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Lagoons for Management of Livestock Manure Planning, Construction, Operation

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A lagoon is a specifically designed manure storage facility. A properly designed lagoon also functions as a treatment system. Manure in any storage facility undergoes some biological decomposition. However, any decomposition of organic matter which occurs in a conventional storage is coincidental and not part of the design procedure or considerations.

The proper design of a lagoon gives special consideration to biological decomposition of organic matter. In fact, the design is intended to promote or enhance the breakdown of organic matter. Except for periodic removal of the sludge layer (every 25-50 years is the current best estimate), only discolored water containing dissolved solids is removed from a lagoon on a routine basis.

A properly designed lagoon should **not** be agitated prior to removal of water. Designing for once-per-year or annual pumpdown is recommended. This reduces the cost of system management and the risk of environmental pollution. Applying lagoon water to agricultural land during the portion of the growing season when crops usually require supplemental water — mid-June through August — makes use of water for irrigation, reduces the risk of runoff and allows nutrients to be used immediately by crops.

Types of Lagoons

Lagoons may be designed as one of three distinct types:

Aerobic: Sufficient dissolved or "free" oxygen is available in the lagoon water to allow aerobic bacteria to flourish. Aerobic lagoons are generally shallow (five feet is a typical maximum depth), have large surface areas, are biologically very lightly loaded, i.e., the quantity of organic matter added per unit volume of lagoon per unit time, e.g., per day, is very low and produce minimal odors. (Experiences by several municipalities in Nebraska have demonstrated that if overloaded, even "aerobic" lagoons emit unacceptable odors.) The usual primary loading criterion is Biological Oxygen Demand (BOD) per unit surface area per day.

Anaerobic: Anaerobic bacteria thrive and grow without free oxygen. For comparison, they can be considered as using the oxygen found in the various oxygen-bearing compounds or the organic matter itself. Anaerobic bacteria are very efficient and effective at decomposing most kinds of organic matter. Anaerobic lagoons are generally deep, have small surface areas compared to the organic loading rate, and frequently emit large quantities of unpleasant odors. A septic tank is an example of an anaerobic decomposition system.

Most of the "lagoons" in use on many livestock farms are either earthen bank storages or anaerobic lagoons. The primary design criterion is pounds of volatile solids per unit volume per day. As the loading rate (pounds of volatile solids per unit volume) increases, the likelihood of objectionable odors increases.

Facultative: A facultative lagoon is a hybrid system and incorporates both aerobic and anaerobic features. The efficiency of anaerobic digestion of organic matter is maintained in the bottom zone. The top zone is dilute enough to allow sufficient dissolved oxygen to be present — due primarily to wave action — to maintain an aerobic layer. This results in "clarification" of the surface liquid layer and keeps odor release to a minimum. An intermediate zone or "layer" favors the growth of facultative bacteria capable of thriving in either aerobic or anaerobic conditions as lagoon characteristics change.

Defining Some Terms:

Biological or Biochemical Oxygen Demand (BOD) is the quantity of oxygen used in the biochemical oxidation of organic matter under specified conditions in a specified time. (A "standard time" is five days, hence the designation BOD-5.) The BOD, or BOD-5, value is often used to characterize the relative "strength" of various biological "waste" products, including manure.

Volatile solids (VS) are, in general terms, those solids that are biodegradable. The non-biodegradable solids are called ash.

The need for free (not chemically bound up in the organic matter) or dissolved oxygen to maintain aerobic conditions leads to BOD load per unit surface area of the lagoon being the primary criterion (aside from maximum depth) used in designing and sizing aerobic lagoons. Large surface areas enhance oxygen absorption. A shallow depth allows sunlight penetration to promote growth of limited algae. This is beneficial in maintaining aerobic conditions since during daylight hours the plants release oxygen.

Volume is important in designing facultative lagoons. Inadequate volume results in a lagoon being biologically overloaded and increases odor release due to absence of a sufficiently thick aerobic layer at the top of the lagoon. Consequently, volatile solids per unit volume per day is the critical criterion in designing a facultative lagoon.

Planning Guidelines

No matter what type or style lagoon is planned, the design must provide sufficient volume to meet minimum requirements following summer pumpdown. This minimum volume is referred to as the "permanent pool." The permanent pool assures the presence of adequate volume to meet organic loading rate criteria, a sufficiently large bacterial population to ensure continued degradation of the incoming organic matter, and sufficient depth to ensure retention of an aerobic surface layer. Experience indicates the minimum permanent pool depth to be about eight feet. Odor emission is greater at shallower depths.

Assuming a once-per-year pumpdown, the lagoon also must have sufficient capacity to store the annual volume of manure, feces, wasted water and spilled feed; washdown, flush or backfill water; runoff from lot areas (if any); annual precipitation; and rainfall associated with a 25 year-24 hour precipitation event. The design must provide adequate freeboard, i.e., unused storage space, to prevent overflow. Freeboard requirements normally range from one to two feet of depth. The lagoon volume can be decreased by the expected amount of evaporation. Experience indicates evaporation from a lagoon is typically about 60 percent of the published lake evaporation rates for the area.

After deciding upon the general design, obtain approval (permit if required) from the Nebraska Department of Environmental Quality (DEQ) before starting construction. Contact DEQ: **Suite 400, The Atrium; 1200 N Street; Lincoln, NE 68509** - (402) 471-4239 or **200 South Silber; North Platte, NE 69101** - (308) 535-8142.

Since 1995, Nebraska State law requires a minimum 180-day storage capacity on new installations and those undergoing renovation or expansion. A one-year capacity is recommended for most efficient operation and cost-effectiveness. Designing for once-per-year pumpdown enhances manageability and makes best use of water and nutrients.

If possible, locate the lagoon northeast or southwest of the farm home and neighbors (especially those within one half mile of the lagoon). A proper location reduces the risk of complaints. Prevailing summer breezes are from the south and southeast. Prevailing winter winds are from the north and northwest. Summer breezes are of most concern with respect to odors.

Divert all extraneous surface water around the lagoon. Clean water is best diverted directly to drainage channels. Any water containing manure must be controlled and not allowed to leave the owner's property. Discharge to road ditches, neighbors' property, streams, tile drains, road culverts, etc. is unlawful. The lagoon must be designed with sufficient capacity to store any runoff to be impounded. If runoff is allowed to enter the lagoon, the design must provide for storage of runoff from a 25 year-24 hour storm over the drainage area as well as precipitation directly on the lagoon. This requirement increases normal or apparent "freeboard" requirements.

Some installations are designed to make use of recirculated lagoon water. This practice might "save" water, but seldom reduces installation or operating costs. Potential problems include disease spread (especially Treponema, i.e., bloody scours and TGE in pigs), internal parasites, equipment maintenance, and blockage of pipes and pumps due to ammonium-magnesium-phosphate crystals.

In addition to problems with pipe and pump blockage, excess salt concentrations can hinder bacterial action and increase odor levels. The "salt" buildup may include compounds of any of the major cations (Na, Mg, K, Ca, Zn, Mn). Chlorinated water from a rural water system, antibiotics, and growth promotants such as copper, zinc, and chromium also can inhibit lagoon action.

In dairy barns, problems have been encountered with excessively slippery walking surfaces due to algae growth on alleys when using recycled water for flushing. Algae growth is worse during warm weather. If recycling is planned, a three-cell series lagoon system is recommended. All pumping is from the third cell. Experience suggests there is little, if any, benefit to a two-cell system.

Earthen Storage

Though not the specific topic of this publication, an earthen storage also must be sized to store each of the quantities listed for lagoons and to provide freeboard. However, there is no minimum volume or permanent pool requirement since the entire contents of the storage can be removed — within limits of the pumping equipment. The 180-day "duration of storage" requirement applies to all storages. Design should be based on the six-month interval with the greatest net precipitation, i.e., precipitation less evaporation. The design should incorporate allowance for the two to four foot depth that cannot be easily removed on a regular basis.

With dairy and beef manure, a conventional earthen storage works well because floating fibrous solids form a mat or cover that limits odor release except during agitation and loadout. Especially with small dairies, an earthen storage may be more economical than a lagoon.

However, with larger installations, i.e., more than 100 cows, difficulty in achieving thorough agitation and hauling costs usually make a lagoon system the best option. The use of sand as bedding for free-stalls may make alternative manure handling systems a more viable system. To date, no practical and reliable system is available to separate sand from scraped manure.

Swine and poultry manure cannot be satisfactorily stored in an open conventional storage due to excessive odor emissions. This occurs because of differences in chemical composition and inadequate floating solids to form an odor-controlling mat over the manure surface. (The author recognizes that some states allow and even encourage earthen bank storages for swine manure.) Covered storages for swine manure can be managed with minimal odor release except during agitation and loadout. Significant odors will be released during land application unless the manure is injected or immediately incorporated into the soil.

Both liquids and suspended solids are routinely removed from a conventional storage during pumpout. Agitation is required prior to and continuously during pumpout to keep settleable and floatable solids in suspension to allow removal. Failure to provide constant agitation results in the composition of the manure changing continually from load to load.

Design Suggestions

Wisdom dictates that given today's concerns about environmental quality, lagoons should be designed to minimize the risk of objectionable odors being released. Experience with the facultative design procedures being used suggests there could be some odor for seven to 10 days in the spring just as the surface ice melts. A few breezy days generally will correct this situation. Otherwise, the lagoon should be virtually odor-free.

Volume Determination:

As a starting point, the following depths are suggested.

- Minimum total depth is 13 1/2 feet.
- Top one and one half feet will be freeboard plus emergency storm/rainwater storage (25 year-24 hour) as required by Federal and State law.
- Bottom eight feet are the "permanent pool."
- Water in "middle" four feet is annual working volume.

Therefore, the "start pumping" or "design full" level is one and one half feet from the top and "stop pumping" level is eight feet from the bottom. Greater depths can be used where soil and site conditions allow. A greater depth requires a smaller surface area to yield the same volume. However, as depth increases beyond approximately 20 feet, construction costs also increase.

Based on the author's experience, the permanent pool should never be less than eight feet deep. Permanent pool depths up to 16 feet have been used successfully. Each installation requires a customized design to fit site conditions and production facility requirements for greatest cost effectiveness. The basic relationship of the various levels and volumes is illustrated in *Figure 1*.

The total lagoon volume must be at least equal to the sum of the minimum permanent pool volume; manure production; wasted feed and water; flush or backfill water (if applicable); precipitation less evaporation (use 60 percent of open lake evaporation values); runoff from any contributing areas; 25 year-24 hour rainfall; and freeboard. Each volume must be calculated for the most severe situation during the duration of storage interval selected for the design. Larger volumes with lower biological or organic loading rates increase construction costs but reduce the risk of objectionable odors from the lagoon and during land application of effluent.

As an initial estimate of the required lagoon size, expect the total volume (to "design full" level) per pound of hog contributing manure to be about six cubic feet for fresh water flush or five cubic feet for a pull-plug system. For a dairy, expect the minimum volume to be about 10 cubic feet per pound of animal for scraped systems and 12 cubic feet per pound of animal for flush systems. Undersized lagoons result in more odors and more difficult management.

For more precise design, actual volatile solids (VS) production data should be used. Recommended values are listed in *Table I*.

The probability of excessive odor development and release increases as the biological loading rate increases. Based on both field experience and research, the maximum recommended loading rate in pounds of volatile solids per day per 1,000 cubic feet of permanent pool is: Northern Nebraska - 0.9; Central Nebraska - 1.0; and Southern Nebraska - 1.1. The resulting loadings rates are approximately 40 percent of the minimum values recommended by Nebraska Department of Environmental Quality for anaerobic lagoons located in odor-sensitive areas.

The author's experience, coupled with research results from North Carolina, suggests the risk of objectionable odors with the recommended design and loading rates is near zero. In contrast, the designs traditionally used in Nebraska have objectionable odor-risk probabilities of at least 10-30 percent.

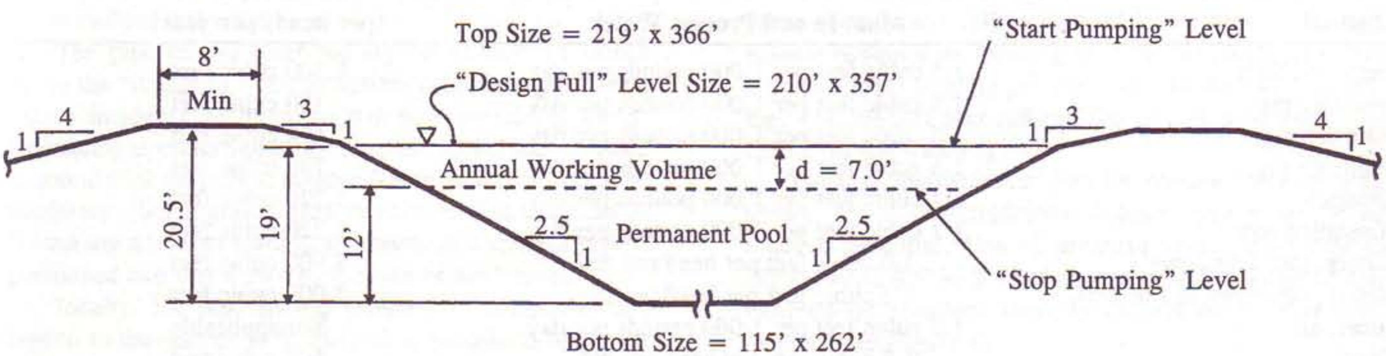

Figure 1. Cross-section of a typical facultative lagoon.

Table I. Volatile solids (VS) production rates for selected animals for use in designing facultative lagoons.

Animal	Average weight in pounds	Pounds VS per pound per day
Sow and litter	500	0.0064
Nursery pig	Varies	0.0048
Grower pig	Varies	0.0048
Finisher pig	Varies	0.0048
Boars	450	0.0024
Gestating sow	400	0.0024
Dairy, lactating cow	Varies	0.0097*
Dairy, dry cows and heifers	Varies	0.0080
Beef, all	Varies	0.0060
Veal	Varies	0.0038

* Volatile solids production will vary with milk production and feed intake. For herds producing over 25,000 pounds per cow per year, use 0.010 pounds VS per pound per day.
SOURCE: Adapted from MWPS-18.

The minimum permanent pool volume is calculated by multiplying the pounds of animal contributing manure × VS production rate *(Table I)* × the appropriate location multiplier (0.9, 1.0 or 1.1) × 1,000. Use a higher multiplier for locations with greater odor sensitivity. When different types of animals, i.e., stage of production cycle, contribute manure to the lagoon, sum the required volumes for each type of animal. This volume is then added to the minimum annual working volume to determine the minimum "design full" volume.

The minimum annual working volume is estimated by summing the annual volume of manure, wasted feed, process water, flush or backfill water and precipitation less evaporation. Suggested manure production rates and water volumes are listed in *Table II*. Rainfall and evaporation data are listed in *Table IX*. The data in *Table IX* reflect normal annual precipitation data (30 year average). Use of greater rainfall amounts will provide more flexibility in years of above-average precipitation.

When the lagoon does not receive runoff from an external drainage area, the water level one and one half feet from the top is considered the "design full" level. This depth/volume provides for storage of up to six inches of rainfall on the lagoon resulting from a 25 year-24 hour storm plus one foot of freeboard. Depths may vary depending upon manure handling system, geographic locations, soils, external drainage area, etc.

Permanent markers are recommended as an aid in managing the lagoon. Markers may be concrete, PVC, pressure-treated wood, or strips of stainless steel or PVC attached to inlet pipe supports. All markers should be easily seen and of a permanent design. Permanent markers are needed at two levels:

- "Design full" or "start pumping" level.
- Top of permanent pool or "stop pumping" level.

Clearly identifying these two depths will help ensure compliance with federal and state laws by visually indicating when pumping should commence in order to preserve the required volume for storage of 25 year-24 hour precipitation. Easily observed markers will also help in controlling odors by assuring that the minimum permanent pool depth and volume are always retained at the end of pumping.

Table II. Suggested values for use in estimating annual volumes of manure, process or wasted water and flush water for selected animals.

Animal	Manure and Process Water	Flush Water* (per head, per year)
Sow and litter	1.5 cubic feet per 1,000 pounds per day	1,700 cubic feet
Nursery pig	1.5 cubic feet per 1,000 pounds per day	150 cubic feet
Grower pig	1.5 cubic feet per 1,000 pounds per day	490 cubic feet
Finisher pig	1.5 cubic feet per 1,000 pounds per day	730 cubic feet
Boars	1.1 cubic feet per 1,000 pounds per day	1,220 cubic feet
Gestating sow	1.1 cubic feet per 1,000 pounds per day	1,220 cubic feet
Dairy, lactating cows	3.0 cubic feet per head per day	4,900 cubic feet
Dairy, dry cows and heifers	1.5 cubic feet per head per day	2,000 cubic feet
Beef, all	1.2 cubic feet per 1,000 pounds per day	Not applicable
Veal	1.2 cubic feet per head per day	500 cubic feet

* For pull-plug systems as used in many swine facilities, use 25 percent of the flush water volumes to estimate backfill water volume.

Embankment Design and Slopes:

Inside lagoon bank surfaces should have a maximum slope (rise:run) of 1:2 and outside surfaces should have a slope of 1:4 or flatter. To assure stability of the earthen embankment under saturated conditions, the combination of inside and outside slopes should never be less than 1:5. Slopes steeper than 1:4 cannot be safely mowed or maintained with conventional agricultural equipment. Inside slopes that are too flat increase problems with weed growth and mosquito breeding.

Some contractors want slopes no steeper than 1:2.5 for easier equipment operation. An inside slope of 1:3 from the "design full" level to top of the berm allows safer mower operations. A typical facultative lagoon cross-section is shown in *Figure 1*. Side slopes and relative proportions of the permanent pool, annual working volume and 25 year-24 hour rainfall plus freeboard depths or volumes will vary depending upon the actual design. An eight-foot minimum width is recommended for a filled berm.

A lagoon width:length ratio of 1:2 is desirable. That is, the lagoon should be rectangular with the length two times the width. These ratios enhance introduction of manure in a desirable area to help ensure good distribution of incoming solids.

Piping:

Install the conveyance pipe from the production facility to the lagoon with a 0.5-2.0 percent slope (one-sixteenth to one-quarter inch per foot) and no low spots. Use a six-inch minimum inside diameter pipe for swine nurseries and an eight-inch minimum inside diameter pipe for swine farrowing, growing/finishing, and breeding/gestation facilities. A 12-24-inch diameter pipe is needed for dairy manure. The diameter is dependent upon the manure handling method. Uniform slope is crucial to minimize risk of blockage due to solids buildup.

Provide external protection under roadways if the pipe is less than five feet below grade. Protection can be provided by passing the pipe to the lagoon through a larger culvert.

Install the pipe from the building(s) to the lagoon below frost level (three- to five-feet minimum) if possible. Doing so will reduce the risk of pipe heaving due to freeze/thaw action and the risk of low spots developing where solids buildup can occur.

The pipe should enter the lagoon at least six inches above the "design full" level. Submerged inlet pipes have a higher incidence of blockage due to accumulated solids. Depending upon terrain of the site, adding fill soil to create a mound over the pipe to achieve freeze protection might be necessary. (Some gravity flow designs used in dairy installations use a bottom-loading arrangement where the pipe is positioned two feet above the bottom of the lagoon.)

Ideally, the pipe should extend far enough into the lagoon so the manure is discharged in the middle one-ninth of the surface area (see *Figure 2*). As an absolute minimum, extend the pipe to at least the inner toe of the bank, i.e., junction of inside bank and bottom, near the middle of a long side. Inflow should not be allowed to drop on the lagoon bank under any circumstances.

WORST	FAIR	WORST
POOR	BEST (excellent)	POOR
WORST	FAIR	WORST

Figure 2. For best distribution of incoming solids, entrance pipe should extend to the "middle" one-ninth of the lagoon.

Install a downward-turned elbow on the end of the inlet pipe to reduce freezing due to cold air blowing up the pipe. Do not cement the elbow in place. Drill a small hole in the top of the pipe and elbow and insert a stainless steel cotter pin or similar fastener to keep the elbow in position. With flush systems, a small sump and plug at the building exit are desirable to prevent trickling flow and freezing during extreme winter weather. The entry pipe should be supported by pipes or poles with a catwalk along at least one side, and safety rails to allow access to the end of the pipe should service be necessary.

For safety reasons, use of hand or safety rail design procedures as specified by the Occupational Safety and Health Administration (OSHA) is recommended. While these standards are intended to safeguard an employee's work place, they represent a good design in all instances.

The OSHA requirements for a wood hand rail can be met with 2 × 4 posts spaced not more than eight feet on-center; a height of 42 inches; a top rail made of a 2 × 4 on edge with a flat 2 × 6 cap; a 2 × 4 mid-height rail; and a 2 × 4 toe rail. The design is intended to withstand the force of a person falling against it, to prevent an off-balance person from toppling over the rail, and to prevent a person from slipping off the walkway beneath the railing. The toe rail also reduces the risk of a dropped tool falling off the walkway.

Because maintenance may be required during wet, snowy, icy or dry conditions, a design that is safe at all times is essential. Use of pressure preservative-treated (PPT) wood (CCA, 0.4 pcf minimum) and hot dipped galvanized or stainless steel bolts and nails is recommended (see *Figure 3*).

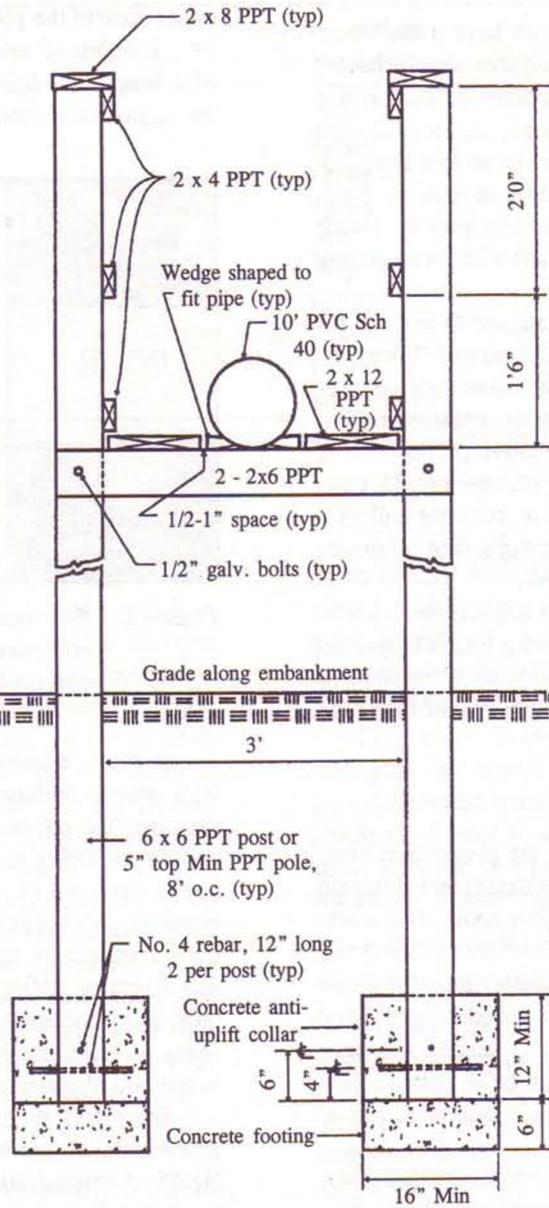

Figure 3. Suggested drain support and walkway structure.

Provide a cleanout tee or wye at 90-foot intervals; at all turns of 45° or more; within 25 feet of all tees, wyes, or other junctions of lines; and at the outside of the building. The 90-foot distance is to allow cleaning with 100-foot commercial sewer cleaning "snakes," if necessary. Cap cleanouts and carefully identify locations on a site map, with permanent on-site marker, or other suitable means. Extend cleanouts to the surface if in an area where they will not interfere with vehicle traffic or where inaccessible to livestock. Installation of guard posts around any cleanout brought to the surface is a good practice to provide further identification, protection from mowing equipment, etc.

As a general rule, no pipes should be run through a lagoon embankment. (All lagoons are designed for "zero discharge," hence, overflow pipes and spillways are neither required nor recommended.) However, in some instances freeboard and 25 year-24 hour runoff storage and a deep annual working volume depth can result in the dynamic suction head exceeding the capabilities of most irrigation pumps. (Most pumps have a 15-foot limit on dynamic suction head — elevation plus friction head in the suction line.) Under these circumstances, a flooded inlet pump installation is necessary. Before installing a pipe through the embankment, contact a qualified engineer for design assistance and DEQ for approval.

In all instances, minimum requirements for any pipe that penetrates a lagoon embankment are two anti-seep collars, two lockable valves, and compaction of soil around the pipe with a vibrating compactor, e.g., "jumping jack," along the pipe and to a fill depth at least two feet above the pipe. After the initial protective layers of soil are in place and compacted, additional fill can be compacted the same as the rest of the fill. The anti-seep collars must extend outward at least two feet in all directions, be securely fastened to the pipe in a watertight fashion and located at least four feet apart. As a minimum, the drains must be capable of being locked or chained in the closed position or having the handle removed.

A knife or fast-acting gate valve is desirable for routine daily operations. A second valve installed within the berm and requiring a special long-handled wrench to access and operate it is recommended to reduce the likelihood of it being opened by vandals.

Lagoon Construction

Check with DEQ to ascertain requirements to comply with construction site runoff and erosion control regulations. A storm water permit is required if the construction site involves an area of five acres or more. Embankment heights greater than 25 feet above grade also require special permits. Embankment height measurements are from the lowest part of the outer or downstream toe to the top of the berm. A special permit is required if the impoundment stores more than 15 acre-feet (180 acre-inches; 4,887,360 gallons or 653,380 cubic feet) of water or impounds drainage from more than 25 acres, excluding lot areas.

Remove all vegetation and topsoil (six-inch minimum cut) before placing fill on existing soil. Failure to do so can result in seepage as the organic matter decays and open spaces develop.

To reduce seepage at the natural soil/fill soil interface, cut a key trench at least one foot deep and six feet wide. Replace soil in six- to eight-inch layers or lifts and compact with a vibrating or sheepsfoot roller, or equivalent.

Place all subsequent fill in layers or lifts not exceeding eight inches thick. A six-inch layer is preferred. Thoroughly compact each layer before placing the next layer. Compaction by construction equipment alone is generally inadequate. Achievement of low permeability as required by current law to minimize percolation and protect groundwater quality requires use of equipment specifically designed to increase compaction.

To achieve maximum compaction and minimum risk of seepage requires proper soil moisture content. Excessively wet or overly dry soils compact poorly. Delay construction to let soils dry or add water if necessary.

The final bottom surface should be as nearly level as feasible. After making the final cut and removing final soil from bottom, scarify to a depth of 12 inches and recompact with a vibrating or sheepsfoot roller, or equivalent.

During construction, maintain vigilance for any evidence of sand, gravel or other coarse material inclusions or lenses. All coarse materials must be removed to a depth of at least two feet below or beyond finished grade. Fill the resulting depression with clay. Place and compact the clay in six-inch thick layers. Also be on the lookout for seepage into the impoundment.

As a general rule, at least two feet of tight clay or other low permeability or "impermeable" soil is required above the seasonal groundwater table. If seepage into the lagoon is observed, steps may be required to intercept and divert the seepage before it enters the lagoon. Excessive seepage may make the site unsatisfactory for a lagoon. Such incidences usually require a site-by-site determination as to the best corrective action or alternative. If seeps are encountered, contact a qualified licensed Professional Engineer and DEQ for further guidance.

To achieve the compaction necessary to reduce seepage to the maximum allowable rate mandated by current state regulations (one-quarter inch per day), all surfaces must be well compacted. Do not rely on track-mounted equipment such as bulldozers and backhoes for compaction. Only in the most unusual and special circumstances is the compaction provided by track-mounted equipment adequate and sufficient by itself.

Using a heavy, weighted, wheel-mounted tractor with good cleats on the rear tires to pull the roller will enhance compaction efforts. A vibrating compactor is even better.

A vibrating roller moved slowly over the surface will generally provide sufficient compaction of each 6- to 8-inch layer or lift with a single pass. A sheepsfoot roller will require multiple passes per lift to achieve the same degree of compaction since only 10-15 percent of the surface is actually contacted by the feet on the roller. Achieving the required compaction with a sheepsfoot roller requires rolling until the roller "walks out" of the soil, i.e., the feet are actually at or near the soil surface.

Do **not** rely upon compaction by either wheel- or track-mounted construction equipment without a thorough evaluation of soil compactability before construction and a check of permeability when construction is complete. Verification of as-built permeability is best performed by a qualified soils analysis company. Field verification is recommended in all instances where any reason exists to question the permeability of the lagoon surfaces.

Earth-moving is relatively inexpensive if planned from the beginning. Generally total depth is about 50 percent cut and 50 percent fill. Of total volume, about 30-40 percent is cut and 60-70 percent is fill in most situations. These cut:fill ratios will vary depending upon lagoon size, site topography, etc. Avoid surprises and added investments for sumps, pumps, etc. by careful planning to assure that final lagoon elevations are compatible with building and drain elevations.

Lagoon Operation and Maintenance

Apply fertilizer and lime in accordance with soil test recommendations prior to seeding. These practices, in conjunction with good seedbed preparation, help assure a good vegetative cover in the shortest feasible time.

Seed all bank and disturbed soil surfaces as soon as feasible upon completion of grading. Use a quick germinating grass nurse crop such as oats, rye, or fescue to stabilize soil, reduce runoff and minimize erosion. Apply straw or mesh mulch to help stabilize the soil until grass germinates and becomes established.

Seed a crop such as creeping crown vetch or birdsfoot trefoil to yield a low maintenance long-term cover crop. Although expensive to establish, such cover crops reduce long-term maintenance costs.

All lagoons and storages should be fenced to prevent accidental entry by animals, small children and persons not familiar with the storage of manure. Appropriate signs should be installed to warn visitors of the potential hazard. Fences should be located where they will not interfere with mowing, access by pumping equipment, etc.

Keep weeds mowed. Allowing large weeds such as lambsquarter, red root, velvet leaf and sunflowers to grow results in open seepage channels when the weeds die and the roots decay. The result can be drainage of lagoon effluent deep into the embankment. In extreme cases, these channels can become pathways for continual seepage and can initiate failure of the embankment. Use appropriate herbicides as necessary. Excessive weed growth inhibits the growth and establishment of desirable vegetation.

Pump at least four feet of water into the lagoon before introducing manure. A depth equal to at least 50 percent of the permanent pool depth is recommended. Lagoons put into service during spring and summer have a lower risk of producing objectionable odors during the first year than do lagoons started during the fall or winter.

Discharge manure into the lagoon as consistently as possible. Adding manure on a daily basis is best. The loading interval should not exceed one week. If several buildings or rooms discharge to the same lagoon, establish a schedule to introduce manure at regular intervals. The schedule might involve draining one room or pit each day, every two days, etc.

Adding large amounts of manure at one time, i.e., slug loading, increases the probability of odor release. Practices such as pumping the entire contents of an existing deep, under-building storage into a lagoon at one time should be avoided.

Start making plans to irrigate out of the lagoon by mid-June or about the time the final cultivation of corn is complete. However, do not let the water level exceed the design full level. Apply the effluent onto growing crops throughout the growing season. The water level should be at the "stop pumping" or top of the permanent pool level by late August or early September.

Apply the effluent at rates consistent with crop needs. Use an effluent application rate consistent with soil infiltration capabilities to minimize runoff. In heavy clay soils where surface cracks have developed, high application rates and cracked soils can lead to flow directly into tile lines and out to waterways. Such discharges are direct violations of State and Federal law and must be prevented.

Except for large installations, seldom is there enough water on an annual basis to justify the investment in an automated or mechanized irrigation system. A PTO pump, several hundred feet of pipe, and one or two "big guns" are all that is needed in most situations. With larger installations a center pivot, traveling gun or similar device can be

Table III. Nutrient production (per year).

Unit	Total Pounds of Animal	Pounds of N: Per pound	Pounds of N: Pounds per year	Pounds of P_2O_5: Per pound	Pounds of P_2O_5: Pounds per year	Pounds of K_2O: Per pound	Pounds of K_2O: Pounds per year
Farrowing	______	× 0.175 =	______	× 0.168 =	______	× 0.175 =	______
Nursery	______	× 0.164 =	______	× 0.124 =	______	× 0.131 =	______
Grow	______	× 0.164 =	______	× 0.124 =	______	× 0.131 =	______
Finish	______	× 0.164 =	______	× 0.124 =	______	× 0.131 =	______
Grow/Finish	______	× 0.164 =	______	× 0.124 =	______	× 0.131 =	______
Breeding/Gestation	______	× 0.084 =	______	× 0.062 =	______	× 0.062 =	______
Dairy	______	× 0.149 =	______	× 0.060 =	______	× 0.119 =	______
Beef	______	× 0.124 =	______	× 0.091 =	______	× 0.105 =	______
Total pounds per year			______		______		______

Table IV. Nutrients to be managed per year.

	Covered Storage		1-Cell Lagoon		3-Cell Lagoon	
Nitrogen*	______ × 0.80 =	______	______ × 0.20 =	______	______ × 0.05 =	______
Phosphate	______ × 1.00 =	______	______ × 0.20 =	______	______ × 0.05 =	______
Potash	______ × 1.00 =	______	______ × 0.95 =	______	______ × 0.95 =	______

* Depending upon time of year and application/incorporation methods, up to 50 percent of the nitrogen available in the storage can be lost in the field.

used. The pump should have a floating inlet and draw water from within two feet of the surface. The pump should extract water from the lagoon at a location as far away from the inlet as feasible. This arrangement reduces the likelihood of pumping "untreated" or raw manure out onto the field, and hence the risk of odors. All irrigation systems should be equipped with low water pressure shutoffs to turn off the system in the event of a line break. The engine or tractor used to power the pump should be equipped with low oil pressure and high water temperature shutoffs to protect the power unit.

During warm weather some lagoons turn various shades of pink or purple. Do not dismay. That condition is excellent. The purplish color is caused by "sulfur-eating" bacteria. A reddish-brown color is good but a more brilliant reddish-pink or dark lavender is better. When this condition exists, odors are at an absolute minimum. The purple color is a sign of good lagoon action. Our challenge, and goal, is to have every lagoon turn purple within the first year of operation and to retain the pink or purple color at least eight months per year. In several instances the purple color has been retained year-round.

Lagoons are a very appropriate option for managing manure if they are properly designed, constructed and maintained. Failure to use good practices in any phase can result in environmental pollution and/or odors, possibly with lawsuits and fines. Don't cut corners. Build it right the first time!

Nutrient Management

The final step in managing a manure handling system and lagoon is to use the nutrients as effectively as possible. Efficient use of nutrients, as well as environmental stewardship, requires that nutrients be applied at rates consistent with crop needs. In determining application rates recognize that manure is seldom, if ever, the sole source of nutrients. Other sources include soil residual, cover crops or plant residue, starter fertilizer and irrigation water. The design example and worksheets that follow are intended as a general guide in helping determine soil needs. Whereas phosphorus or nitrogen is usually the application-rate-limiting nutrient with manure from a pit or earthen storage, potassium is usually the limiting nutrient with lagoon effluent.

A properly sized single-cell facultative lagoon will result in biological degradation of most of the organic matter introduced into the lagoon. Consequently, an estimated 80 percent of the nitrogen produced by the animals will be lost to the atmosphere. (In most instances, at least 20 percent of the nitrogen voided by the animals will be lost before the manure reaches the lagoon regardless of the handling system.) As a result, the lagoon effluent will contain a relatively small amount of nitrogen.

An estimated 80-90 percent of the phosphorus produced by the animals will be retained in the lagoon as part of the sludge layer. Current best estimates are that the phosphorus-rich sludge layer will require removal in 25-50 years. Upon removal, the sludge will need to be applied to agricultural land based on phosphorus content. For at least several years following sludge application, the fertilization program for areas receiving sludge will need to be modified to avoid excessive levels of phosphorus.

An estimated 95 percent of the potassium produced by the animals will remain in solution and be removed annually when the effluent is applied on land. These values are reflected in the multipliers in *Table IV* to estimate the annual quantity of nutrients to be managed. The differences between the quantity of nutrients calculated in *Table III* and those in *Table IV* reflect both losses (nitrogen) and nutrients retained in the non-biodegradable sludge layer (phosphorus and potassium).

Over-applying any crop nutrient can have adverse effects on soil productivity, crop production and/or water quality. Excess nitrogen increases the risk of groundwater contamination due to nitrate leaching. Excess phosphate (current best estimate is over 400 pounds per acre or 200 ppm) will reduce crop yield and may add to groundwater pollution. Phosphorus carried into surface waters via runoff will stimulate aquatic plant growth that can lead to depletion of dissolved oxygen and suffocation of fish and other aquatic animals.

Excess potash (current best estimate is over 1,500-1,800

Table V. Estimated annual volume.

________	cubic feet
________	gallons (cubic feet × 7.48)
________	acre-inches (gallons ÷ 27,152)

Table VI. Nutrient concentration in annual volume.

	Pounds per 1,000 gallon	Pounds per ton*	Pounds per acre-inch
Nitrogen	________	________	________
Phosphate	________	________	________
Potash	________	________	________

* Assume 250 gallons per ton.

Table VII. Crop nutrient use (total needs from all sources).

Crop	Unit	Normal yield	Pounds of nutrient per production unit		
			N	P_2O_5	K_2O
Corn	Bushel	80-200 bushels	1.6	0.6	1.2
Soybeans	Bushel	30-60 bushels	5.1	1.0	2.4
Wheat	Bushel	40-80 bushels	2.1	0.8	1.8
Alfalfa	Ton	4 ton	50	10	53
Sorghum	Ton	3 ton	63	23	50
Orchardgrass	Ton	4 ton	50	17	63
Timothy	Ton	3 ton	38	14	63
Sorghum Sudan	Ton	6 ton	40	15	58
Corn Silage	Ton	16 ton	6.9	2.6	7.2

Table VIII. Minimum acreage requirements. (Based on crop-use application rates; assumes manure is only nutrient source. Acreages are minimums and are valid only if there are no nutrients available to crops from other sources. Use as guideline for planning purposes only. Adjust applications based on soil test results.)

Crop	Expected yield	N*		P_2O_5**		K_2O***	
		Pounds used per acre	Required acres	Pounds used per acre	Required acres	Pounds used per acre	Required acres
Corn	______	______	______	______	______	______	______
Soybeans	______	______	______	______	______	______	______
Alfalfa	______	______	______	______	______	______	______

* Excess nitrogen increases risk of groundwater contamination due to nitrate leaching.

** Excess phosphate (>400 pounds per acre or 200 ppm) might reduce crop yields and add to groundwater pollution.

*** Excess potash (>1,500-1,800 pounds per acre or 750-900 ppm) will reduce infiltration of water and increase runoff due to dispersion or deflocculation of clay particles, i.e., destruction of soil structure.

pounds per acre or 750-900 ppm) will reduce infiltration of water and increase runoff due to dispersion or deflocculation of clay particles, i.e., destruction of soil structure. In addition to the obvious environmental and erosion problems associated with increased runoff, crops can be more susceptible to damage during hot, dry weather because of reduced soil moisture.

The estimated annual volume will be calculated during design of the lagoon. Once this quantity is known *(Table V)*, the concentration of nutrients in various volumes can be determined *(Table VI)*. These data can then be used to calculate land application rates and to evaluate alternative effluent handling methods.

The quantity of nutrients from all sources required for production of various crops is listed in *Table VII*. Using typical yields for a particular field or area will allow determination of minimum acreage requirements for long-term management of nutrients from the animals and lagoon system *(Table VIII)*.

In the real world of production agriculture, manure is never the sole source of nutrients for a crop, so the acreage requirements calculated in completing *Table VIII* represent unrealistically low land needs. At the same time, the results will help illustrate why some producers have experienced depressed yields or other problems in fields receiving large quantities of manure. Additionally, the results point out the importance of having access to an adequate land base for application of manure as part of a livestock operation.

NOTE: Not all of the nutrients in manure will be available in the year of application. Application of crop nutrients at agronomic/crop-use rate is recommended in all instances. Consider nutrients from all sources when planning a manure management program, including soil residual, irrigation water, starter fertilizer, manure, plant residue, etc. Although estimates of nutrient availability vary, one set of guidelines lists nitrogen availability at 50 percent during the year of application, 15 percent the second year and 7 percent the third year. Availability in subsequent years is small and generally not considered in planning a fertilization program.

Table IX. Normal annual precipitation, 25 year-24 hour rainfall, estimated annual lake evaporation and expected annual evaporation from lagoons in Nebraska, by county.[a]

	Rainfall (inches)		Annual evaporation (inches)	
County	Annual (normal)	25 year-24 hour	Lake	Lagoon
Adams	27.8	4.9	49	29.4
Antelope	23.6	4.7	41	24.6
Arthur	18.7	4.1	46	27.6
Banner	14.1	3.5	46	27.6
Blaine	20.8	4.4	43	25.8
Boone	27.9	4.8	42	25.2
Box Butte	16.4	3.7	45	27.0
Boyd	22.9	4.5	39	23.4
Brown	22.4	4.3	41	24.6
Buffalo	24.8	4.7	47	28.2
Burt	29.3	5.2	40	24.0
Butler	29.8	5.1	43	25.8
Cass	29.7	5.4	42	25.2
Cedar	24.8	4.8	39	23.4
Chase	19.1	4.1	51	30.6
Cherry	18.2	4.2	42	25.2
Cheyenne	16.2	3.7	47	28.2
Clay	27.0	5.0	48	28.8
Colfax	27.7	5.0	42	25.2
Cuming	28.6	5.0	40	24.0
Custer	22.6	4.5	45	27.0
Dakota	25.9	5.0	38	22.8
Dawes	15.4	3.6	44	26.4
Dawson	21.9	4.5	48	28.8
Deuel	17.0[b]	3.9	47	28.2
Dixon	25.4[c]	4.9	39	23.4
Dodge	30.4	5.1	41	24.6
Douglas	29.9	5.3	41	24.6
Dundy	18.4	4.1	53	31.8
Fillmore	29.2	5.1	47	28.2
Franklin	24.4	4.8	52	31.2
Frontier	20.8	4.4	52	31.2
Furnas	22.1	4.5	53	31.8
Gage	32.2	5.5	46	27.6
Garden	17.2	3.9	46	27.6
Garfield	22.3	4.6	42	25.2
Gosper	22.7	4.5	51	30.6
Grant	19.1	4.1	45	27.0
Greeley	25.6	4.7	43	25.8
Hall	24.9	4.8	47	28.2
Hamilton	27.4	4.9	46	27.6
Harlan	22.3	4.7	53	31.8
Hayes	20.6	4.3	52	31.2
Holt	23.6	4.5	40	24.0
Hitchcock	20.8	4.3	53	31.8
Hooker	21.1	4.2	44	26.4
Howard	24.1	4.8	45	27.0
Jefferson	30.3	5.4	47	28.2
Johnson	32.4	5.5	44	26.4
Kearney	24.8	4.8	50	30.0
Keith	17.8	4.1	47	28.2
Keya Paha	21.2	4.4	39	23.4
Kimball	17.4	3.5	47	28.2
Knox	26.3	4.7	39	23.4
Lancaster	28.3	5.3	44	26.4
Lincoln	19.3	4.3	48	28.8
Logan	21.6[d]	4.3	45	27.0
Loup	23.6	4.5	43	25.8
Madison	25.2	4.9	41	24.6
Mcpherson	20.6	4.2	45	27.0
Merrick	26.5	4.9	45	27.0
Morrill	15.9	3.7	46	27.6
Nance	26.5	4.8	43	25.8
Nemaha	31.7	5.6	43	25.8
Nuckolls	28.0	5.1	50	30.0
Otoe	30.5	5.5	43	25.8
Pawnee	32.3	5.6	45	27.0
Perkins	19.1	4.1	49	29.4
Phelps	25.2	4.6	51	30.6
Pierce	24.8[e]	4.8	40	24.0
Platte	27.6	4.9	42	25.2
Polk	28.2	5.0	44	26.4
Red Willow	20.7	4.4	53	31.8
Richardson	34.1	5.7	44	26.4
Rock	23.5	4.4	40	24.0
Saline	29.5	5.2	46	27.6
Sarpy	29.7	5.4	42	25.2
Saunders	34.9	5.2	42	25.2
Scotts Bluff	15.3	3.5	46	27.6
Seward	27.2	5.1	44	26.4
Sheridan	18.6	3.8	44	26.4
Sherman	25.7	4.7	45	27.0
Sioux	16.8	3.5	45	27.0
Stanton	27.4	5.2	40	24.0
Thayer	28.7	5.2	48	28.8
Thomas	22.6	4.3	44	26.4
Thurston	27.6	5.1	39	23.4
Valley	24.2	4.6	44	26.4
Washington	30.1	5.3	40	24.0
Wayne	26.0	4.9	39	23.4
Webster	26.4	5.0	52	31.2
Wheeler	24.6	4.7	42	25.2
York	28.2	5.1	45	27.0

[a] Source: 1961-90 precipitation normals, NOAA
[b] Average of Cheyenne and Keith counties
[c] Average of Cedar and Dakota counties
[d] Average of McPherson and Custer counties
[e] Average of Antelope and Wayne counties

Design Example and Explanation of Procedures

Given:

Assume a 250-sow farrow-to-feeder pig production facility located in York County, Nebraska. The facilities feature four 10-crate farrowing rooms, five 100-pig nurseries, and a 220-sow gestation building with space for eight boars and 30 gilts. A pull-plug system with fresh water backfill is used to remove manure from the farrowing and nursery units. The gestation unit uses a fresh water flush manure removal system. Nursery pigs are kept on-site from weaning (15 pounds) to 50 pounds. Gilts weigh an average of 250 pounds. A once-per-year pumpdown frequency is desired. The livestock operation is in an area that is particularly prone to odor complaints due to the location and proximity of neighbors. No runoff from outside areas will enter the lagoon.

Required:

Determine size of a facultative lagoon to manage the outflow from the facility. Develop guidelines for land application area requirements.

1. Calculate animal weights (Table I offers some weight guidelines).

Animal	Range	Average weight		Number of pigs		Total design weight
Farrow		500	×	40	=	20,000 pounds
Nursery	15-50	32.5	×	500	=	16,250 pounds
Gilts		250	×	30	=	7,500 pounds
Boars		450	×	8	=	3,600 pounds
Gestating Sows		400	×	220	=	88,000 pounds

2. Calculate annual manure production (from Table II).

Animal	Total weight		Manure and process water*		Days		Annual manure volume
Farrow	20,000 lbs.	×	1.5	×	365	=	10,950 cubic feet
Nursery	16,250 lbs.	×	1.5	×	365	=	8,897 cubic feet
Gilts	7,500 lbs.	×	1.5	×	365	=	4,106 cubic feet
Boars	3,600 lbs.	×	1.1	×	365	=	1,445 cubic feet
Gestating sows	88,000 lbs.	×	1.1	×	365	=	35,332 cubic feet
Total							60,730 cubic feet

* cubic feet per 1,000 pounds per day

3. Calculate volatile solids (VS) production (Table I).

Animal	Total weight in pounds		Pounds VS per pound per day		Pounds per day
Farrowing	20,000	×	0.0064	=	128.0
Nursery	16,250	×	0.0048	=	78.0
Gilts	7,500	×	0.0048	=	36.0
Boars	3,600	×	0.0024	=	8.6
Gestating sows	88,000	×	0.0024	=	211.2
Total #VS					461.8

4. Calculate minimum permanent pool volume. (Because of the odor-sensitivity of the lagoon location [as noted in problem description], use a multiplier of 1.1 even though under more general conditions a multiplier of 0.9 or 1.0 would be appropriate).

MINIMUM PERMANENT POOL VOLUME = # VS 461.8 × 1000 × 1.1 = 507,980 cubic feet

5. *Calculate lagoon size at mid-point or mid-depth of permanent pool. As a starting point, a permanent pool depth of 12 feet is selected. Judgment is needed to determine the most appropriate depth of the permanent pool for a particular site.*

SIZE AT SIX-FOOT DEPTH = 507,980 cubic feet + 12 feet = 42,332 square feet

To maintain a width-to-length ratio of approximately 1:2, the selected dimensions are 145 feet × 292 feet.

6. *Calculate bottom size (0-foot depth).*

With 1:2.5 side slopes, each side of the lagoon will become smaller at the rate of 2.5 feet per foot of depth. Therefore, the bottom will be **2 × 2.5 × 6 = 30** feet smaller than at the six-foot depth.

BOTTOM DIMENSIONS = (145 - 30) × (292 - 30) = 115 feet × 262 feet.

7. *Calculate size at top of permanent pool (12-foot depth).*

With uniform 1:2.5 side slopes, each side will become longer at the rate of 2.5 feet per foot of depth. Therefore, the size at a depth of 12 feet will be **2 × 2.5 × 6 = 30** feet larger than at the six-foot depth.

DIMENSIONS AT 12-FOOT DEPTH = (145 + 30) x (292 + 30) = 175 feet × 322 feet.

This is the size of the lagoon at the "stop pumping" level and top of the permanent pool.

8. *Calculate annual working volume (first estimate).*

This step requires a combination of direct calculations and estimates since some components (e.g., precipitation) are dependent upon final lagoon size.

A. Annual manure production (from step 2). 60,730 cubic feet

B. Annual water use (*Table II*).

Animal	Number of pigs		Water use		Multiplier		Total (cubic feet)
Farrow	40	×	1700	×	**0.25	=	17,000
Nursery	500	×	150	×	**0.25	=	18,750
Gilts*	30	×	730	×	1.0	=	21,900
Boars	8	×	1220	×	1.0	=	9,760
Gestating sows	220	×	1220	×	1.0	=	268,400
Total							335,810

* Use "Finisher Pig" data since developing and bred gilts are usually on full feed.
** Pull-plug system reduces water use.

C. Annual precipitation.

To estimate annual precipitation, we need to estimate the top size of the lagoon. If an annual working depth of six feet is assumed, the size of the lagoon at the top of the annual working volume, i.e., at the "start pumping" or "design full" level will be **2 × 2.5 × 6 = 30** feet larger than at the top of the permanent pool. Therefore, size at the "design full" level (18-foot depth) will be: **(175 + 30) × (322 + 30) = 205 feet × 352 feet.** Per standard recommendations to enhance maintainability, the slope from the "design full" level to the top of the berm will be constructed with a 1:3 slope *(Figure 1)*. The 25 year- 24 hour rainfall for York County is 5.1 inches *(Table IX)*. Therefore a six-inch allowance is acceptable.

With one foot freeboard, the height from the "design full" level to the top of the berm will be **6 inches + 1 foot = 1.5 feet**, yielding a total depth of 19.5 feet. The size at the top of the berm will be **2 × 3 × 1.5 = 9** feet greater than at the "design full" level or: **(205 + 9) × (352 + 9) = 214 feet × 361 feet**. The normal annual rainfall for York County is 28.2 inches *(Table IX)*. Therefore, the average annual precipitation volume is:

$$\textbf{214 feet} \times \textbf{361 feet} \times \textbf{28.2 inches} \times \frac{\textbf{1 foot}}{\textbf{12 inches}} = \textbf{181,547 cubic feet}$$

D. Annual evaporation.

To calculate the estimated annual volume of water lost due to evaporation, we need to arrive at an estimate of the surface area from which evaporation will occur. A reasonable estimate can be determined by using the area at mid-depth of the annual working volume, i.e., three feet above the "stop pumping" level. The size at this depth (15 feet above bottom) will be

$2 \times 2.5 \times 3$ = **15** feet greater than the size at the top of the permanent pool. Therefore, the average area from which evaporation will occur is: **(175 + 15) × (322 + 15) = 190 feet × 337 feet.** Using data from *Table IX*, the annual volume of water lost through evaporation is estimated to be:

$$\textbf{190 feet} \times \textbf{337 feet} \times \textbf{-27.0 inches} \times \frac{\textbf{1 foot}}{\textbf{12 inches}} = \textbf{-144,068 cubic feet}$$

The minus sign indicates this is a loss.

E. Estimated annual volume (sum of A, B, C, and D).

(A)	Manure	60,730 cubic feet
(B)	Water use	335,810 cubic feet
(C)	Precipitation	181,547 cubic feet
(D)	Evaporation	-144,068 cubic feet
Total		**434,019 cubic feet**

9. Verify annual working volume.

Several assumptions were required to allow calculation of the estimated annual volume. Therefore, we must verify those assumptions are correct by comparing the actual annual working volume provided in the lagoon with the estimated total annual water accumulated in the lagoon.

The annual working volume provided is the product of the lagoon size at mid-depth of the annual working volume depth (step 8D) times our assumed annual working volume depth (step 8C). Therefore, the annual volume provided is: **190 feet × 337 feet × 6 feet = 384,180 cubic feet**. Note that the annual volume provided (384,180 cubic feet) is less than our estimated annual volume of water collected (434,019 cubic feet). Therefore, our initial assumption of a six-foot depth for the annual working volume was incorrect. A second trial is required.

Had the volume provided been equal to or exceeded the expected annual volume to be stored, we could have stopped at this point. If the volume provided had exceeded the estimated annual volume collected, judgment would be required as to how much over-design is acceptable. Generally speaking, over-design by up to 10 percent is considered acceptable. In all instances, the volume provided must be at least equal to the estimated annual volume produced, i.e., under-design is not acceptable.

10. Revise/calculate annual working volume (second estimate).

Now that we have a general idea as to the depth required to provide storage for the estimated annual working volume, we can make several additional calculations to help us arrive at a satisfactory answer. Our goal is to answer the question: Must the depth of the annual working volume be 6.5, 7, 7.5, 8 feet, etc.? **NOTE:** Given normal construction tolerances and the variability in actual volumes compared to estimated volumes, seldom is it necessary to consider depths in increments less than 0.5 feet.

Although we know the size of the annual working volume at mid-depth will increase as the depth increases, for estimating purposes such fine-tuning is seldom warranted. To illustrate the procedures, let's consider several alternate depths.

Depth		Size at mid-depth		Volume provided
6.5 feet	×	190 feet × 337 feet	=	416,195 cubic feet
7.0 feet	×	190 feet × 337 feet	=	448,210 cubic feet

A depth of 6.5 feet is obviously not adequate since the approximate volume provided (416,195 cubic feet) is still substantially less than the volume required (434,019 cubic feet). However, a depth of 7.0 feet appears reasonable for a second trial.

We recognize that no changes will occur in manure production (step 8A) or water use (step 8B). Thus, we can move directly to revision of step 8C.

8C (revision). Annual precipitation.

With an annual working volume depth of seven feet, the size of the lagoon at the "design full," "start pumping" or top of the annual working volume will be $2 \times 2.5 \times 7$ = **35** feet greater than the size at the 12-foot depth ("stop pumping" or top of permanent pool level, step 7) or: **(175 + 35) × (322 + 35) = 210 feet × 357 feet.** We know from our previous calculations (step 8C) that the top size will be nine feet greater than the size at the "design full" level. Thus, the revised top size will be: **(210 + 9) × (357 + 9) = 219 feet × 366 feet**. The new estimate of normal annual precipitation entering the lagoon is:

$$\textbf{219 feet} \times \textbf{366 feet} \times \textbf{28.2 inches} \times \frac{\textbf{1 foot}}{\textbf{12 inches}} = \textbf{188,362 cubic feet}$$

8D (revision). Annual evaporation.

The revised average surface area from which evaporation will occur is at the new mid-depth of the annual working volume; that is, 3.5 feet above the top of the permanent pool or at a depth of 15.5 feet. The size at this level will be **2 × 2.5 × 3.5 = 17.5** feet larger than the size at the top of the permanent pool or: **(175 + 17.5) × (322 + 17.5) = 192.5 feet × 339.5 feet**. The revised estimate of annual evaporation is:

$$\mathbf{192.5\ feet \times 339.5\ feet \times -27.0\ inches \times \frac{1\ foot}{12\ inches} = -147{,}046\ cubic\ feet}$$

8E (revision). Estimated annual volume {sum of 8A, 8B, 8C (revised), and 8D (revised)}.

(A)	Manure	60,730 cubic feet
(B)	Water use	335,810 cubic feet
(C)	Precipitation	188,362 cubic feet
(D)	Evaporation	-147,046 cubic feet
Total		**437,856 cubic feet**

11. Verify revised annual working volume.

Annual storage volume provided, as revised, is: **192.5 feet × 339.5 feet × 7.0 feet = 457,476 cubic feet**. Since the estimated annual storage volume provided (457,476 cubic feet) exceeds the estimated annual volume of water and manure to be stored (437,856 cubic feet), the design is considered satisfactory. In this instance, the annual working volume provided exceeds our estimated needs by:

$$\mathbf{\frac{457{,}476 - 437{,}856}{437{,}856} \times 100 = 4.5\ percent}$$

Because the overdesign is within 10 percent of the required volume, the design is acceptable and can be recommended.

12. Summarize design and make sketch.

• Size at top	219 feet × 366 feet
• Size at "design full"/"start pumping" level	210 feet × 357 feet
• Size at "stop pumping" level/top of permanent pool	175 feet × 322 feet
• Size at bottom	115 feet × 262 feet
• Depth, total	20.5 feet
• Depth, "design full"/"start pumping" level	19.0 feet
• Depth, "stop pumping"/top of permanent pool	12.0 feet
• Depth, freeboard allowance	1.0 feet
• Depth, 25 year-24 hour storm allowance	0.5 feet
• Depth, annual working volume	7.0 feet
• Volume, permanent pool (provided)	518,880 cubic feet
• Volume, annual working (provided)	457,476 cubic feet
• Volume, annual working (required)	437,856 cubic feet
• Volume, 25 year-24 hour storm	33,186 cubic feet
• Volume, freeboard	78,274 cubic feet
• Volume, total	1,525,672 cubic feet
• Berm width (minimum)	8 feet
• Side slopes, bottom to "design full" level	1:2.5
• Side slopes, "design full" level to top	1:3.0
• Side slopes, outside of berm	1:4.0

13. Minimum design requirements.

In some instances, an individual might choose to install an anaerobic lagoon, contrary to the author's recommendations. Such facilities are allowed under current state regulations. Design procedures are set forth in WP-42 forms available from DEQ. The procedures set forth both minimum requirements and suggested procedures for use in odor-sensitive locations. For the example installation, these two options would yield designs as follows.

	Minimum size requirements	Odor-sensitive locations
• Size at top	119 feet × 201 feet	153 feet × 266 feet
• Size at "design full" level	110 feet × 192 feet	144 feet × 157 feet
• Size at bottom	50 feet × 132 feet	84 feet × 197 feet
• Depth, total	13.5 feet	13.5 feet
• Depth, "design full" level	12.0 feet	12.0 feet
• Depth, freeboard allowance	1.0 feet	1.0 feet
• Depth, 25 year-24 hour storm allowance	0.5 feet	0.5 feet
• Volume, liquid (required)	166,320 cubic feet	321,336 cubic feet
• Volume, total	200,099 cubic feet	379,616 cubic feet
• Berm width (minimum)	8 feet	8 feet
• Side slopes, bottom to "design full" level	1:2.5	1:2.5
• Side slopes, "design full" level to top	1:3.0	1:3.0
• Side slopes, outside of berm	1:4.0	1:4.0

14. Allowance for runoff storage.

In this example, the 25 year-24 hour rainfall was less than the six-inch depth we planned to provide; therefore, no further calculations were necessary. Similarly, because no extraneous runoff will be allowed to enter the lagoon, no storage for either runoff from normal precipitation events or runoff from a 25 year-24 hour storm was required. However, if the 25 year-24 hour rainfall amount had exceeded six inches or if runoff from an outside area, e.g., open feeding floor, exercise lot, etc., was allowed to enter the lagoon, additional calculations would be necessary to assure adequate storage for all runoff, including that resulting from a 25 year-24 hour storm. For design purposes, the quantity of runoff from the different surfaces can be adjusted by applying the runoff coefficients in *Table X*.

Table X. Suggested coefficients for use in designing lagoons to store runoff from extraneous areas.

Type of surface	Normal rainfall	25 year-24 hour rainfall
Roof	1.0	1.0
Concrete lot (<5% slope)	0.9	1.0
Concrete lot (>5% slope)	0.95	1.0
Unpaved lot (<5% slope)	0.8	0.9
Unpaved lot (5-10% slope)	0.9	0.95
Unpaved lot (>10% slope)	0.95	1.0

15. Annual volume equivalencies.

For ease in determining land area requirements, convert the estimated volume {step 8E (revised)} to equivalent volume *(Table IX)*. Conversion factors:

cubic feet × 7.48 = gallons
gallons ÷ 27,152 = acre-inches

437,856 cubic feet (step 8E revised)
3,276,163 gallons
120.6 acre-inches

16. Calculate annual nutrient production.

Use *Table III* and the calculations from step 1 to estimate annual nutrient production.

Nutrient production (per year) (Table III).

Units	Total pounds of animal	Pounds of N		Pounds of P_2O_5		Pounds of K_2O	
		Per pound	Pounds per year	Per pound	Pounds per year	Per pound	Pounds per year
Farrowing	20,000	× 0.223 =	4460	× 0.168 =	3360	× 0.175 =	3500
Nursery	16,250	× 0.164 =	2665	× 0.124 =	2015	× 0.131 =	2129
Finish/Gilts	7,500	× 0.164 =	1230	× 0.124 =	839	× 0.131 =	5679
Breeding/Gestation	91,600	× 0.084 =	7694	× 0.062 =	5679	× 0.062 =	5679
Total pounds per year			16,049		11,984		12,291

17. Calculate nutrients to be managed.

Some loss of nutrients in inevitable between the time of excretion by the animals and application on land. The nutrient most susceptible to loss is nitrogen. The level of loss is highly dependent upon the management system used.

Systems that allow manure to remain on the soil surface for an extended period of time result in the greatest losses (see *Table XI*). Runoff results in the loss of all nutrients.

In lagoons, most of the phosphorus and some of the potassium, though not lost, will be retained in the sludge that accumulates in the bottom. These nutrients will be recovered when the sludge is removed (25-50 years). Use *Table IV* to estimate the nutrients to be managed on an annual basis. The losses suggested by the multipliers in *Table IV* are typical values for the swine industry. The multiplier for other systems can be inserted as appropriate. Recognize that the multipliers in *Table IV* are the amount retained. Hence, losses are equal to 1.0 minus the multiplier. For example, a multiplier of 0.80 indicates an 80 percent retention or 20 percent loss. Complete *Table IV* by multiplying the quantities from *Table III* by the appropriate retention value.

Table XI. Nitrogen losses at various application — incorporation intervals.

Application - incorporation interval, days	Percent of nitrogen loss		
	Warm, dry soil	Warm, wet soil	Cold, wet soil
1	20-40	5-20	0-10
4	30-50	10-30	5-15
7 or more	40-60	20-40	5-20

Nutrients to be managed per year (Table IV).

	Coverage storage	1-cell lagoon	3-cell lagoon
Nitrogen*	_______ × 0.80 = _______	16,049 × 0.20 = 3,210	_______ × 0.05 = _______
Phosphate	_______ × 1.00 = _______	11,984 × 0.20 = 2,397	_______ × 0.05 = _______
Potash	_______ × 1.00 = _______	12,291 × 0.95 = 11,676	_______ × 0.95 = _______

* Depending upon time of year and application/incorporation methods, up to 50 percent of the nitrogen available in the storage can be lost in the field.

18. Calculate nutrient concentration.

To assist in developing your annual manure management and fertilization program, calculate the quantity of nutrients per unit volume of manure or lagoon effluent. As is always the case, a laboratory analysis of the actual product to be applied on land is superior to generalized estimates. Knowing the nutrient concentration is a requirement for system calibration and determination of the quantity of effluent to be applied per unit area of land. When used in conjunction with soil test analysis and known starter fertilizer application rates, these data allow proper credit to be given to nutrients in the manure or effluent, minimize the risk of environmental degradation and avoid costly over-application of nutrients. Use the volumes calculated in step 15 and the quantities of nutrients to be managed from *Table IV* (step 17) to complete *Table VI.*

Nutrient concentration in annual volume (Table VI).

	Pounds per 1,000 gallon	Pounds per ton*	Pounds per acre-inch
Nitrogen	0.98	0.25	26.6
Phosphate	0.73	0.18	19.9
Potash	3.56	0.89	96.8

* Assumes 250 gallons per ton.

19. Calculate minimum acreage requirements.

The data from *Tables IV* (step 17) and *VII* can be used to determine the minimum acreage requirements for land application of the nutrients. Because manure is seldom, if ever, the sole source of nutrients for a crop, the acreage requirements computed and inserted in *Table VIII* are absolute minimums — assuming no losses between storage and the time the crops use the nutrients.

Minimum acreage requirements (Table VIII). (Based on crop-use application rates; assumes manure is only nutrient source. Acreages are minimums and are valid only if there are no nutrients available to crops from other sources. Use as guideline for planning purposes only. Adjust applications based on soil test results.)

		N*		P_2O_5**		K_2O***	
Crop	Expected yield	Pounds used per acre	Required acres	Pounds used per acre	Required acres	Pounds used per acre	Required acres
Corn	160 Bushel	256	13	96	25	192	61
Soybeans	50 Bushel	255	13	50	48	120	97
Alfalfa	5.5 Ton	275	12	55	44	292	40
Sorghum	2.8 T (100 B)	176	18	64	37	140	83

* Excess nitrogen increases risk of groundwater contamination due to nitrate leaching.

** Excess phosphate (>400 pounds per acre or 200 ppm) might reduce crop yields and add to groundwater pollution.

*** Excess potash (>1,500-1,800 pounds per acre or 750-900 ppm) will reduce infiltration of water and increase runoff due to dispersion or deflocculation of clay particles, i.e., destruction of soil structure.

20. Calculate soil test-based acreage requirements.

Table VIII can be easily converted to acreage requirements for your cropping operation by replacing the "pounds used per acre" value in step 18 with a "pounds required per acre" value from your soil test report. Although some nutrients in manure will not be available to the crop in the year of application, essentially all of the nutrients in lagoon effluent are available in the year of application. A revised *Table VIII* was developed to illustrate this procedure. Typical or average yields and nutrient requirements for irrigated crops in York County were used in developing the table.

Soil test based acreage requirements (Table VIII revised).

		N*		P_2O_5**		K_2O***	
Crop	Expected yield	Pounds required per acre	Required acres	Pounds required per acre	Required acres	Pounds required per acre	Required acres
Corn	160 Bushel	150	21	26	92	20	584
Soybeans	50 Bushel	75	43	28	86	33	354
Alfalfa	5.5 Ton	0	0	28	86	115	102
Sorghum	2.8 T (100 B)	100	32	27	89	15	778

* Excess nitrogen increases risk of groundwater contamination due to nitrate leaching.

** Excess phosphate (>400 pounds per acre or 200 ppm) might reduce crop yields and add to groundwater pollution.

*** Excess potash (>1,500-1,800 pounds per acre or 750-900 ppm) will reduce infiltration of water and increase runoff due to dispersion or deflocculation of clay particles, i.e., destruction of soil structure.

Many soils in Nebraska do not require any additional phosphorus or potassium, so an application of these nutrients can increase the residual in the soil. Routine soil testing and monitoring of nutrient levels is required to help avert long-term problems. Producers forced to find a way to manage potassium-rich lagoon effluent might need to enter into a crop-sharing program with neighbors who have a need for alfalfa and corn silage.

Producing alfalfa for three to four years followed by a one-year production of corn silage before re-seeding to alfalfa is a suggested strategy to maximize use of excess potassium. Corn silage removes about 1.7 times as much phosphorus and 4.4 times as much potassium as grain corn. As the quantity of stover or residue removed increases via pasturing of beef cattle, losses due to wind, etc., the removal by corn approaches silage removal rates.

Summary

Lagoons are a viable option for managing manure in most locations within Nebraska. Properly designed, constructed and managed lagoons provide a cost-effective, labor-efficient management system with minimal risk to water or air quality.

NOTES