Runoff Control for Livestock Feedlots - State of the Art

Conrad B. Gilbertson, R. Nolan Clark, John C. Nye, Norris P. Swanson
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RUNOFF from open feedlots may transport large quantities of organic matter, polluting public waters and resulting in fishkills (Ifeadi and Lawhon, 1974; Waybrant, 1974). The objective of this paper is to summarize the current state of the art for runoff control from beef, dairy, swine, sheep, and turkey feedlots. Layers and broilers are essentially all produced under housed conditions and thus do not create a runoff control problem. A summary of legal implications of feedlot runoff control, quantity and quality of runoff, runoff control facilities and their applications, and disposal of the controlled runoff are included in this paper.

REGULATORY REQUIREMENTS

Many questions have been raised regarding feedlot pollution and the broad legal implications involved (Nelson, 1975). Feedlot operators, property owners, neighboring residents, and communities in some cases, should be aware of the legal aspects. If feedlot runoff produces adverse consequences, litigation may result.

During the 1960's, feedlots were identified as sources of water pollution by several states. Reported fishkills were sometimes attributed to the uncontrolled feedlot runoff. By the early 1970's, a few states had passed water pollution laws aimed at livestock producers. The requirements varied, but most regulations specifically prohibited discharge of feedlot runoff or livestock manure to any public stream, lake, or pond (Forster, et al., 1975).

In 1972, the 92nd Congress passed PL 92-500, the Federal Water Pollution Control Act Amendments. A national goal of eliminating the discharge of pollutants to waters of the United States was established with the intent that by 1983 all waters would be safe for fishing and swimming. To achieve this goal, a program was introduced to issue permits to all point sources of pollution. Feedlots were included under the industrial category and identified as a point source.

The United States Environmental Protection Agency (US-EPA) was charged with the responsibility of enforcing PL 92-500 (Nye, 1976). Numerous regulations were proposed, and after several legal challenges the National Pollutant Discharge Elimination System (NPDES) permit program was established. The regulation affecting livestock producers was promulgated on March 19, 1976. Three situations require a producer to obtain a permit:

1 A feedlot with a discharge or potential discharge and capacity of 1,000 animal units.*

2 A feedlot with a one time capacity of between 300 and 1,000 animal units that also has: (a) A stream flowing through the lot. (b) A man-made conveyance of runoff to a stream.

3 Any feedlot that is a significant contributor of pollutants as determined on a case by case basis.

Feedlot operators who are within the three definitions must submit a permit application to either the approved state water pollution control agency (in states with an approved NPDES permit program), or to the Regional Office of EPA. The NPDES issuing authority then prepares a preliminary permit which is reviewed by the permittee, the interested State and Federal agencies, and the general public. The intention to issue such a permit is announced in a public notice. The permit is issued for a 5-year period after the public notice period and after any serious problems in permit conditions are resolved.

The permit has several basic elements. The effluent limits are site specific and must comply with a published effluent guideline. The effluent guideline for the feedlot industry was based on a study by Hamilton Standard (Denit, 1975). They concluded that the best practical treatment (BPT), for feedlots was discharge of runoff only after an unusually large storm. This storm had to be large enough to overflow a structure designed to control runoff from a 24-h, 10-yr recurrence interval storm. This BPT level was to be achieved by July 1, 1978. A second level of control, the best available technology (BAT), is to be implemented by July 1, 1983. The BAT level of control requires that the structures be designed to contain the 24-h duration, 25-yr recurrence interval storm runoff.

The greatest problem associated with the NPDES permit program has been the interpretation of the effluent guideline. It is still uncertain exactly what level of management, what dewatering schedule to empty runoff retention ponds, and what monitoring records would be used for enforcement purposes in cases of reported discharge. The US-EPA has stated that the discharge would be investigated and legal action would be taken on a case by case basis (McDowell et al., 1978). Any discharges of pollutants, from either point sources or nonpoint sources, urban or rural, will share in responsibility to achieve the goals of water quality.

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The authors are: CONRAD B. GILBERTSON, Agricultural Engineer, USDA-SEA-AR, Lincoln, NE; R. NOLAN CLARK, Agricultural Engineer, USDA-SEA-AR, Southwest Great Plains Research Center, Bushland, TX; JOHN C. NYE, Agricultural Engineer, Purdue University, West Lafayette, IN; and NORRIS P. SWANSON, USDA-SEA-AR, Lincoln, NE.

*1,000 animal units of livestock is equal to 1,000 beef, 750 mature dairy cows, 2,500 swing over 55 lb., 5,000 sheep, 55,000 turkeys, 100,000 chickens and 5,000 ducks (Nye, 1976).

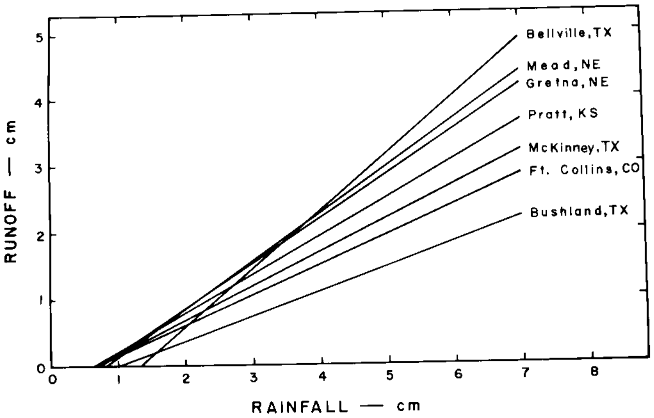

FIG. 1 Rainfall-runoff relationship at several locations in the Great Plains (Clark et al., 1975).

FEEDLOT HYDROLOGY

Controlling runoff from any feedlot site requires a working knowledge of feedlot hydrology. Runoff from both paved and unpaved open lots result from rainfall and snowmelt. The relationship between rainfall and runoff is linear (Fig. 1). The first centimeter of rainfall is retained on the feedlot surface. The slopes of rainfall-runoff equations varied from 0.36 to 0.86 and fluctuated with the antecedent moisture conditions, shape, slope, and type of feedlot.

The Soil Conservation Service (SCS) runoff volume estimating equation (Schwab et al., 1966) has been adapted to predict feedlot runoff volumes. The SCS equation is

$$Q = \frac{(I - 0.2\ S)^2}{(I + 0.8\ S)}$$

where Q = direct runoff;

I = the storm rainfall; and

$$S = \frac{1000}{N} - 10$$

N is an arbitrary curve number varying from 0 to 100

The value of N varies for concrete and unpaved lots. For example, Vanderholm et al. (1979), indicated that N values calculated from measurements made on paved dairy lots ranged from 95 to 99.9. Dickey and Vanderholm (1977) determined an N value of 90 for paved beef cattle feedlots. The N value was smaller because beef cattle feedlots are not cleaned as often as dairy lots, so the volume of runoff is lower. Hauser (1975) found considerable difference between the estimated and actual quantity of runoff measured from the several Texas research sites with unpaved lots. Runoff volume predicted from the SCS equation (N = 90) was 1.8 times higher than the actual runoff reported from the sites. Hauser's recommendation was to use an N value of 82 for Texas unpaved feedlots.

Snowmelt runoff is a component of the total annual runoff which must be considered in areas north of 42°N latitude (Gilbertson et al., 1978). Snowmelt runoff is very different from rainfall-runoff because it depends on the quantity of snow and ice buildup within a lot and the climatological conditions during thaws. Snowmelt becomes important where snowfall exceeds 50 cm. Snowmelt runoff can amount to 30 percent of the annual runoff (Madden and Dornbush, 1971).

The cumulative quantity of annual runoff is greater than that from the design storm used for calculating volumes of holding ponds. About 30 percent of the annual rainfall runs off unpaved lots and 80 percent off paved lots (Gilbertson et al., 1979; Nienaber et al., 1975; Swanson et al., 1975; Butchbaker and Paine, 1975).

Clark et al. (1975) developed a regression curve for predicting annual runoff based on the annual moisture deficit. This approach would be especially useful in arid areas since moisture deficits may be greater than 200 cm.

Very little, if any, information is available in the literature on the quantities of runoff from sheep and turkey feedlots. A curve number of 85 to 87 may be used in the SCS predictive equation for estimating runoff from these lots. Even though sheep and turkey lots are relatively smooth as compared with beef and dairy cattle feedlots, antecedent moisture conditions are generally lower.

RUNOFF QUALITY

Chemical constituents transported in feedlot runoff vary widely (Powers et al., 1975). Several studies have reported trends in runoff constituents as a function of the feedlot hydrology (Kang et al., 1970; Wise, 1972; Koelliker et al., 1975; Gilbertson et al., 1975; Clark, 1975; Swanson, 1972). The wide range of transported material reported in published values is due to the type of ration fed, type of feedlot surface (paved or unpaved), climatological conditions, antecedent moisture conditions, and storm intensities and duration. Feedlot slope does not have a significant affect on material transport (Gilbertson et al., 1975). The impact of each of the many variables on chemical constituents transported in runoff has not been isolated, but there are definite interactions. The most important variables are the antecedent moisture conditions and the type of runoff-snowmelt or rainfall. An extremely dry and powdery feedlot surface may have a low initial water intake. Keeton et al. (1970) reported that runoff from a relatively dry mass produced channeling resulting in transport of quantities of suspended pollutants. On the other hand a relatively rough feedlot surface will retain pockets of water, reducing runoff and the chance that channelized flow will occur. The storm intensity and duration, however, are still the dominating factors.

Snowmelt runoff can occur as a lava-type flow. The solids content can be as high as 20 percent; however, this type of flow usually occurs only in areas north of 42°N latitude and in areas with 50 cm or more snowfall.

In most cases, the quantity of solids transported in runoff annually does not exceed 10 percent of the quantity of manure voided by the animals. Total solids transported annually in feedlot runoff from unpaved feedlots may be estimated by assuming a total solids concentration of 1.5 percent for beef cattle and 0.75 percent for swine, sheep, and turkeys (Gilbertson et al., 1979). For paved lots, best usable values for total solids concentration in runoff are 3.5 percent for beef and dairy cattle and sheep, and 7 percent for swine feedlot runoff. Because paved lots are not recommended for turkeys, estimates were not given.

Chemical constituents transported in feedlot runoff

TABLE 1. SOME SELECTED CHEMICAL CONSTITUENTS IN UNPAVED BEEF CATTLE FEEDLOT RUNOFF IN THE GREAT PLAINS

Runoff type and location	Total solids	Volatile solids	Total N	Total P	K	Na	pH	Electrical conductivity	Chemical oxygen demand
	Runoff constituent								
	------ % ------		------------ ppm ------------					mmhos/cm	ppm
Snowmelt									
Nebraska†									
Low	0.8	0.6	190	5	—	—	4.1	3	14,100
High	21.8	14.3	6,528	917	—	—	9	19	77,100
Rainfall									
Nebraska†									
Low	0.24	0.12	11	4	50	90	4.8	0.9	1,300
High	3.3	1.5	3,593	5,200	8,250	2.750	9.4	5.3	8,200
Texas*									
Low	0.5	0.9	600	130	900	400	—	6	10,000
High	1.50	1.40	1,100	200	1,600	1,100	—	10	20,000
Kansas‡									
Low	0.84	0.36	165	9	42	63	—	2	800
High	1.92	0.96	1,580	242	1,983	1,597	—	13	16,000

*Clark et al., 1975
†Gilbertson et al., 1975
‡Manges, 1971

can be estimated as a function of the total solids transported. Although more variable than total solids transported, values for the quantity of elements transported may be estimated by assigning coefficients to them (Overcash et al., 1975; Converse et al., 1975; Nienaber et al., 1975; Swanson, 1972; Edwards and McGuinness, 1975; Power et al., 1975). Expressed as a percent of the manure voided, the maximum quantities of N, P, and K transported annually from a dairy and beef feedlot are about 10, 20, and 50 percent, respectively, and 5, 10, and 25 percent, respectively, for swine, sheep, and turkey lots. For elements such as Fe, Zn, Mn, Ca, Na, Mg, and Cu, it can be assumed that 100 percent of the elements voided in the manure may be transported from beef and dairy lots, whereas 50 percent of those elements voided may be transported from swine and turkey lots. Although amounts of these elements in runoff are sometimes more than 100 percent of the manure elements voided, this can be explained by the addition of soil, bedding, or other debris mixed with manure by normal animal movement. These materials contain more elements than the voided manure itself. Some ranges in selected chemical constituents transported in feedlot runoff are shown in Table 1.

RUNOFF CONTROL FACILITIES

Runoff from feedlots can be controlled by combinations of the following steps (Nye and Sutton, 1976; Pittman, 1971; Ifeadi and Lawhon, 1974; Nienaber et al., 1975; Sewell, 1975; Klocke, 1976; White, 1975; Swanson et al., 1975):

1 Diverting runoff from outside the feedlot area.
2 Providing proper feedlot drainage.
3 Using debris basins (settling basins).
4 Using detention or holding ponds.
5 Providing proper techniques for land application.

In many cases, diverting outside surface water from the lot can comprise the runoff control system. An upstream dam or protective dikes along the side of the stream are often required since some feedlots are on the sloping land adjacent to an intermittent stream.

Providing proper drainage of the feedlot surface is of primary importance. Each pen should have an independent drainage system. Feedlot slope does not effectively change the volume of water that runs off a feedlot surface (Gilbertson et al., 1975), but steeper slopes may increase solids transport. Adequate slopes for feedlots are between 3 and 10 percent. Mounding the manure within the feedlot is recommended, especially if the feedlot slope is less than 3 percent. Good drainage may be provided by allowing 2.8 m^2 area per animal for the mound design. The height of the mound should not exceed 1.5 m and should be oriented perpendicular to the feedbunk to provide adequate drainage.

Debris basins are recommended for all feedlot runoff control systems. Debris basins remove up to 75 percent of the total solids transported in a runoff event (Moore et al., 1975; Gilbertson et al., 1975; Nye et al., 1974; Swanson and Mielke, 1973). The debris basins remove about 40 percent of the total solids transported in runoff within 30 min and 50 percent or more within 1 to 2 hr of detention. Small particles (less than 2 μm) transported are slow to settle; thus, the quantity of settled solids is somewhat site specific. Reducing the transported solids in the runoff reduces odors from the detention pond, increases the life of the detention pond, and make the runoff easier to pump through irrigation systems. The debris basin, however, must be well managed. For satisfactory performance, it may be located within or outside the feedlot area (Butchbaker and Paine, 1975; Swanson et al., 1973). The location of the debris basin depends somewhat on the layout of the particular feedlot and to some extent on the climate of the area. If snowmelt runoff is a primary factor, basins inside the lot are most efficient. Normally, the maximum depth within the debris basin is 1.3 m. Solids should be removed from the debris basin before they accumulate to 0.3 m depth within the basin. If a deep debris basin more than 1.3 m deep must be installed, a concrete ramp should be placed within the basin to allow access with conventional front-end loading farm tractors.

The volume of the debris basin must allow for the accumulation of settled solids, short term storage of runoff, and a freeboard volume (Linderman et al., 1974). The cumulative settled solids volume should be designed for semiannual or annual accumulation. The short term runoff volume should handle the largest 24-h recurrence interval storm for that area. The freeboard volume is determined by adding a 0.2 m berm to the existing volume.

Detention ponds or holding ponds should be designed for temporary storage of runoff. Under normal circumstances these ponds should not be designed as a waste treatment facility, such as anaerobic lagoon or oxidation pond (McGhee et al., 1976). The ponds should be emptied after each runoff event. The EPA regulations require a detention capacity for a 24-h duration, 25-yr recurrence interval storm.

The expected runoff volume may be approximated by use of the SCS runoff equation (Schwab et al., 1966). Antecedent moisture condition III, Soil Group D, and curve number 90, may be used to estimate unpaved feedlot runoff volume. A curve number of 94 to 96 should be used for paved lot runoff volume (Wise, 1972).

A combination debris basin and holding pond has been acceptable where not enough space is available to provide area for a debris basin and a separate holding pond. The volume of a combination debris basin holding pond must be at least 125 percent of the 24-h, 25-yr recurrence interval storm (Nebraska Department of Environmental Control, 1977).

Several methods are acceptable for disposal of the runoff detention pond liquid and the settled solids that accumulate iin the debris basin. The method depends on the size of the unit and the regional location. In areas where the annual evaporation exceeds the annual precipitation by 50 cm or more, it may be advantageous to install an evaporation pond. However, if irrigation equipment is available, then using the holding pond effluent on cropland as a fertilizer supplement is advisable (Hinrichs et al., 1974).

Field sinks, vegetative filters, or switchback (serpentine) waterways are popular disposal methods for liquids if the topography permits and the operation is not overly large (Swanson et al., 1975; Dickey and Vanderholm, 1977). Field sinks, switchback waterways, and vegetative filters allow direct land disposal of the effluent by gravity flow from the debris basin, eliminating the need for a holding pond and pumping equipment. The area of the field sink or waterway is normally not more than twice that of the feedlot. Such installations have been used for dairy, beef, and swine operations (Nebraska Department of Environmental Control, 1977; Vanderholm et al., 1979; Dickey and Vanderholm, 1977).

Pumping the effluent from the holding pond to cropland is another method of disposal. Tank transport systems are not recommended because the volume of runoff results in high labor and application costs. Operator dependance on feedlot runoff as a source of irrigation water is not recommended. Normally, fields are wet when water is available and holding ponds are empty during dry periods. The land area required for disposal of holding pond effluent depends on the nutrient needs and water use of crops, the holding capacity of the soil, application rates, the amount and characteristics of the runoff, and state laws or regulations. Because runoff can be classified as low-nutrient level fertilizer, economics may dictate the use of a small disposal area seeded to grass or other high-water and nutrient use crops. The minimum land area required is about a 1:1 ratio of feedlot runoff area to land disposal area (Nienaber et al., 1974; Butchbaker and Paine, 1975).

DISCUSSION

Maintenance of runoff control facilities is a prerequisite to satisfactory operation and pollution control. If solids removed and dewatering are neglected, the debris basin and holding ponds will produce odors and create nuisance problems. The groundwater level is a consideration in the area where the settling basin, holding pond, and disposal area are to be located. There are no set guidelines for the distance from the bottom of a basin or holding pond to a potable water table. A large area would not likely be affected by nutrients leaching into a water table from a holding pond or a debris basin; however, the local water would be suspect. Ponds may be sealed with an approved sealant, such as plastic or rubber, or with material such as clay and bentonite. It has also been found that manure will seal ponds (Davis et al., 1973; Baier et al., 1974; Osterberg, 1972; Meyer et al., 1972; Clark, 1975). However, local regulatory agencies should be consulted before use of any of these materials. It is doubtful that problems will arise on the disposal area provided the nitrogen uptake of the crop prevents buildup of nitrogen in the soil profile. Therefore, the land disposal area should be designed based on the type of crop, soil conditions, and the quantity and quality of the runoff applied. Salinity problems can develop in areas of low rainfall and must be considered in the design and operation of the facility. Dilution water is recommended to prevent salinity problems when disposing of holding pond liquids in low rainfall areas.

SUMMARY

The Federal Water Pollution Control Act Amendments of 1972 established a goal to eliminate pollutant discharges into the nation's waterways by 1983. Enough information is available to design and control runoff from feedlot surfaces and to dispose of this controlled runoff without further pollution problems. Considerations in runoff control from a feedlot surface include diverting outside runoff, establishing good drainage on the feedlot area, and providing a settling or debris basin to remove settleable solids transported, a detention or holding pond for temporary storage of the runoff, and a disposal area. The minimum design volume for runoff control structures is the 24-h duration, 25-yr recurrence interval storm. The SCS rainfall runoff equation may be used for estimating the quantity of runoff for the design storm. A SCS soil cover complex curve number of 90 should be used for unpaved beef, dairy, swine, and sheep lots, whereas a curve number of 85 should be used for turkey lots. For paved lots, a curve number of 95 should be used.

The detention pond is required for temporary storage of runoff; it is not designed as a waste treatment facility. The minimum volume depends on the maintenance—however, pumping the holding pond after each runoff event is recommended.

The controlled runoff may be disposed of in several ways. The most common method is applying it to the land — either by gravity flow through a serpentine waterway, field sinks, or vegetative filter, or by pumping to

cropland. Normally the land area required is a minimum of 1:1 ratio of feedlot area to field disposal area. In areas where the annual evaporation exceeds rainfall by 50 cm, evaporation holding ponds may be used for control and disposal.

Each state has developed regulations by interpreting the 1972 Water Pollution Control Act Amendments. Although the rainfall runoff relationships are fairly well documented, it is doubtful that a consistent design will be applicable to all states. Local regulatory agencies should be contacted to confirm the design of any runoff control and disposal systems before construction and operation.

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