


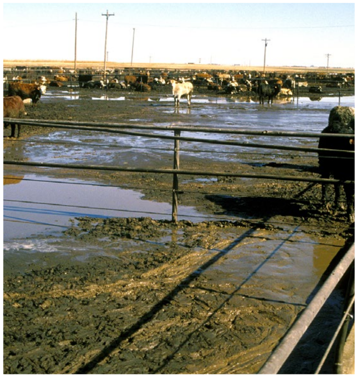

FEEDLOT DESIGN AND CONSTRUCTION

10. Pen and drainage systems

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Introduction

Stormwater runoff from feedlots contains contaminants that, if allowed to enter natural watercourses, would constitute an environmental hazard. Feedlots must have a system that controls runoff from contaminated areas and provides for environmentally acceptable utilisation of the valuable water and nutrient resources of that runoff.

Design objectives

Feedlot pens and drains should be designed, constructed and maintained to ensure that

- All free rainwater drains quickly so that pens can dry quickly
- The pen surface does not erode during runoff
- Pens do not carry manure into other pens
- Odour emissions are minimised by quick pen surface drying
- Manure movement in pens is minimal
- Flow constrictions that could cause manure to deposit e.g. pipes/culverts/bends are designed to ensure that entrapped manure remains in the water flow
- There is minimal settling of manure in drains
- Drains are not subjected to excessive erosion or scouring
- Drains have sufficient capacity to convey design flow rates without overtopping
- Drains surfaces are impermeable to prevent effluent infiltration into groundwater
- Drains can be cleaned easily.

Mandatory requirements

The National Guidelines for Beef Cattle Feedlots in Australia state that a controlled drainage system should be designed so that

- Drains can safely carry the peak flow rates resulting from a design storm event with an average recurrence interval (ARI) of 20 years.
- The duration of the design storm event should be taken as being equal to the time taken for water to flow from the most remote point of the catchment area to the catchment outlet (time of concentration).
- Flow velocities in drains during the 20-year ARI design storm event should be greater than 0.5 m/s but at the same time be non-scouring.
- Catchment and primary drains should be underlain by a thickness of at least 300 mm of clay or other suitable compacted soil, or a synthetic liner able to provide a design permeability of $<1 \times 10^{-9}$ m/s (~0.1 mm/d).
- Manure stockpiling and/or composting areas should be underlain by a thickness of at least 300 mm of clay or other suitable compacted soil, or a synthetic liner, to provide a design permeability of $<1 \times 10^{-9}$ m/s (~0.1 mm/d).

Pen drainage design

A controlled drainage area for a feedlot must include a drainage system for conveying stormwater runoff from pens to holding ponds.

A controlled drainage area (see Figure 1) is typically established using

- A series of catch drains to capture rainfall runoff from the feedlot pens and all other surfaces within the feedlot complex, and convey that contaminated runoff to a collection and utilisation system.
- A series of diversion banks or drains placed immediately upslope of the feedlot complex to divert any 'clean' or uncontaminated upslope runoff (sometimes termed 'run-on') around the feedlot complex away from the controlled drainage area.

Where feedlots are built close to the crest of a hill or ridge and there is no side slope, and hence no 'run-on', a controlled drainage area might not need any upslope diversion banks. However, in practical terms it is unlikely that no diversion banks and drains will be required.

Depending on the topography and layout of the site, a feedlot may have more than one controlled drainage area. The controlled drainage system should include the following elements

- production pens
- livestock handling facilities including livestock loading and unloading facilities
- hospital and recovery pens
- solid waste storage and processing facility
- feed commodity storage and processing facilities
- cattle and truck washdown facilities
- cattle lanes
- feed lanes or alleys
- silage pits
- runoff catch drains
- run-on diversion banks
- sedimentation system
- holding pond(s).

Aerial photo of a feedlot catchment area draining down to a holding pond.

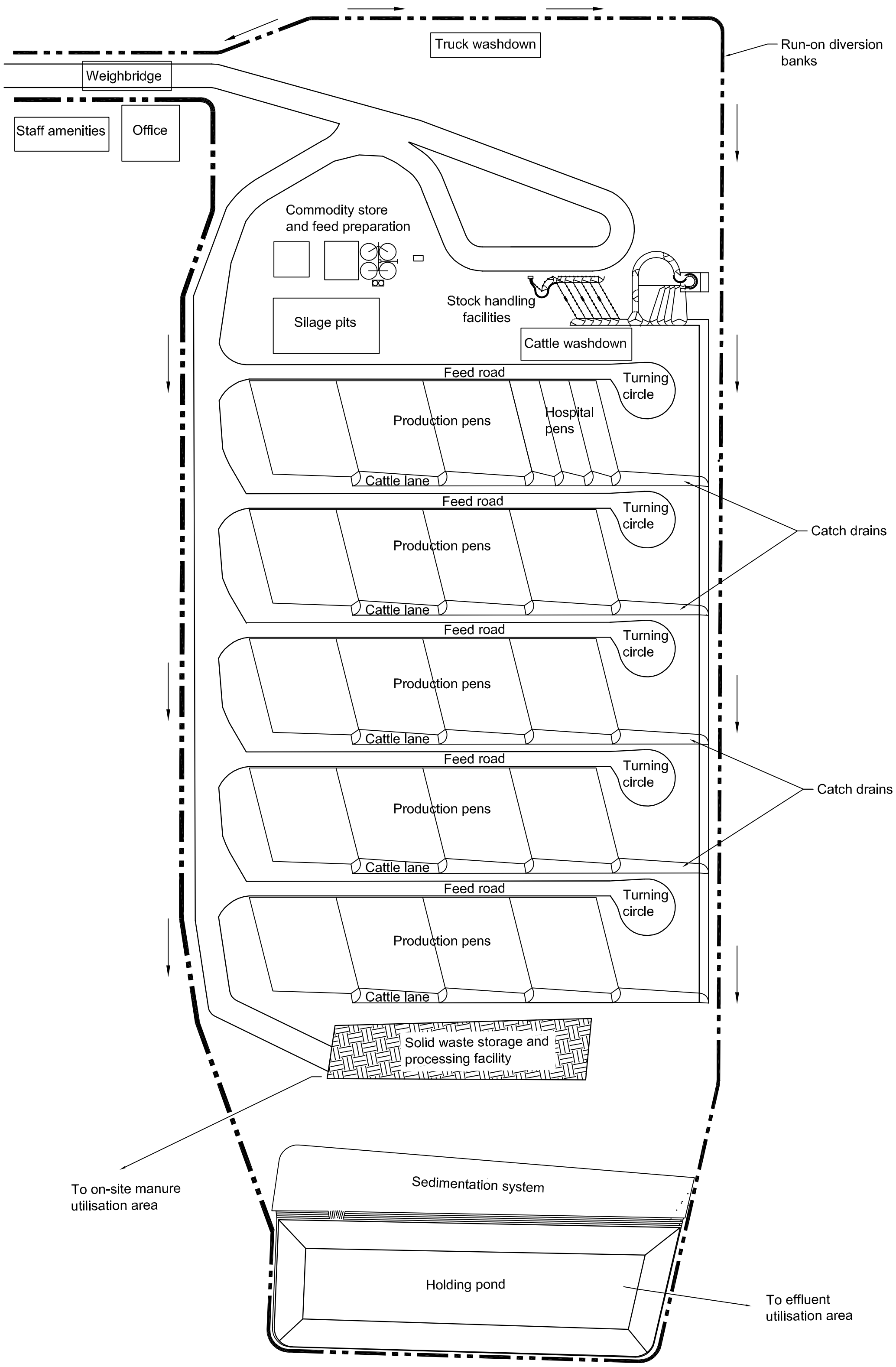


Figure 1. Controlled drainage area for a feedlot

The design layout shown in Figure 1 provides uninterrupted flow for runoff, eliminating the need for culverts.

See *Section 2 – Feedlot site layout* for further information on feedlot layout.

Design choices

Pen slope

A pen slope of between 2.5% and 6% will ensure quick drainage of rainfall, without runoff scouring excessive amounts of manure from the pen surface. Pen slope is the fall of the pen surface perpendicular to the feed bunk (see Figure 2).

Pen slopes less than 2.5% do not drain well as any imperfection in the pen surface or accumulation of manure will cause rainfall to pond in the pens. This would enhance damage to the pen surface and potential damage to the base material underneath the impermeable manure interface. Wet patches in pens can emit odour at 50 to 100 times the rate of dry pen surfaces. Wet patches also lead to discomfort of cattle and dags on cattle coats.

Pen slopes over 6% are difficult to manage and should be avoided. Runoff after heavy rainfall on steep pens can transport large quantities of manure and even erode the base of the pen surface. In addition to the pens having adequate slope, the drains at the lower end of the pens need slope to drain runoff toward the storage areas (see Figure 2). Drains should not run transversely across the middle of pens as they are difficult to clean and maintain, and often are full of manure.

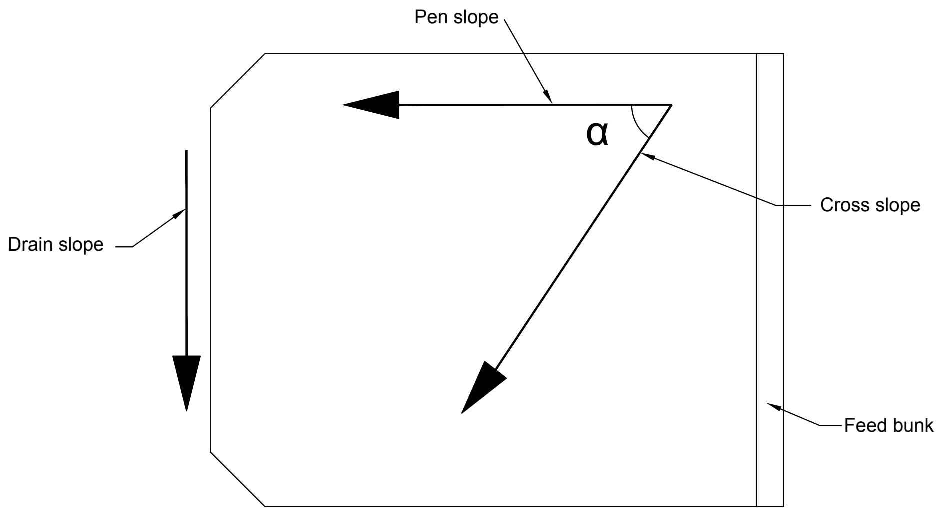
Steeper bed slopes are possible for drains constructed with well-compacted gravel bases that are resistant to erosion or concrete beds.

Figure 2 shows that when there is a combined pen and drain slope across the site, the maximum pen slope is not perpendicular to the feed bunk. The magnitude of this slope and its angle from perpendicular to the bunk will depend on the relative magnitude of each of the pen and drain slopes. Table 1 shows the maximum slopes for a range of pen and drain slopes. Table 2 shows the angles at which the maximum slopes occur (see Figure 2).

Pens with inadequate pen slope will not drain storm rain.

Ponding of water in feedlot pens with inadequate pen slope.

Figure 2. Combination of pen and drain slope



Drains should not be formed in the middle of the pens as they promote pen to pen drainage. Note how the lower rail on the fence blocks drainage.

Pen to pen drainage is a poor design.

Table 1. Maximum slope for a range of pen and drain slopes.

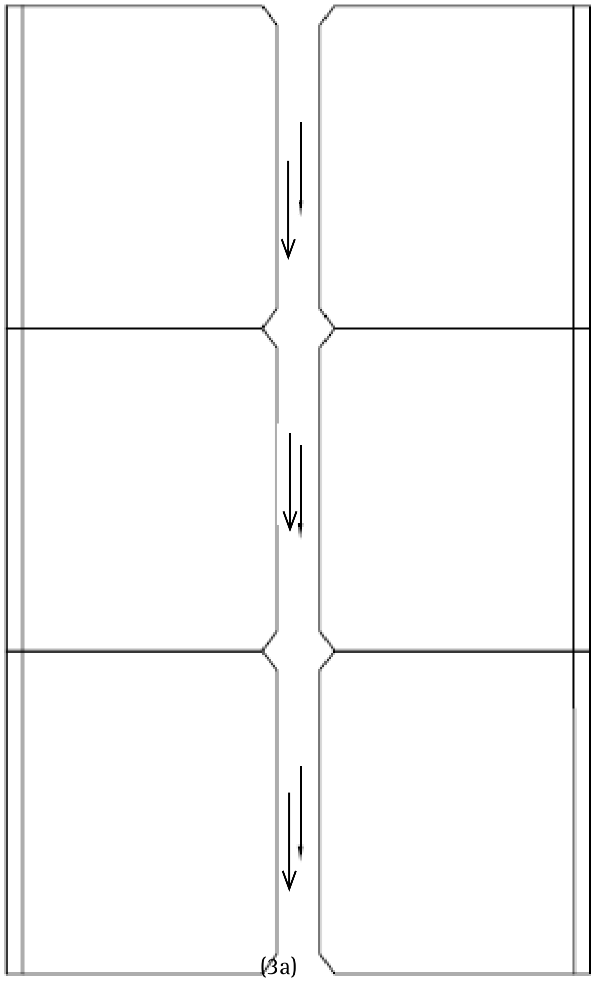
	Drain slope (%)					
Pen slope (%)	0.50	0.75	1.00	1.25	1.50	1.75
	Cross slope (%)					
2.5	2.55	2.61	2.69	2.80	2.92	3.05
3.0	3.04	3.09	3.16	3.25	3.35	3.47
3.5	3.54	3.58	3.64	3.72	3.81	3.91
4.0	4.03	4.07	4.12	4.19	4.27	4.37
4.5	4.53	4.56	4.61	4.67	4.74	4.83
5.0	5.02	5.06	5.10	5.15	5.22	5.30
5.5	5.52	5.55	5.59	5.64	5.70	5.77
6.0	6.02	6.05	6.08	6.13	6.18	6.25

Table 2. Angle at which maximum slope occurs for a range of pen and drain slopes.

	Drain slope (%)					
Pen slope (%)	0.50	0.75	1.00	1.25	1.50	1.75
	Angle α, degrees					
2.5	11	17	22	27	31	35
3.0	9	13	18	22	27	30
3.5	8	12	16	19	23	27
4.0	7	11	14	17	21	24
4.5	6	10	13	16	18	21
5.0	6	9	11	14	17	18
5.5	5	8	10	13	15	18
6.0	5	7	9	12	14	16

When considering the slope of pens during the design of the feedlot, it is the cross slope that will determine the likelihood of ponding or excessive manure entrapment.

Figures 3a and 3b show typical pen and drain layouts. Although there is a cross slope due to the combination of pen slope and drain slope, little pen to pen drainage occurs whenever pen slope is much higher than drain slope. Where for various reasons drain slope is high, any pen to pen drainage can be eliminated using an angled pen design as shown in Figure 3b.



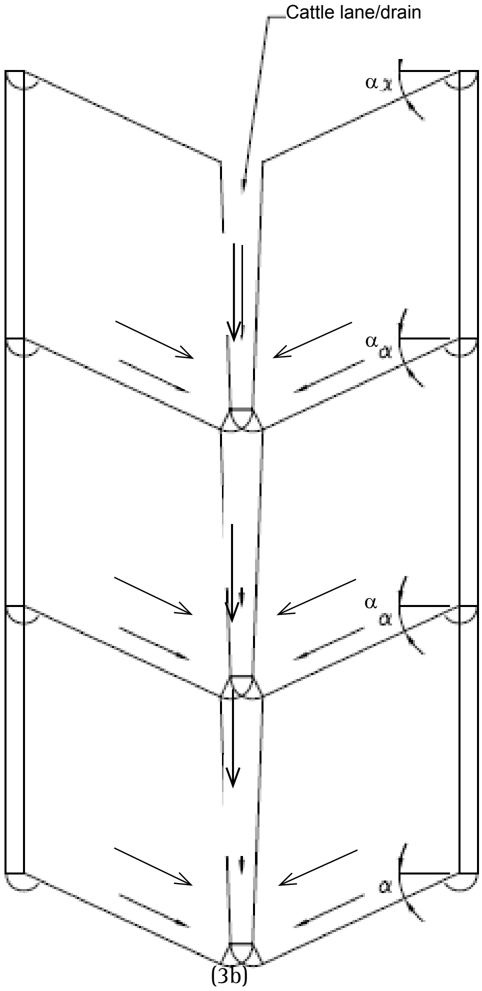


Figure 3. Conventional square pens (3a) vs angled pens (3b) to minimise pen-to-pen drainage

Conventional square pens (as in 3a)

Angled pens to minimise pen-to-pen drainage (as in 3b)

Pen to pen drainage is not desirable. Here a row of pens runs up the slope towards the feed mill with little cross slope. Runoff and manure flows through all pens before exiting at the lower end. This runoff is from a leaking water trough in a pen in the middle of the row.

Pen to pen drainage without good manure management may lead to unacceptable pen conditions. Here, runoff has to flow through each pen towards the manure stockpile.

Drainage design

The function of the controlled drainage system is to convey runoff (and entrained manure) from the pens and other areas to the sedimentation system and holding pond(s). The drains must have sufficient capacity to handle significant storm events and manure loads. The steps involved in designing a drainage system include

1. Determine the location of the drain, including the drain slope.
2. Determine the area and characteristics of the catchment draining into that drain.
3. Determine the design flow rate for that drain.
4. Determine the drain physical characteristics (dimensions, lining characteristics).
5. Calculate the predicted flow depth at the design flow rate and determine if this is acceptable.

Drain location and slope

Within the feedlot, the location of drains is usually determined when the controlled drainage area is laid out. Catch drains below each row of pens and a series of primary drains take runoff from the catch drains to the sedimentation system.

To minimise the settling of solids conveyed in the runoff, the flow velocity in both the catch and primary drains should be greater than 0.5 m/s but not so fast as to cause scouring of the drain.

Where high velocities (i.e. generally >1.5 m/s) are unavoidable, the drain should be lined with an appropriate, durable liner (e.g. compacted gravel, masonry or concrete). Drop structures or energy dissipaters may be installed to reduce the slope and flow velocities in a drain, without having to line the entire length.

Catchment area and characteristics

The next step in drain design is to determine the area draining into the drain and the characteristics of the components of the catchment area. In feedlots, it is usual to break the catchment down into three main sub-components, each of which has different runoff characteristics. They are

- pen area – areas containing cattle and covered with manure
- hard catchment – areas with a high runoff yield including roads, feed alleys, drains, roofed areas and manure stockpiles
- soft catchment – areas with a low runoff yield such as grassed and other vegetated areas within the controlled drainage area.

Design flow rate

Drainage systems are designed to cater for rainfall events of specific frequencies and durations. These frequencies are typically expressed in terms of an average recurrence interval (ARI) which is the average interval between two events of a specific size. Importantly, the interval between two such consecutive events may be greater or less than the average interval; over the long term, however, the average interval between events will approach the ARI.

Commonly used ARIs are 10 and 20 years, the value chosen depending on the assessed consequences of overtopping of the designed structure. For catch and main drains, a 20-year ARI generally applies and is used in the National Guidelines. The design storm is defined in *Section 12 – Holding pond design* as a rainfall event, with a nominated average recurrence interval (ARl) that has a duration equal to a catchment's time of concentration according to Australian Rainfall and Runoff (Pilgrim 2001).

Diversion banks and/or drains

Uncontaminated upslope runoff should be diverted away from the feedlot controlled drainage area in order to minimise the quantity of runoff requiring treatment. Diversion banks or drains should be designed to carry flow rates resulting from a design storm event with an average recurrence interval of 20 years. Diversion banks and drains should carry flow at a non-scouring velocity which, in practice, means having slopes of <1.5 m/s.


With very flat pens, pen to pen drainage may form in the middle of the pens.

Catch and primary drains

Runoff from the controlled drainage area should initially drain into a collecting drain system, discharge into a sedimentation system and finally, through to holding ponds and/or evaporation systems. Drains should be designed to produce velocities sufficient to transport manure but not sufficient to produce scouring and erosion. Catch drains should be designed to carry, at non-scouring velocity, peak flow rates resulting from a design storm with an average recurrence interval of 20 years, using a runoff coefficient of 0.8.

Design standards

The National Guidelines outline design standards i.e. both diversion banks and drains and catch drains should be designed to carry the peak flowrate resulting from a 20-year average recurrence interval (ARI) design storm. The duration of the design storm should be taken as being equal to the time of concentration of the catchment area; this is the time taken for water to flow from the most remote point of the catchment to the catchment outlet. After this time, runoff from the entire catchment area is contributing to flow at the catchment outlet and should be at a maximum.

Rational method

While other more complex methods are available, it is recommended that the Rational Method (Pilgrim 2001) be used for determining the design flow rate (Q) for feedlot drains. This relatively simple method is widely used in the water engineering field for estimating design flow rates for minor hydraulic structures. This method determines a peak flow of selected average recurrence interval (ARI) from an average rainfall intensity having the same ARI.

In its simplest form, the **Rational formula** is:

$$Q = \frac{C \times I \times A}{360}$$

Where: Q = peak flow rate (m^3/s),
C = runoff coefficient,
I = rainfall intensity of 20 yr ARI design storm (mm/hr)
A = catchment area (ha).

Use the ratio of rainfall to surface runoff (runoff coefficient) to calculate for adequate drainage.

Runoff coefficient

To reflect the ratio of rainfall to surface runoff, a runoff coefficient (C) is used. Some suggested ranges for this runoff coefficient for a feedlot controlled drainage area are shown in Table 3 (MLA, 2013b)). The first four catchment types apply to areas upslope of diversion banks and drains (i.e. outside of the controlled drainage area).

The lower values for each of these four catchment types should be applied to low relief catchments that are dominated by overland flow or contour drains, and to catchments having deep sandy soils with high infiltration rates.

Conversely, the higher values for each of the catchment types should be applied to high relief terrain that has well-defined watercourses, minimal surface storage, and rocky, clayey or other poorly absorbent soil; and/or catchments with scant ground cover. Intermediate values should be applied where intermediate conditions exist.

A value of 0.8 for runoff coefficient C can be applied to most feedlot complexes where there are only small areas of grass or other vegetation (soft catchment) within the controlled drainage area.

Table 3. Suggested ranges for the value of the runoff coefficient (C) for a feedlot controlled drainage area

Catchment type	Coefficient (C) range
Forest	0.1–0.6
Pasture/grassland	0.1–0.6
Cultivation	0.3–0.8
Roads	0.9
Residential/industrial	0.4–0.8
Feedlot complex	≥0.8

Rainfall intensity

The generally accepted method for determining the design storm intensity (*I)* is that provided by Canterford et al. (2001) in 'Australian Rainfall and Runoff'. Tabulated intensity-frequency-duration (IFD) values are available for major population centres in Australia or calculated online. A variety of software is also available that will calculate values for sites away from major towns and cities. Drains should be designed to carry the peak flow rate resulting from a 20-year ARI design storm.

The duration of the design storm should be taken as being equal to the time of concentration (t_c) of the catchment area. This is the time taken for water to flow from the most remote point of the catchment to the catchment outlet. After this time, runoff from the entire catchment area is contributing to flow at the catchment outlet.

Time of concentration

Several methods are available to determine the time of concentration of a small catchment. Some of these are detailed in Pilgrim and Cordery (1993) and Pilgrim and Doran (2001). There is no definitive method for estimating time of concentration and any appropriate method provided in a recognised text should be acceptable.

One of the more widely accepted methods of estimating time of concentration uses the Bransby Williams Formula, which is given

$$t_c = \frac{58 \times L}{A^{0.1} \times S_e^{0.2}}$$

by:

Where: t_c = time of concentration (min),
L = length of mainstream (km) from the outlet to the catchment divide,
A = area of catchment (km^2)
S_e = equal area slope (m/km) as defined in the National Guidelines for Beef Cattle Feedlots (MLA,2012b).

Having established the time of concentration of the catchment, it is then possible to determine the intensity *(I)* of a 20-year ARI design storm at the development site. This design storm would have a duration equivalent to the time of concentration of the catchment.
The Rational Method is then used to calculate design flow rate.

Drain physical characteristics

The drain physical characteristics include cross-sectional dimensions and surface type.

Cross-sectional dimensions

The diversion and catch drains in feedlots usually have either trapezoidal or vee-shaped cross-sections. These two cross-sectional designs are illustrated in the figures below where:

d = flow depth (m),
W = drain bed width (m), and
z_1 and z_2= drain batters (1 vertical to z horizontal)

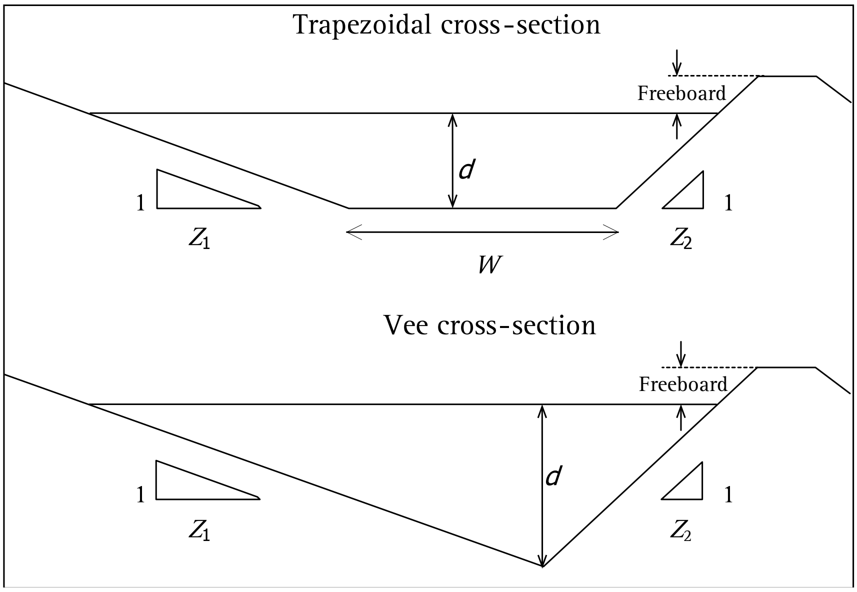


Figure 4 - Typical profiles of feedlot drains (trapezoidal and V-drain)

Concrete drains can be used in steep drain sections to prevent erosion. However, the drain must be wide enough to allow access by cleaning equipment.

Primary drains with vegetation as surface cover are difficult to maintain as they remain wet, the vegetation grows and manure is deposited. These areas can be a source of excessive odour emission and a fly breeding site.

The empirical Manning Formula can be used to estimate flow rates and velocities in drains. The method for estimating the flow rates and velocities in drains is outlined in Appendix A – Design of controlled drainage systems of the National Feedlot Guidelines (MLA, 2012a)

The side batters on drains should in general be no steeper than 1 vertical:2 horizontal (z = 2).

All feedlot drains and embankments should have a free board, following post-construction consolidation, of at least 0.15 metres above the design flow depth in a 20-year ARI design storm. To accommodate this freeboard and to allow for variations in embankment height, soil type and construction method, it may be advisable to build embankments 25–40% higher than the estimated requirement.

In catch drains, the freeboard may be provided within the adjoining cattle lane or pen, and it may not be necessary to allow for settling due to soil compaction during construction.

Surfacing of drains

Excessive flow velocities can cause scouring of drains, particularly earthen drains. Some suggested maximum flow velocities in earthen channels with various types of vegetative cover are provided in Table 5.

Where soils are easily eroded, values less than those shown should be adopted. However, as flow velocity values of less than 0.5 m/s are likely to result in excessive sedimentation in feedlot catch and main drains, readily erodible soils should either be dressed with non-eroding soils or lined with an erosion resistant material (e.g. compacted gravel, concrete, or masonry).

Table 5. Recommended maximum flow velocities in earthen channels

Soil cover	Flow velocity (m/s)
Couch and similar low growing stoloniferous grasses	1.5
Mid-height, mat forming grasses	1.4
Native and other culmiferous grasses	1.2
Lucerne	1.2
Annual weeds	0.8
Coarse gravel	1.3 – 1.8
Bare, consolidated, stiff sandy clay	1.3 – 1.5
Bare, consolidated, coarse sand	0.5 – 0.7
Bare, consolidated, fine sand	0.2 – 0.5

Drain design – practical issues

Cross-sectional dimensions

The above calculations are important for main drains where a large catchment area is being drained. However, for small sub-sections of the catchment, the required cross-sectional dimensions required to carry the design flow can be small. In these cases, practical issues determine the cross-sectional dimensions of the drain.

For example, where a cattle lane also serves as a drain, the cross-sectional area of the cattle lane is often larger than the theoretical design dimensions for the drain. Similarly, the bed width of drains is often determined by the width of the machinery used to construct and maintain the drain. Most trapezoidal drains cannot have a bed width less than about 4 m, as construction of an earthen drain with a narrower bed width is impractical.

A well-maintained concrete drain within a feedlot. The dimensions of this drain allow access for cleaning equipment.

Surface type

It is generally inadvisable to allow vegetation to grow in either catch or main drains, even though vegetation may resist erosion and thus allow higher design velocities. Vegetation in the drain

- alters the flow characteristics (i.e. impeding flows or increasing the hydraulic pressure and the likelihood of drains overtopping)
- increases manure deposition within the drains
- may be killed in any parts of the drain exposed to extended flows (e.g. during lengthy, low intensity rainfall events).

Where primary drains or diversion banks need to be vegetated, low growing, stoloniferous grasses should be used. Vegetation should be kept short by regular slashing or mowing.

Concrete lined drains can be used in unavoidable steep sections where high velocities would cause erosion. Ideally, a high flow channel lined with concrete or masonry should be used within the vegetated main drain to overcome some of the problems described above.

Upslope diversion drains are usually vegetated or bare earth. They need to provide non-scouring flow velocities. Such diversion drains should be able to safely disperse flows at their discharge points, such that the discharge does not contribute to downslope erosion and does not cause any other significant changes in flow characteristics in stream catchments. This is particularly important where there are other structures (e.g. contour banks, dams, culverts, table drains) nearby and lower in the catchment area.

Gravel based drain

While it is preferable for diversion drains to be vegetated, the growth should be kept short by regular slashing, mowing or grazing to ensure that flow velocities are within design values.

To minimise the risk of groundwater pollution the catch and main drains must be lined with a low permeability clay or other suitable compactable soil or durable synthetic liner. Clay liners should be of sufficient thickness and layered to ensure that their integrity is not compromised. Repair or replacement of the liner may be necessary from time to time due to wear and tear associated with drain cleaning operations. To protect liners during cleaning operations it may be necessary to overlay the liner with a suitably durable material (e.g. compacted gravel).

Cattle lane and catch drain – Option 1. The cattle lane is not fenced allowing free access by drain cleaning and under-fence pushing equipment. However, extra stockmen may be needed to move cattle.

Cattle lane and catch drain – Option 2. Runoff passes through the cattle lane into the catch drain. Manure should not be deposited in the cattle lane and the drain can be easily maintained.

Cattle lane and catch drain – Option 3. The cattle lane and the catch drain are combined, but a control bank on the outside of the cattle lane fence keeps runoff in the lane.

Cattle lane and catch drain – Option 4. The cattle lane and the catch drain are combined.

Cattle lanes versus catch drains

There are a number of options for a cattle lane and catch drain.

Option 1. The cattle lane is not fenced which allows free access by drain cleaning and under-fence pushing equipment. However, moving stock requires stock handling skills or more stockmen.

Option 2. The runoff passes through the cattle lane into a catch drain that is not fenced. Access to the drain for maintenance is unrestricted and manure should not be deposited in the cattle lane. However, this does require a wider easement than Option 3.

Option 3. The cattle lane and the catch drain are combined but with a control bank on the outside of the cattle lane fence that constrains runoff to stay in the lane. This design can pose problems when moving cattle during wet conditions as they can bog up the drain and restrict flow.

Option 4. The cattle lane and the catch drain are combined; pens are located on either side of the catchment drain/cattle lane and no control bank is required.

Figure 5 shows three possible configurations of cattle lane and associated catch drains.

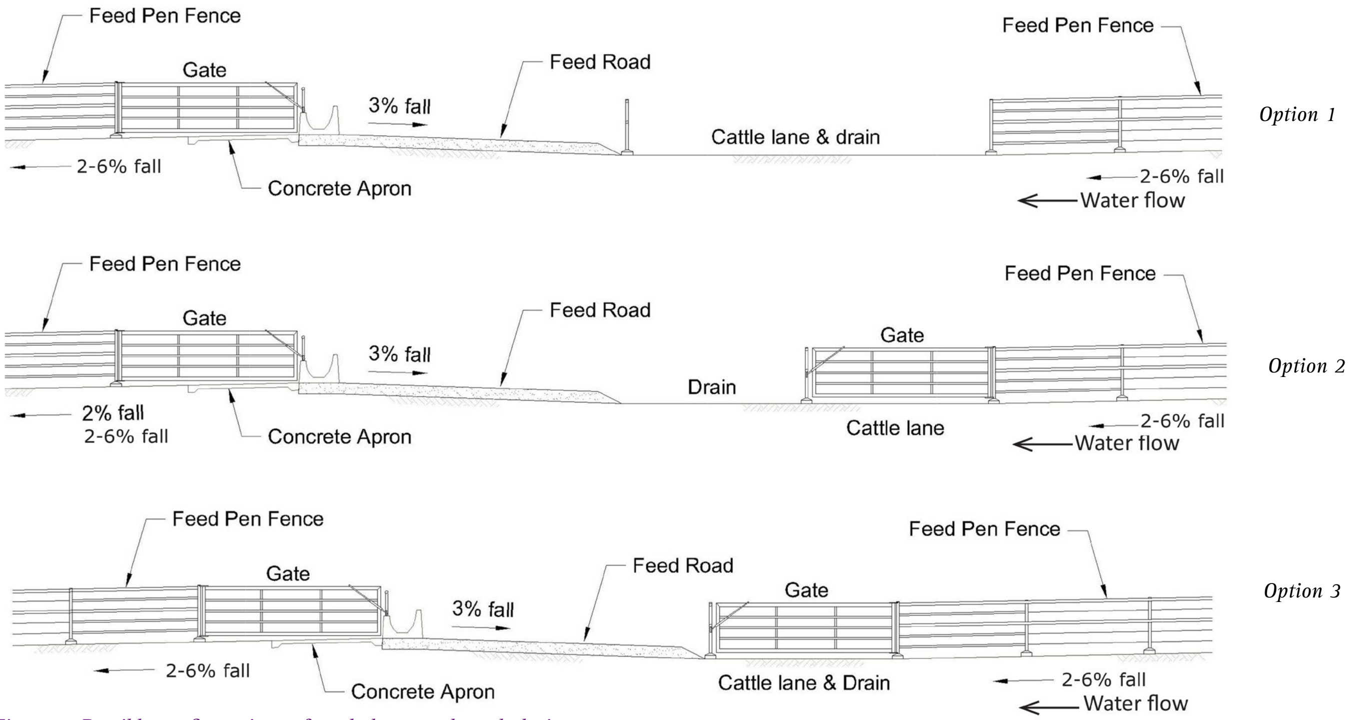


Figure 5. Possible configurations of cattle lanes and catch drains

Culverts and other obstructions

Manure that is entrained in runoff from the pens should remain entrained until it reaches the sedimentation system where settling is expected. Drain obstructions that decrease flow velocity result in the entrained manure being deposited and require unnecessary drain cleaning.

Flow velocity in a drain may be changed by

- culverts (box or pipe)
- changes in grade
- changes in direction
- vegetation

Any possible obstructions need to be designed to maintain flow velocity and prevent manure deposition.

This concrete box culvert allows cleaning of settled manure in the drain on both sides of the culvert.

Grid culvert drain crossing makes it difficult to clean under the grid.

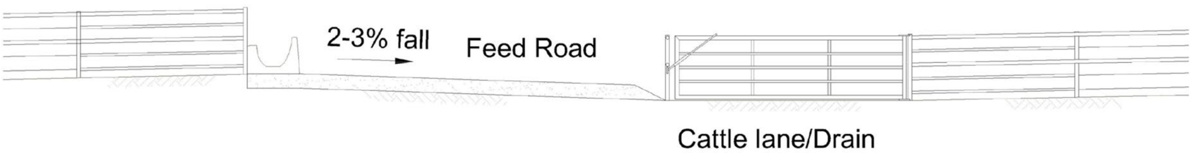
Sediment is deposited when vegetation reduces stormwater flow through culvert.

Drainage of feed roads

Feed roads are part of the catchment within a controlled drainage area. They readily shed rainfall resulting in runoff but this should not be allowed to pond beside the feed bunk. The feed road should be shaped so that runoff drains away from the feed bunk. Figure 6 shows how feed roads should be drained for back to back and sawtooth configurations. *Section 9 – Overall pen layout* provides information on pen layouts.

Figure 6. Cross section of feed roads showing cross-slopes for drainage.

Option 1



Option 2

Drainage of feed roads showing slope towards the centre as in Option 1 of Figure 6.

Feed roads need 2–3% slope for adequate drainage.

Further reading

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