoon. A concrete channel is suitable only in a warm climate. The discharge end of the inlet pipe can be below or above the surface of a primary lagoon, but a submerged discharge is more likely to plug. In cold climates, provide inlets with a tight stopper or valve at the building to prevent liquids from freezing and clogging the pipe. Trickle flows above the lagoon water level can freeze and close the pipe. During freezing weather, collect a quantity of manure in a gutter or collection pit and empty it to provide enough flow to avoid freezing. Provide a clean-out wye every 75-100 feet so you can rod the inlet pipe clean. Using manure ramps or loading a lagoon by pushing the manure directly into the edge will create large deposits of manure at the loading point. However, bacterial activity and resulting gas bubbles will eventually distribute much of the manure into the lagoon.

**Shape**

The lagoon shape affects how well wave action can mix its contents. Circular and square shapes facilitate mixing. You can use long, narrow rectangular lagoons if construction will be by a drag line and if a drag line will remove accumulated sludge.

**Lagoon Systems**

Where lagoon water will recirculate as flushing water in a confinement facility and where further treatment is desired, you can use a combination of lagoons. One system is an anaerobic lagoon followed by a naturally or mechanically aerated lagoon. This system will provide flushing water that does not have disagreeable odors, and also makes the treated manure more attractive for land disposal by irrigation.

Another system is a mechanically aerated lagoon followed by a naturally aerated lagoon. This system will cause no disagreeable odors because both lagoons operate aerobically. The final treated manure, low in solids, can be used for flushing water and can be applied to the land by irrigation.

**Final Disposal**

Where evaporation does not exceed the volume of rainfall plus the liquid manure, a potential exists for lagoon overflow. If there is potential for lagoon overflow, make
the final disposal of treated manure on land, whether from a single lagoon or multiple lagoons. Never discharge lagoon contents to any watercourse or water body. Rather, pump the lagoon down to allow space for both manure and rainfall.

Use sprinkler or surface irrigation systems to dispose of excess lagoon liquid on the land. Do this during dry seasons when groundwater and surface runoff pollution will not occur. Lower the lagoon level before wet seasons begin to provide storage space for seasonal rain. Using lagoon contents to irrigate provides these benefits: disposes of excess lagoon liquid to prevent outflow, supplies some of the crop water requirements, and adds fertilizer elements to the soil.

Lagoon supernatant (liquid) recirculated for flushing will accumulate salts in the lagoon system. You will need to plan on periodic pumpdown and replacement with fresh water to avoid inhibiting bacterial activity and to prevent the adverse effects of salt on crops.

You can accomplish supernatant and sludge removal in one operation. Lagoon liquid provides substantial plant nutrients. Mixing liquid and sludge provides more nutrients and adds much more organic matter. Sludge consists of ash and slowly biodegradable organic compounds such as lignin and cellulose. Sludge is high in phosphorous, whereas the supernatant contains most of the nitrogen and potassium. Nutrient analysis by a competent laboratory is the first step in planning application rates. A low-cost tester that provides a reasonable nutrient estimate is a calibrated hydrometer* that requires a lagoon solids content of 2% or more. A more expensive Swedish test kit* will give more accurate results, but only analyzes nitrogen.

*These are available from Agri-Waste Technology, Inc., 3504 Sloan Court, Raleigh, NC 27606. (919-851-8528) See the nutrient budgeting method presented in PNW0239, How to Calculate Manure Application Rates in the Pacific Northwest, available at your county extension office. Contact your extension agent for recommendations on agronomic manure application rates.

**Construction**

Follow these pointers in constructing your lagoon.

1. Make sure the inlet pipe is well supported and extends beyond the toe of slope in the lagoon. Use an inlet pipe with a diameter of at least 6 inches.

A minimum of 8 inches is recommended for dairy cattle manure. Lay the pipe on a minimum slope of 1 foot per 100 feet (1/8 inch per foot). Livestock manure is corrosive, so use a pipe material that resists corrosion.

2. Make top width of dike around lagoon 8 feet or more to allow for equipment travel.

3. Increase design height of the embankment at least 5% to ensure meeting the design top elevation after settlement.

4. Provide 2 feet of additional depth above design depth as a safety factor against overflow.

5. Use slopes below the waterline as steep as soil stability properties permit and use flat slopes above the waterline for ease in mowing.
6. Seed banks with appropriate grass-legume mixture and keep them mowed.

7. Divert surface water and roof drainage away from lagoon, unless needed in areas of low rainfall and high evaporation.

8. Install a fence to keep out animals, children, and trespassers. Post warning signs and keep the gate locked.

9. Provide a grass spillway for embankment protection if surface runoff from outdoor lots drains into the lagoon. The spillway should have the capacity for a 24-hour, 25-year rainfall.

10. Where it is necessary to have an overflow to another lagoon or holding pond, install an overflow device at the design lagoon surface level that has a minimum capacity of 1 1/2 times the peak daily inflow rate. Make a "T" on the outlet pipe to draw liquid from at least 18 inches below the surface to prevent solids transfer. Use a reverse slope on the outlet pipe with the inlet below the water surface as an alternative. It will drain water from below the surface scum or crust as needed. Note that dairy cattle manure solids form thick surface crusts, and design accordingly.

11. Place one or more concrete tractor access ramps in corners for mixing, and for pumpout if PTO (power takeoff) operated. Use a local design or a slope of 7:1.

12. Protect lagoon bottom from scour during agitation where required by soil conditions.

Management

Follow these pointers in managing your lagoon.

1. Partially fill the new lagoon if needed to make a dilute manure slurry.

2. Manure must not contain substantial amounts of bedding. Bedding can plug the inlet sewer from livestock building and decomposes slowly.

3. Keep manure solids covered with water at all times. You may need to add dilution water to the raw manure inflow at a rate of 5 gallons of water per gallon of raw manure.

4. The lagoon will accumulate sludge because solids digestion is not complete. Only periodic sludge removal will restore the lagoon to its designed volume.

5. Control mosquito breeding by adding diesel fuel or larvicide. Limit vegetation to no closer than 6 inches from the anticipated normal waterline to reduce suitable mosquito habitat.

6. If the lagoon water does not evaporate fast enough to prevent
overflow, pump the lagoon contents onto the land with an irrigation system. Leave some of the contents in the lagoon as seed to continue the bacterial process. Rotate acreage to avoid salt buildup. Or, if the salt content of the lagoon water is too high for the crop, blend lagoon water with irrigation water.

7. Salt concentration greater than 5000 parts per million inhibits lagoon bacteria. Control the salt concentration by using irrigation withdrawal and replacing some lagoon effluent with fresh water.

8. Start a lagoon at the beginning of warm weather because bacterial activity begins more rapidly when the lagoon temperature is well above 50°F.

9. Keep pH above 6.7 by applying hydrated lime or caustic soda if the lagoon becomes malodorous, using an initial rate of 1 pound per 1000 square feet of lagoon surface. An anaerobic lagoon functioning properly will have a slightly basic pH of 7.5.

10. Convert a malodorous anaerobic lagoon to an aerobic process by adding a mechanical aerator. See Table 1 for aerator sizing. You can also use the alternative method of aerator sizing to provide 1 horsepower of aerator for each 1000 square feet of lagoon surface. It results in greater horsepower requirements, but better odor control. Carefully evaluate the annual energy cost and the aerator cost before choosing this process.

11. It is better to use two aerators of half the total power required; so one will always continue operation in the event of mechanical breakdown.

12. Do not install lagoons where the sulfate concentration in the water exceeds 200 ppm.

13. Keep weeds, wire, twine and other trash out of lagoon because they will plug pumps. Weeds will grow on floating solids that form a crust. The crust will reduce odor emissions, but if weed growth is extensive it may be wise to agitate to destroy weed growth. Base this lagoon management decision on local conditions.

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**Sludge Management**

**Accumulation.**

Lagoons at best are only about 70% efficient in destroying solids, so solids do accumulate. They accumulate rapidly in a facility designed only for storage because solids destruction may be no more than 30%. A major disadvantage of lagoons for cattle manure is the problem of sludge removal. Solids will accumulate in dairy-cow lagoons at an annual rate of about 260 cubic feet per head.

For small lagoons with irrigation disposal, you will need a separate pump for mixing. The pump should be a high-volume, liquid manure pump. As an alternative, tractor PTO-operated propellers move liquid at a high rate and effectively agitate lagoon solids into suspension. For large dairy-cow lagoons, remove the solids before
discharging manure into the lagoon. If you flush the building with water, you can remove the solids with a special screen (solids separator). A solids separator will remove about 40% of the solids, and you can then safely reduce lagoon volume per cow to 70% of the volume specified in the table for anaerobic lagoons. Using a solids settling basin with a gutter cleaner to remove and elevate the solids to a pile or truck is an alternative method.

Solids will accumulate in a hog lagoon at a rate of about 12 cubic feet per finishing hog per year. You will usually need to remove sludge about every 10 years, for a properly designed anaerobic hog lagoon.

In cattle manure lagoons, floating solids and solids that are buoyed up from bottom sludge by normal warm-weather gas production frequently form a crust on the lagoon. The crust is beneficial; it reduces odor emission and the loss of ammonia nitrogen.

Lack of a crust is not a sign of lagoon malfunction, however. If barns are cleaned by flushing, the volume of water is so great that solids are less likely to form a crust. Solids separation creates a holding pond with only fine solids and no source for a solids crust. Because you cannot always control the volume of water put into a lagoon, do not attach too much importance to whether your lagoon has a floating crust.

**Agitation for pump-out.**
Agitation must destroy any crust of floating solids and mix into suspension a large part of the bottom sludge. A tractor PTO-powered propeller is the common agitator because it moves a greater volume of water per minute for a given horsepower.
Agitate the storage lagoon with the propeller slightly below the surface at a flat angle so you direct the flow into the crust. Directing flow along the sides of the lagoon is more effective than directing flow to the middle. Only deep agitation can suspend bottom sludge. Never agitate deeply in one location for more than a few minutes to avoid rupturing the bottom seal. Breaking the seal can cause the lagoon to leak to groundwater until it is re-sealed when the lagoon is returned to operation.

Thorough mixing may require agitation from more than one location.

The lagoon is ready for pump-out when the contents swirl and move around. Constant agitation may be necessary to keep the solids suspended for pump-out. Never leave the tractor unattended while agitating deeply.

### Runoff Storage

A lagoon must have the capacity to store the manure plus runoff from feedlots and confinement facilities. Runoff storage regulations came about because of the Federal Water Pollution Control Act Amendments of 1972 and continue with the Federal Water Quality Act of 1987. The act set up the National Pollutant Discharge Elimination System Permits under the Environmental Protection Agency. Ecology, which administers the permit system in Washington, is developing a statewide general permit to help control discharge from dairy farms, with help from a dairy advisory committee. Ecology expects to begin issuing the dairy discharge permits to protect surface and groundwater in the fall of 1992. Before constructing any lagoon, check with Ecology to see whether a permit is required.

### Lagoon Design
Determine the design volume for an anaerobic lagoon in two ways. First calculate the lagoon volume needed according to the method in Table 2. Then calculate the volume needed to store the manure (Table 3) plus parlor and holding pen wash water, flush water if used, and contaminated lot runoff accumulated during the design storage period. You will need the larger of the two volumes for the anaerobic storage lagoon.

A second-stage lagoon is useful for storage of liquid overflow for recirculation and recycling as flush water. Although lagoon liquid is unsuitable for stream discharge, it is suitable for flushing barns. Make the second-stage lagoon one-half the volume of the first-stage lagoon.

An alternative design for the second-stage lagoon if treatment is important, is to design the first stage as an anaerobic lagoon that will minimize odors, and size the second storage lagoon to store the overflow manure plus water for the design storage period.

**Table 3. Manure production.**
Values are approximate and in practice easily vary 20% above or below table values. Includes wasted water, and for dairy cows, water from cleaning milking center and equipment.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Size lb.</th>
<th>Total manure production (cu. ft./day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cattle</td>
<td>1400</td>
<td>2.0</td>
</tr>
<tr>
<td>Beef cattle</td>
<td>750</td>
<td>0.8</td>
</tr>
<tr>
<td>Hogs</td>
<td>150</td>
<td>0.2</td>
</tr>
<tr>
<td>Laying hens</td>
<td>4</td>
<td>0.004</td>
</tr>
<tr>
<td>Broilers</td>
<td>2</td>
<td>0.0028</td>
</tr>
</tbody>
</table>

**EXAMPLE DESIGN**

Design an anaerobic storage lagoon to store the manure and wash water from 100, 1,400-lb. milk cows for 150 days:

Lagoon volume = 100 cows x 2 cu. ft./lb. x 1,400 lb./cow = 280,000 cu. ft.*

Volume for storage = 100 cows x 2 cu. ft./cow-day * 150 days * = 30,000 cu. ft.

Use lagoon volume design for best odor control, because it is greater than the 150-day storage volume. If odor control is unimportant, the 150-day storage volume can be used.

**For Design Volume = 280,000 cu. ft.**

From Table 4, a lagoon with a liquid depth of 12 ft. (14 ft. total depth), waterline dimensions of 192 ft. x 192 ft., and bottom dimensions of 144 ft. x 144 ft., will be adequate because the capacity of 341,000 cu. ft. exceeds the 280,000 cu. ft. needed. Note that the design volume can be provided more closely by using the following equation:
Volume = water depth x length at mid depth x width at mid-depth

* (From Table 2.)
** (From Table 3.)
*** (Based upon climate, soil and cropping system)

Above-surface inlet.
Distributes solids into storage when surface is ice free.
Inlet can freeze.

Below-surface inlet.
Useful if there is not enough fall between manure source and storage.
Prevents freezing, but tends to plug with solids.
Needs cleanout.

Straight overflow pipe to second stage lagoon.
Reverse slope to transfer solids-free wastewater.

T-junction overflow pipe to second stage lagoon.
T-junction inlet to transfer solids-free wastewater.

### Table 4. Water volume of anaerobic lagoons of a range of sizes
(Total depth 14 ft.—water depth 12 ft.)

<table>
<thead>
<tr>
<th>Volume to waterline (cu. ft.)</th>
<th>Top</th>
<th>Waterline</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (ft.)</td>
<td>Width (ft.)</td>
<td>Length (ft.)</td>
</tr>
<tr>
<td>24,500</td>
<td>75</td>
<td>75</td>
<td>67</td>
</tr>
<tr>
<td>57,800</td>
<td>100</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>78,200</td>
<td>125</td>
<td>100</td>
<td>117</td>
</tr>
<tr>
<td>98,600</td>
<td>150</td>
<td>100</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>119,000</td>
<td>175</td>
<td>100</td>
<td>167</td>
</tr>
<tr>
<td>139,400</td>
<td>200</td>
<td>100</td>
<td>192</td>
</tr>
<tr>
<td>169,400</td>
<td>150</td>
<td>150</td>
<td>142</td>
</tr>
<tr>
<td>180,200</td>
<td>250</td>
<td>100</td>
<td>242</td>
</tr>
<tr>
<td>247,700</td>
<td>175</td>
<td>175</td>
<td>167</td>
</tr>
<tr>
<td>341,000</td>
<td>200</td>
<td>200</td>
<td>192</td>
</tr>
<tr>
<td>449,300</td>
<td>225</td>
<td>225</td>
<td>217</td>
</tr>
<tr>
<td>572,600</td>
<td>250</td>
<td>250</td>
<td>242</td>
</tr>
<tr>
<td>710,900</td>
<td>275</td>
<td>275</td>
<td>267</td>
</tr>
</tbody>
</table>

1 Side slopes are 2:1

For further information and assistance contact your county Cooperative Extension, Soil Conservation Service and Conservation District personnel.

OTHER SUGGESTED EXTENSION REFERENCES

EB1031, *Flush Cleaning Dairy Facilities.*
EM3759, *Animal Manure Data Sheet*
EM4169, *Flushing Systems for Swine Buildings*

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