FEEDLOT ENGINEERING & DESIGN

by
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Functional feedlot design requires integration of multiple elements to form a complete system. Planning is facilitated by combining those elements into specific subsystems. The list of subsystems will vary between designers but I generally use the following list: 1) cattle handling and treatment; 2) cattle feeding; 3) water supply and distribution; 4) feed storage, processing, transport and delivery; 5) manure management and runoff control; 6) vehicle traffic; 7) cattle shelter, if desired; 8) wind control; 9) snow management; 10) lighting; and 11) personnel. Each subsystem must be designed giving consideration to function, cost, relationship to and integration with the overall system, manageability and--above all--safety for both personnel and livestock.

This paper is not a complete designer's "how to" treatise. My purpose is to provide an overview of some basic and important aspects of feedlot design to create an enhanced awareness of the importance of total system design. The paper is complementary to others being presented at the conference and to the listed references addressing specific topics.

CATTLE FACILITIES

There are many different designs of production facilities. The general categories include: Open unpaved lot, open unpaved lot with shelter, open paved lot with shelter, and total confinement. There are many variations of each around the country. The numerous examples and failures in each category provide clear evidence there is no one "best" design. Perhaps most importantly, the failures point out the need for good design and the need to match the system and its manageability to the management skills of the owner or person who will be operating the completed installation. Many designs which sound good or look good on paper are disasters in disguise due to day-to-day management input requirements which exceed the operator's motivational level, skills or resources. Factors to consider when selecting a system include available land area; rainfall; topography; soils; proximity of neighbors; finances (capitol and taxes); proximity of streams and public roads; labor availability; and personal preferences. Yes, applicable local, state, and federal regulations will also govern design choices.

Open unpaved lots are best suited to sites with gentle slopes and low to moderate annual rainfall (30 inches per year or less). (NOTE: The annual rainfall across the U.S. ranges from 4 inches in the desert southwest to 150 inches in the Pacific northwest.) Long slopes and slopes over 4% greatly increase the risk of erosion and transport of sediment off the lot. Slopes under 1% impede runoff and result in lots being wet for greater lengths of time following rain or snow melt. The required area varies from 150 to over 800 feet^2 per 1000 lb animal unit (kwt) and is dependent upon soils, slope, rainfall and extent to which mounds are used.

Open unpaved lots with shelters are a good choice in areas prone to ice and freezing rain--as contrasted to snow. Sheltered feeding and watering facilities help assure consistent feed intake during inclement weather. A minimum shelter area of 25 feet^2/kwt is recommended. Lot areas of 100 to 400 feet^2/kwt are commonly provided.

Open paved lots with shelters reduce total runoff because of less area but increase the percent of runoff due to the impermeable surface. Feeding is frequently in the open lot with the shelter used primarily for shade and protection from inclement weather. The shelter should provide at least 25 feet^2/kwt. Lot areas of 75 to 100 feet^2/kwt are common. Larger lot areas offer more drying of manure but require management of larger volumes of runoff.

Total confinement barns require the least land area and eliminate runoff from the animal environment. The most common system is total slats (except for a 5-6 foot concrete apron adjacent to the bunk). Other systems have been tried with varying levels of success, e.g., flush flume, counter sloped floors with a variety of manure removal methods, combination slat/flush, etc. A pen space of 17-20 feet^2/kwt is typical.

All installations should have a few lots with shelters for handling sick animals. A treatment/restraint area is required in all facilities designed for this purpose. A shelter and lot combination is also desirable as a working/treatment area for incoming cattle. Treatment facilities should have an insulated, lockable storage area for pharmaceuticals. Access to washing facilities, warm water, etc. and indoor parking for the veterinarian's truck are desirable. Separate lot and shelter areas should be provided for working incoming cattle and handling sick animals. All shelters must be well ventilated to control moisture and odors and must be cleanable -- and kept clean! -- to control insects, rodents and the spread of disease.

Strategically located shelterbelts and windbreaks can reduce lot maintenance by controlling snow accumulation and can enhance animal comfort and productivity by helping to assure consistent feed intake. Lots located within 100 feet of a mature shelterbelt are more subject to heavy snow accumulations and hot weather heat stress on cattle due to reduced airflow.

LOT SIZING

Lots are usually sized in multitudes of 60 head to match transport vehicles. Lots in excess of 200 head are not recommended due to excessive social pressures. Lot capacities of 100-120 head are most common. Rectangular lots are preferred.

LIGHTING

Provide sufficient lighting to allow easy observation of cattle. Adequate lighting has a quieting effect on newly arrived cattle, too. Locate lights in fence lines, but avoid locations directly above waterers and bunks. Locate lights where they can be accessed with reasonable ease when maintenance is required.

Mercury vapor, high pressure sodium and quartz lights are more expensive to install but are operationally cost effective. Mounting heights of 20-30 feet are needed to effectively use these lighting styles. All fixtures must be listed for use in wet locations. The design must determine the acceptable compromise between lighting levels, number of fixtures, variation in light levels and shadowing. A lighting level of 5-7 foot-candles (fc) is recommended for general lot areas. A light level of 20 fc is desirable along the bunk.

Localized lighting can be used in treatment facilities to allow better observation of cattle. Provide a general lighting level of 20-30 fc. A light level of 50 fc is desirable in general working treatment and pharmaceutical/supply storage areas. A light level of 100 fc or more is required in areas to be used for conducting veterinary procedures.

MOUNDS

Mounds are recommended in all unpaved lots. Construct mounds so they form a shallow "W" shape across each lot. (Wide lots require additional "V's" or "W's".) The mounds should extend directly to the bunk apron, i.e., do not make cattle walk through a low area between the mound and bunk. Locate fences on top of mounds (not in the valleys). Mounds should have rounded (not flat) tops and side slopes not exceeding 1:3 (rise:run). Excess slope reduces usable cattle resting area. The slope distance of each mound should be limited to 50 feet. Shorter slope lengths enhance drainage and drying. Use compacted clay to form mounds. Mounds built from lot scrapings and containing large quantities of manure are unacceptable. Plan the space between mounds to accommodate lot maintenance equipment. A distance of 15-20 feet is common. See Figure 1.

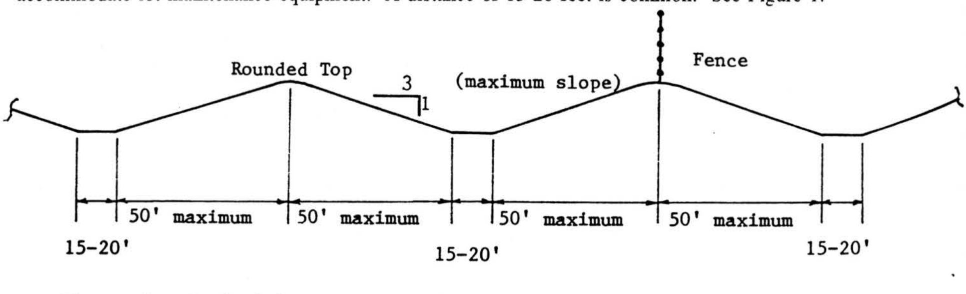

Figure 1. Typical lot cross-section.

FEED BUNKS

Locate feed bunks for easy access by both cattle and feed delivery equipment. There is no perfect orientation for a feed bunk, i.e., north-south vs east-west. The best orientation is dependent upon the site. All-weather accessibility and maintainability are more important than directional orientation.

Set bunks on a solid base (as contrasted to blocks) to minimize debris build up, insect breeding and rodent harborage. (Figure 2.) Match bunk height to the cattle being fed. Recommended bunk (animal throat) heights are:

Calves to 800 lbs	18"
Heifers and finishing steers, 800-1200 lbs	20"
Mature cows and bulls	24"

Bunk space requirements vary from 6 inches per head in confinement operations with feed always available to 30 inches for heavy-weight cattle and once-per-day feed delivery. A step along the cattle side of the bunk helps control aggressive behavior, reduces damage to the bunk during scraping operations and minimizes deposition of manure in the bunk.

Design bunks for easy cleaning with power brooms or scrapers. Bunks which must be cleaned by hand are usually poorly maintained. Cleaning frequency varies from daily in some installations to weekly. A bunk with round corners is preferred for easier cleaning. Routine cleaning is needed to remove non-palatable feed, stones, snow, etc.

Provide a concrete apron 12-14 feet wide on the cattle side of the bunk. (A 3-4 foot extension of the apron at the concrete-soil interface reduces development of soft holes and enhances lot management. [Figure 2.]) An apron along the feed delivery side of the bunk is desirable. An all-weather driveway is a minimum requirement. Slope the area between bunks for good drainage, control of snow melt, etc. Locate bunks at least 16 feet apart. Bunk spacings up to 50 feet are desirable in heavy snowfall areas to allow for storage of snow removed from bunks and feed delivery routes.

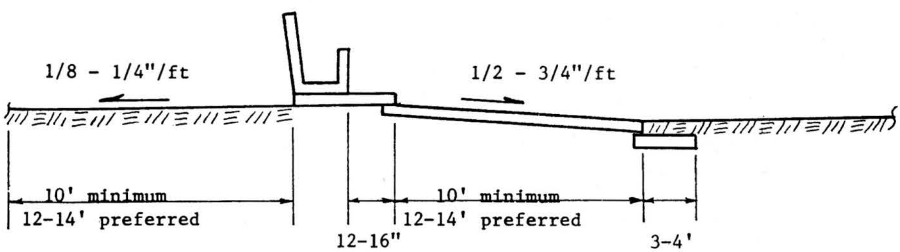

Figure 2. Feedbunk and feeding apron design.

VENTILATION

Animal shelters must be well ventilated to enhance animal comfort and health. Both mechanical (fans used to achieve airflow) and non-mechanical (reliance upon air buoyancy and wind to cause airflow) ventilation systems have been used in cattle production facilities. The predominant system is non-mechanical. To enhance ventilation, a 4:12 roof slope is needed. Provide an air outlet the full length of the building at the high part of the roof (ridge on gable roof or top of high wall on monoslope roof) measuring at least 2 inches wide per 10 feet of building width (clear opening). Provide continuous openings along both eaves--1 inch per 10 feet of building width. Sidewall openings should be within 4 feet of the floor surface, at least 1 foot high per 10 feet of building width and continuous the full length of both walls. An east-west building orientation is best in most localities.

Mechanically ventilated facilities must have adequate fan capacity to remove heat and moisture. Inlets must be adjustable and of a design which assures airflow through the animal space (0-4 feet above the floor). The design of a mechanical ventilation is too detailed to allow all design requirements to be presented here. Suffice it to say that adequate fan capacity (at least 540 cfm/kwt in hot weather), a well-designed inlet system and good management are essential.

WATER SYSTEM

Water must be readily accessible to animals at all times. Provide one water cup or one linear foot of accessible tank perimeter per 15-20 head. Design the water system to provide the daily water needs (8-22 gal/kwt-day) over a three hour time period. This will assure adequate system capacity to meet cattle needs during hot weather. Depriving cattle easy access to adequate quantities of good quality water is never cost effective.

Locate the waterers where they will cause minimal interference with lot maintenance operations. In unpaved lots, locate waterers on a raised area near the feed bunk. A concrete apron between the bunk and waterers and around waterers is desirable. Minimum apron width is 10 feet. In paved lots, locate the waterer where spillage will result in minimal ice formation in the cattle area. Grade the area around the waterer to divert spillage away from the waterer and bunk. A built-in overflow connected to an underground drain will reduce problems associated with valve failure.

ELECTRICAL

Electrically heated waterers require proper installation to assure safe operation and minimize hazards. An improperly installed heater/waterer poses an electrocution hazard and can cause decreased water intake due to extraneous voltage.

During installation a grounding conductor must be provided from the electrical supply service panel and over-current protection device (fuse or circuit breaker) to the waterer. A secondary fused disconnect at each waterer is recommended. A ground rod may be installed at the waterer to complement the circuit grounding conductor. However, a ground rod at the waterer may not be used in lieu of a grounding conductor. An electrically heated waterer installed with just a ground rod, i.e., without a circuit grounding conductor, is neither safe nor legal (*National Electrical Code (NEC), Section 250-51.* The NEC is adopted as state law in many states). All wiring cables, boxes, fittings, etc. must be of a proper design and listed for use in wet locations.

CATWALKS

All working platforms, catwalks, etc. more than 18 inches above the surrounding area should be equipped with hand or safety rails. Design rails to withstand a horizontal force of at least 300 lbs per foot. The top rail should be 42 inches above the working/walking surface. Install a second rail mid-height. A toe rail located 1 inch above the work surface is recommended to control slipping. Locate upright posts 6 feet o.c. If the top rail is constructed from one 2x4 on edge and another 2x4 laid flat and nailed to the "on edge" 2x4, the spacing of posts or uprights can be increased to 8 feet.

Walking surfaces should be equipped with cleats or other skid reducing surfaces. Expanded metal has worked well. The working/walking surface should be at least 18 inches wide and free of trip hazards, protruding nails or bolts, etc. On long working surfaces, provide access ladders or steps at 20 foot intervals for added convenience.

FEED STORAGE AND DELIVERY

Trench and bunker silos are widely used for storage of silage, high moisture grains, and other feedstuffs. Concrete floors or pads sloped for drainage to the entry end, i.e., away from the stored feed, and smooth, tapered, air-tight sides are necessary to minimize losses due to spoilage and to assure all-weather access to the feed. Free-standing piles and plastic bag systems are generally satisfactory and cost-effective only for storing small quantities of excess feed. Feed stored in any horizontal storage system should be covered with plastic to control losses. The plastic must be covered with tires, limestone, sawdust, etc., to prevent billowing during windy conditions.

Inadequate protection and weighting of the plastic allows air to be "pumped" into the stored feed and increases losses.

Tower or upright silos are most satisfactory for feedlots having 300-750 head of cattle on feed. Investment costs and slow unloading rates limit their usefulness on small and large installations.

Storages should be sized to allow daily removal of at least a 3-inch thickness from the exposed face or surface during warm weather. Inadequate feed removal rates result in cattle always receiving feed with decreased feed value. This can reduce feed intake and weight gains.

A mixer box mounted on a tractor-drawn trailer or truck is the most common method of transporting and delivering feed to bunks. All feeding equipment requires scales for accurate ration formulation, feed delivery and records--feed disappearance, feed:gain ratios, etc. Mixer boxes are available with chains, augers and a variety of combinations thereof. The best system--based on uniformity of mixing, power requirements, mixing time, etc.--will be dependent upon the specific feedstuffs being fed. Most mixers are unable to handle dry hay unless it is first run through a tub grinder or chopper. Dust and leaf (and nutrient!) losses are major concerns with grinding operations. An enclosed storage is required for storage of chopped hay to limit losses due to wind and to protect the hay from precipitation.

In larger installations, a stationary mixer box can be used to prepare loads while delivery is being made with a portable unit. This approach requires more investment in equipment but saves labor and expedites feeding.

Mechanical systems for feed delivery include belts, chains (several types) and augers. Mechanized feed delivery systems are best suited to installations having tower silos for silage storage and 300 or fewer head.

RUNOFF CONTROL

The first rule of runoff control is to prevent as much water from entering the lots as possible. Select a site free of natural drainage ways. If natural drainage ways cannot be avoided, design the lot to prevent lot runoff from mixing with natural flow. Allowing any water containing manure to leave the owner's property--including flowing through a culvert under a public road--except during unusual precipitation events is a violation of federal regulations (U.S. Environmental Protection Agency). Most states have similar regulations. Under existing regulations, runoff must be controlled unless the rainfall exceeds the historical 25 year-24 hour precipitation event, i.e., the amount of rain expected during a 24-hour period at least once per 25 years. In Nebraska, the 25 year-24 hour rainfall ranges from 3.5 inches in the western panhandle to approximately 5.8 inches in the southeast. Example rainfall depths across the U.S. are 1.5 inches in the inner desert, 2.5 inches in the northern Rockies, 10-12 inches along the west coast and Gulf of Mexico, and 4 inches in northern New England. Sufficient storage must be available at all times to store precipitation and runoff from a 25 year-24 hour rainfall.

Most states also require sufficient storage for runoff and transported debris or sediment during any 120-day interval. A 180-day duration of storage is recommended for improved manageability. Because of increased evaporation during the summer (e.g., May-October equals 74-78% of annual total in Nebraska), in many instances a storage which requires only a once-per-year pump-down can be provided at little additional cost. The advantages of a longer duration of storage include enhancement of management and increased benefits from the water and crop nutrients. The result is a lower net cost to handle runoff because of increased value and use of the water and nutrients.

The amount of runoff and transported solids varies with frequency of lot cleaning, slope length, lot slope, rainfall intensity, soil type and lot surface. On a paved lot at least 90% of the annual precipitation (rain and snow) will likely leave the lot as runoff. In contrast, runoff from a gently sloping unpaved lot may be less than 50% of annual precipitation. Experience and professional judgement are needed to develop reasonable estimates of annual runoff in a given situation. A conservative estimate is best in the long run in most instances.

Settling or sedimentation basins have been widely used to allow heavier transported solids to settle out before the water enters the storage facility or holding pond. Such devices work well but are historically very difficult to manage and poorly maintained. I believe there are three primary reasons for the poor management level.

1) To keep costs as low as feasible, many settling basins were constructed with earth bottoms. The wet manure solids keep the underlying soil muddy, making access with conventional farm equipment impossible. Renting of specialized construction equipment is expensive and is done with absolute minimum frequency.

2) Accumulated manure solids are very difficult to handle. A dry crust 4-12 inches thick forms, but solids deeper within the accumulation dry very, very slowly. The solids content is generally high enough to make handling by pump very inefficient due to poor flowability. At the same time, the water content is high enough that attempting to handle the accumulated solids with a loader soon converts the solids into a thick, soupy slurry which is not easily handled.

3) Manure handling is a low priority item with most producers. Consequently, facilities are commonly allowed to become overloaded and grown up in weeds, further complicating handling. Too often, management of the manure handling system is undertaken only when "there's nothing better to do" or when pressure is applied because of pollution, water quality degradation, insects, odors, etc.

Increasing concerns over water quality and an increase in the number of lawsuits against livestock producers nationwide alleging unacceptable odor levels and/or insect or rodent populations means many management strategies of the past are not acceptable. No longer can we allow uncontrolled or non-managed runoff to occur.

What then is the solution? Begin with a system design which will minimize the transport of soil and other non-biodegradable solids from the lot. If a satisfactory level of control can be achieved, the water and biodegradable solids are best handled in a facility designed and operated as a facultative lagoon. (Note: An earthen bank storage and a lagoon are not the same!)

Air quality considerations dictate that anaerobic lagoons not be used. Despite their smaller size, the savings do not justify the risks of complaints due to odors. Facultative lagoons in central Nebraska should be designed for a biological loading rate not exceeding 1 pound of volatile solids per 1,000 cubic feet of permanent volume per day. Appropriate loading rates for other parts of the U.S. are illustrated in Figure 3. The volatile solids production rate of beef animals is about 6.0 pounds per kwt per day. The lagoon permanent pool volume must be based on the estimated proportion of these solids that will actually enter the lagoon. (A facultative lagoon must be designed to meet at least the minimum requirements for: a) the permanent pool volume based on volatile solids loading rate; b) adequate annual working volume [precipitation on lagoon + runoff entering lagoon + solids transported into lagoon - evaporation]; c) 25 year-24 hour precipitation on lagoon + plus area contributing to runoff which enters lagoon; and d) freeboard.) In most instances, lagoons should be sized for a once-per-year pumpdown.

In those situations where there is reason to believe soil erosion cannot be controlled at an acceptable level, the best option is to look for an alternative site. If re-location is not a viable option, the runoff should be directed into a concrete (bottom, sides and entrance ramp) settling basin. The basin should be sized for at least a 30-minute retention to allow heavier solids to settle out. Lighter solids which settle very slowly and suspended solids will carry over into the lagoon with the water. Depending upon the actual removal rate of solids by settling, some decrease in the permanent lagoon volume is acceptable. A maximum reduction of 20% is recommended. Settled solids should be removed from the settling basin after every major precipitation event--unless the design allows for some accumulation--using whatever method is found to work best.

Keep solids and liquid storage areas outside of all lot fences. Grade lots to prevent ponding. Uncontrolled wet areas are conducive to insect breeding and increase health risks. A sharp line of demarcation between liquid storage and manure solids is best for insect control.

Design all runoff control channels and cattle movement alleys for easy maintenance. Regular mowing and solids removal are both necessary. Maximum side slopes to safely allow maintenance with conventional farm equipment is 1:4 (rise:run). Provide working space along fences to facilitate maintenance.

The use of licensed Professional Engineers with training and experience in feedlot and runoff control/manure management system design and operation is recommended. The registered engineer assumes responsibility for the design once he or she affixes their seal to the plans. Designs developed by non-engineers or non-registered engineers are developed in conflict with the laws of most states which allow only duly licensed engineers to perform engineering services. Select an engineer familiar with the part of the country and licensed in the state in which the facility will be located.

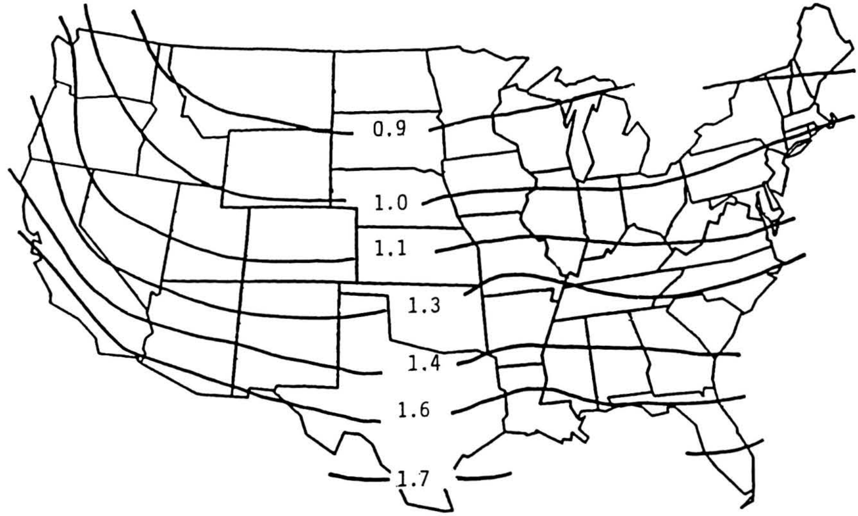

Figure 3. **Recommended maximum loading rates for facultative lagoons.** (Pounds of volatile solids per cubic feet of permanent lagoon volume per day)
(Adapted from ASAE EP 403.1)

REFERENCES

Beef Housing and Equipment Handbook, MWPS-6 ($7.00)
Livestock Waste Facilities Handbook, MWPS-18 ($6.00)
Mechanical Ventilating Systems for Livestock Housing, MWPS-32 ($6.00)
Natural Ventilating Systems for Livestock Housing, MWPS-33 ($5.00)
Farm Buildings Wiring Handbook, MWPS-28 ($6.00)
Agricultural Wiring Handbook ($8.00)
Private Water Systems Handbook, MWPS-14 ($7.00)
Grain Drying, Handling and Storage Handbook, MWPS-13 ($7.00)
Farmstead Planning Handbook, MWPS-2 ($6.00)
Locating a New Feedlot, GPE-5101 ($2.00)
Feedlot Layout, GPE-5201 ($2.00)
Fence Line Feedbunk Design, GPE-5701 ($2.00)
Water System Design for Feedlots, GPE-5700 ($2.00)
Principles of Feedlot Runoff Control, GPE-7520 ($2.00)
Feedlot Runoff Disposal on Grass or Crops, GPE-7521 ($2.00)
Management of Feedlot Runoff Control Systems, GPE-7523 ($2.00)
Fertilization of Crops with Feedlot Manure, GPE-7601 ($2.00)
Control of Dust from Cattle Feedlots, GPE-7803 ($2.00)

The listed references are available from the Agricultural Engineering Planning Service, University of Nebraska-Lincoln, 219A L.W. Chase Hall, Lincoln, NE 68583-0727. Advance payment is required. Nebraska residents must add sales tax at the rate applicable in their county or town. All orders should include postage and handling per the following table:

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SUMMARY

Good design and appropriate consideration of all elements of a feedlot system will help assure a manageable, efficient, environmentally sound, safe and profitable operation. In some instances, a design team is required to adequately address all areas of concern. Professional design services and good construction techniques are always cost-effective investments.