

HYDROLOGIC AND WATER QUALITY CHARACTERISTICS
OF BEEF FEEDLOT RUNOFF

by 6408

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B. S., Kansas State University, 1970

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

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INTRODUCTION

The cattle industry has become a major contributor of agricultural pollutants in the state of Kansas. For many years cattle have been produced on the farm in relatively small concentrations. This production method has not contributed a significant amount of pollution since wastes have traditionally been applied to surrounding cropland with minimal cost.

The more recent concept of cattle production is that of the feedlot operation. Feedlot numbers and size have increased rapidly in Kansas during the last fifteen years. A particularly rapid increase is that of the commercial feedlot, which is defined as those operations with the capacity to feed 1000 cattle or more at any one time. Table 1 shows the number of commercial feedlots and the total cattle being fed at those feedlots over the last fifteen years.

TABLE 1
GROWTH OF COMMERCIAL FEEDLOTS IN KANSAS

Date	Number of Commercial Feedlots	Number of Cattle on Feed	Reference
1956	7	21,000	(45)
1964	58	144,000	(46)
1966	88	260,000	(46)
1967	--	311,000	(41)
1969	--	486,000	(42)
1970	234	606,000	(43), (42)

Kansas State Board of Health regulations issued May 31, 1967, require all existing confined feeding operations with a water pollution potential or a capacity to feed 300 head or more at any one time to register with the Department of Health. Operators of existing facilities were to register by January 1, 1968. Any new or proposed operations must also register. Table 2 shows the size and quantity of cattle feedlot facilities registered as of July 2, 1970 (43).

TABLE 2
CATTLE FEEDLOTS REGISTERED AS OF JULY 2, 1970

Feedlot Capacity at Any One Time	Number of Feedlots
0 - 999	386
1000 - 4999	172
5000 - 9999	28
10000 - over	34
Total	620

On January 1, 1970, the lots with capacities below 1000 were feeding 286,000 cattle as compared with 606,000 cattle on feed in commercial lots. During 1969, the number of grain-fed cattle marketed for slaughter totaled 1.7 million. Commercial feedlots with capacities above 10,000 accounted for 2/3 of the grain-fed cattle marketed for slaughter (42). At the 1969 market volume of 1.7 million, and considering that 2/3 of the volume came from lots with over 10,000 head capacity, the average output per lot was over 33,000 head per year. With such large concentrations of cattle a large water pollution potential exists. Whether or not pollution actually occurs is dependent upon management practices and the physical considerations of the feedlot.

Both ground water and surface waters are subject to quality deterioration from feedlot wastes. This study will primarily be limited to investigation of those factors which may affect the quality of the surface waters. Thus, the study will concentrate on characterization of runoff volume and pollutant concentrations.

PURPOSE OF STUDY

The purpose of this study was as follows:

1. To determine the runoff quantity and variation of various pollution parameters resulting from natural rainfall on a commercial cattle feedlot.
2. To evaluate methods for predicting runoff quantity, rate, and pollutant concentrations.
3. To develop and evaluate equations for estimating hydrologic and water quality characteristics of runoff from a beef feedlot.

REVIEW OF LITERATURE

Hydrologic Considerations

The hydrologic characteristics that are of importance in evaluation of feedlot pollution concern those factors affecting runoff volume and flow rates. Runoff volume information is necessary for design of detention ponds or lagoons and for determination of the amount of polluted water which must be treated and/or disposed of. Maximum flow rate estimates are essential criteria for design of runoff conveyance channels.

Runoff Volume

The factors affecting runoff are those associated with the storm characteristics and those associated with the watershed (11). Storm characteristics affecting runoff include intensity, duration, and total precipitation. Copley et al. (5) studied the relationship of runoff to rainfall intensity and total rainfall per storm. The results of the study revealed an increasing proportion of runoff to rain as the intensity and the total precipitation per storm increased.

Storm duration affects runoff volume in that infiltration to the soil or feedlot surface may decrease with time in the initial stages of a storm. Therefore, a storm of short duration may produce no runoff, whereas a storm of equal intensity but of greater duration may result in runoff (11).

In general, watershed factors affecting runoff are soil, size of drainage area, plant cover, and management practices (6). Specifically applied to feedlots, the main watershed consideration involves water infiltration or detention on the lot surface due to minor depressions. Swanson et al. (13)

stated, "Infiltration on an established beef feedlot appears to be restricted to water storage in the manure pack, with very limited water movement through the profile." Norton and Hanson (12) reported infiltration to the ground water is so small that it can be neglected when determining the total runoff from cattle feedlots. Norton and Hanson go on to state that manure was observed to be a dry hard crust, two to four inches below the surface of the feedlot, after the runoff had ended. Theoretically, if the infiltration capacity of the feedlot surface were known, the volume of runoff resulting from a given storm could be computed by subtracting infiltration and depression storage from total rainfall (7). The reduced infiltration capacity of the feedlot surface results in greater runoff volume. Swanson et al. (13) found annual runoff from a beef feedlot may be two or three times that of adjacent cropland.

Runoff volume from feedlots has been studied by several investigators (1,4,13,18,19,21). Bergsrud (4) applied the Soil Conservation Service (SCS) method of runoff prediction to feedlot surfaces. The SCS method expresses watershed factors in terms of a hydrologic soil cover complex number (10). This number is commonly referred to as the runoff curve number, CN. A CN is calculated for a given watershed by determining soil types, land use, treatment or practice, and hydrologic condition. Corrections may be applied to the CN for differing antecedent moisture conditions. Once this information is obtained, reference is made to tables to arrive at a CN (10,11,2).

Bergsrud (4), in determining a CN for feedlots, used fallow land use, hydrologic soil group C for dirt surfaces and D for concrete surfaces, and average antecedent moisture conditions. The corresponding runoff curve numbers were 91 for unsurfaced lots and 94 for surfaced lots. These values were the same as Miner determined by selecting the CN which best fit his data (1).

Once the CN has been determined, runoff from a particular storm may be calculated by equation or from charts. Figure 1 is the graphical representation of the SCS runoff equation. Bergsrud used thirty years of precipitation data from twelve stations across Kansas to determine the total and temporal distribution of cattle feedlot runoff for each station from the SCS runoff equation. With this information he was able to plot cumulative runoff versus time for a given percent chance occurrence. His calculations were limited to unsurfaced feedlots since the majority of lots in Kansas are unsurfaced except for feeding and watering areas. Partial results of the study are shown in PLATES I-III.

A regression equation for calculating runoff was determined from one and a half years of study in Nebraska (14). The resulting equation with a correlation coefficient, r , of 0.931 was:

$$R = +.694P - 0.201 \quad (1)$$

where R = runoff, inches

P = rainfall, inches

The drainage area was about 1.6 acres with a stocking rate of approximately 250 sq. ft. per animal and a slope of about 6 percent. A sandy soil was underlying the lots. The correlation coefficient, squared, indicates that 86.6 percent of the variation in runoff was explained by consideration of the variation in precipitation amounts. Runoff resulting from winter thaw amounted to 70 percent of the accumulated precipitation for that period.

Another study in Nebraska was undertaken to determine the effect of animal density and surface slope on characteristics of runoff, and other factors, from unpaved beef feedlots (21). Runoff versus rainfall regression equations were determined for slopes of 3, 6, and 9 percent with stocking rates of 100 and 200 sq. ft. per head. Gilbertson et al. (21) go on to state :

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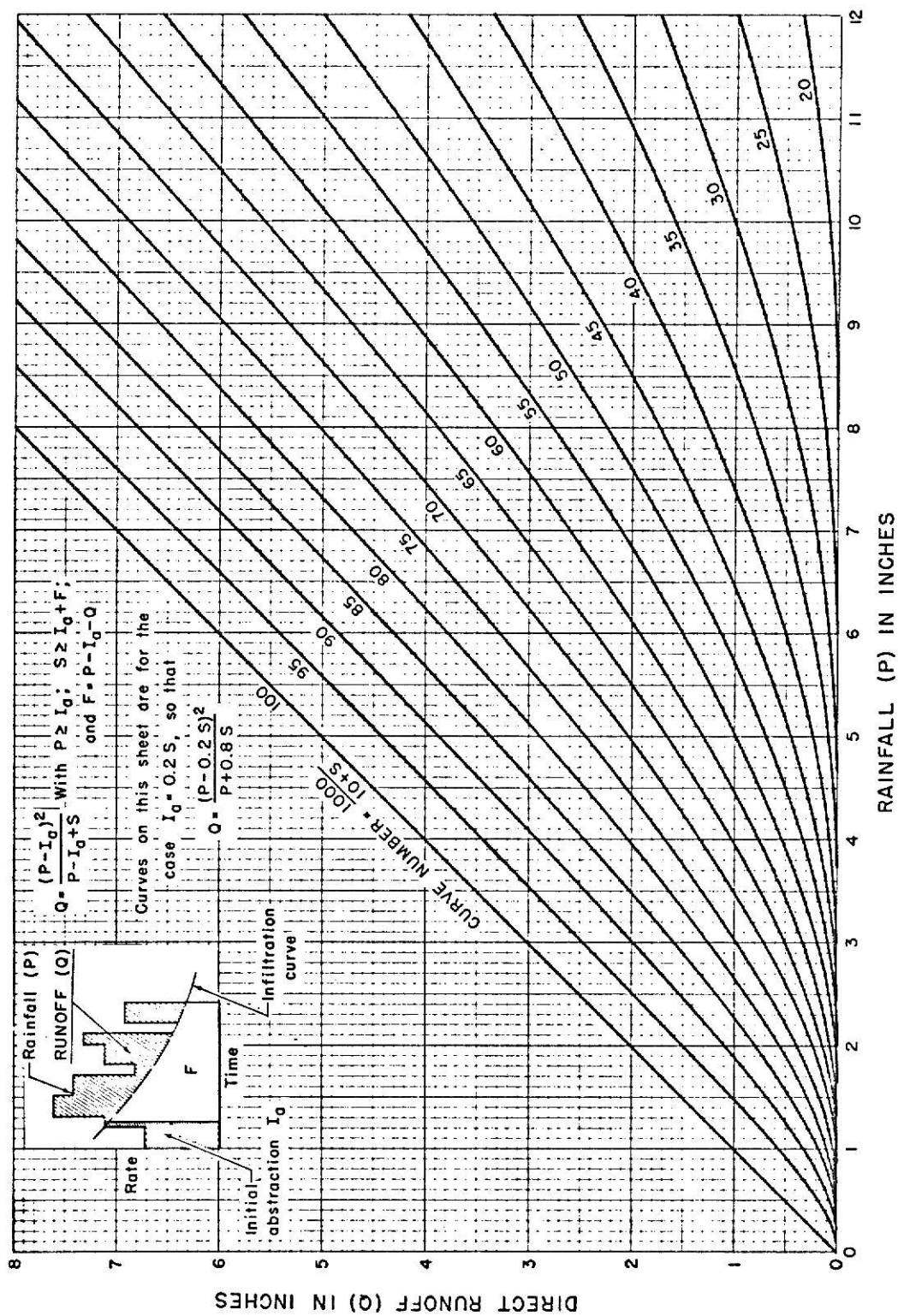


Fig. 1.--Graphical solution of the SCS runoff equation. (From SCS Handbook, 10)

PLATE I

NORMAL ANNUAL PRECIPITATION IN INCHES (AFTER BERGRUD, 4).

PLATE II

NORMAL ANNUAL FEEDLOT RUNOFF IN INCHES, BASED ON AN SCS CN
OF 91 (AFTER BERGRUD, 4).

PLATE III

EIGHTY PERCENT CHANCE OCCURRENCE FEEDLOT RUNOFF IN INCHES,
BASED ON AN SCS CN OF 91 (AFTER BERGRUD, 4)

PLATE I

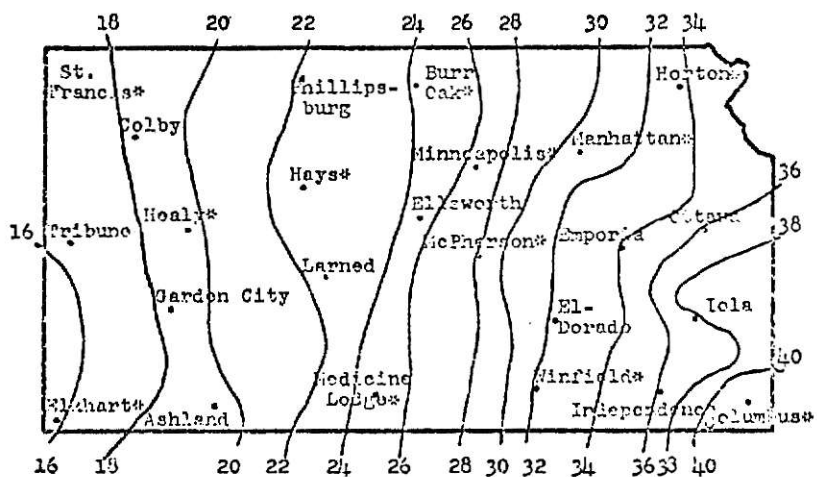


PLATE II

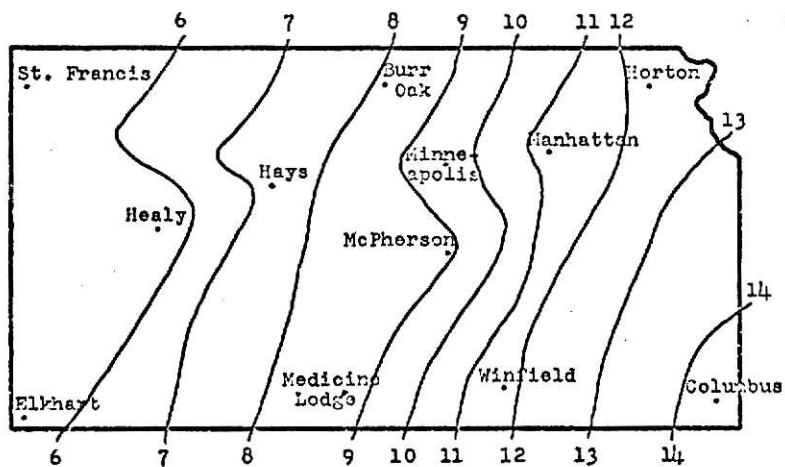
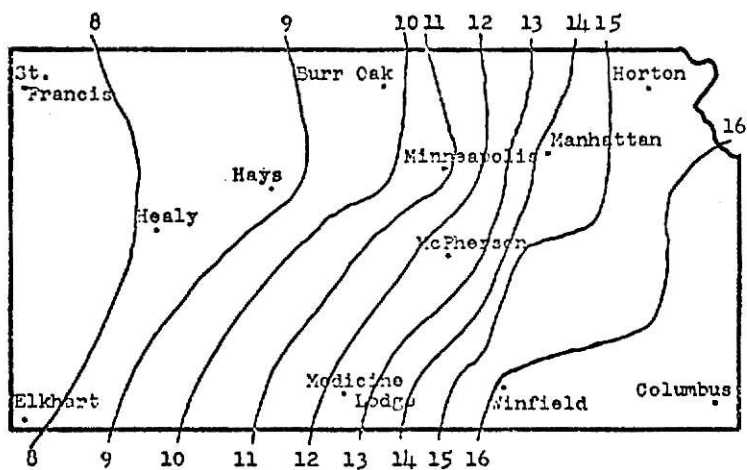


PLATE III



. . . Net differences in runoff, as affected by feedlot slope and cattle density, was not apparent for rainfall accumulations.

. . . An estimating equation computed from data for all treatments was $R = .531P - .135$, $[r = 0.814]$. . .

Runoff resulting from winter thawing conditions indicates high density lots (100 sq. ft. per head) yielded 130 to 170% greater runoff quantities than low density (200 sq. ft. per head) lots. High density lots yielded runoff averaging 81% of the precipitation in the form of snow. Low density lots yielded an average of 54% of rainfall equivalent snowfall. Feedlot slope did not appear to affect the quantity of runoff from snowmelt.

Norton (19) reported that he found no significant increase in runoff from rainfall due to higher cattle densities. However, his studies were limited to summer conditions and for this reason he could not have detected what Gilbertson et al. found regarding increased runoff, due to higher cattle densities, from snowmelt.

Storage Volume Requirements

Dague et al. (18) proposed a method to determine storage volume necessary to store feedlot runoff. The proposal involved plotting precipitation (assuming 100 percent runoff) versus time throughout the year, which was referred to as a mass inflow curve. A mass outflow curve would then be plotted on the same graph to represent application of the runoff to land or introduction to a stream or both. The storage volume required could then be determined from the curve as Dague et al. demonstrated for controlled release to land, Fig. 2. (18). The apparent advantages of this method for determining volume requirements are as follows:

1. If a limited area exists for runoff application, storage volume can be balanced with application rate.
2. If a storage reservoir is already provided, the required land mass may be determined for the desired application rate.

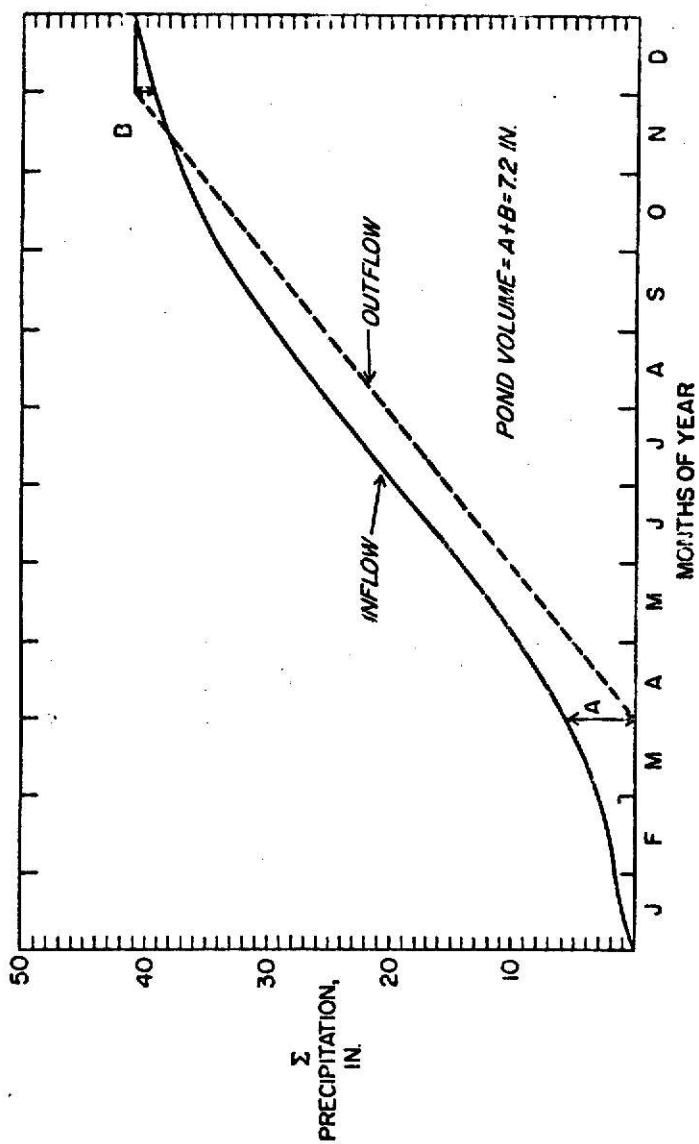


Fig. 2.--Pond storage volume requirements with controlled release to land.
(after Dague, 18)

3. The method permits balancing of land available for runoff applications with application rates, stream discharge rates, and storage volume requirements.

The method of determining storage volume requirements may possibly be improved by using a temporal distribution of cumulative runoff in place of cumulative precipitation as the inflow mass curve. Use of a runoff inflow mass curve instead of a precipitation inflow mass curve would result in a smaller storage structure design. However, the increased cost of building a larger structure may be more economical than future costs of removing accumulated solids from the basin of a smaller sized structure. Hence, management efforts to reduce solids accumulation will need to be considered. Also, a decision must be made as to what percent chance rainfall or runoff accumulation curve will be used. This decision must be weighed against potential damages from overflow versus increased construction costs of the storage structure.

Runoff Flow Rate

Schwab et al. (11) have listed several methods of predicting runoff rates which are applicable to small agricultural watersheds. Cook's method and the rational method will be briefly discussed.

Cook's method. The method developed by Cook (50) for runoff rate estimation uses an empirical relationship between drainage area and peak flow. Watershed characteristics and geographical variations are accounted for in the method. Peak flow is calculated by the following equation:

$$q = PRF \tag{2}$$

where q = peak discharge in CFS

P = peak runoff for a 10-year frequency

R = climatic factor

F = return period factor

Values are obtained for P, R, and F from empirical curves and tables (2,11).

Rational method. The rational formula is:

$$q = CIA \quad (3)$$

where q = peak discharge in CFS

C = a runoff coefficient

I = rainfall intensity in inches
per hour for a duration equal
to the time of concentration
of the watershed

A = drainage area in acres

One acre-inch per hour is equal to 1.008 CFS, hence, the equation is commonly assumed to give peak flow in CFS. Linsley and Franzini (7) noted this method is widely used for estimating design flows for structures conveying runoff from small areas. The above qualification of use on small areas is important because of the assumptions involved in this method (see Appendix I for a listing of the assumptions). Linsley and Franzini mentioned the formula should be used with caution for areas over 100 acres and probably should never be used for areas in excess of 1200 acres.

Ward (22) stated the rational equation could only possibly apply to very small areas and even then the coefficient C ignores the fact that the main determinant of runoff is the continuous changing relationship between rainfall intensity and infiltration. In an attempt to improve results, Gregory (23) derived a formula for the runoff coefficient for impervious surfaces. His equation is:

$$C = 0.175 t^{1/3} \quad (4)$$

where C = a corrected runoff coefficient
for a given duration t

t = duration of rainfall in minutes

One would expect this type of correction to improve results, however, for specific application to feedlots it would probably be necessary to arrive at a correction equation derived from feedlot runoff data.

The design return period for the rational method is inherent in the choice of the value for intensity. Before design intensity can be determined the time of concentration of the feedlot must first be estimated. Theoretically, maximum runoff occurs immediately following the portion of the storm that the most rain falls for a period equal to the time of concentration (24). The rationale is that for a duration less than the time of concentration the entire watershed will not be contributing simultaneously at the outlet, and for a duration greater than the time of concentration one would expect a lower intensity as supported by the U.S. Weather Bureau Technical Paper No. 40 (28).

Several methods are available for estimation of the time of concentration. Some of these will be discussed in a later section.

Once the time of concentration of the feedlot has been determined, curves developed by the Weather Bureau can be used to determine the design intensity for the desired return period. The Rainfall Intensity-Duration-Frequency curves are available for first order weather stations, e.g. Fig. 3.

Water Quality Considerations

Description of Pollution Indicators

Prior to discussion of the results of current research related to beef feedlots, one should be familiar with the significance of various pollution indicators.

Biochemical oxygen demand (BOD). BOD is defined as the amount of oxygen

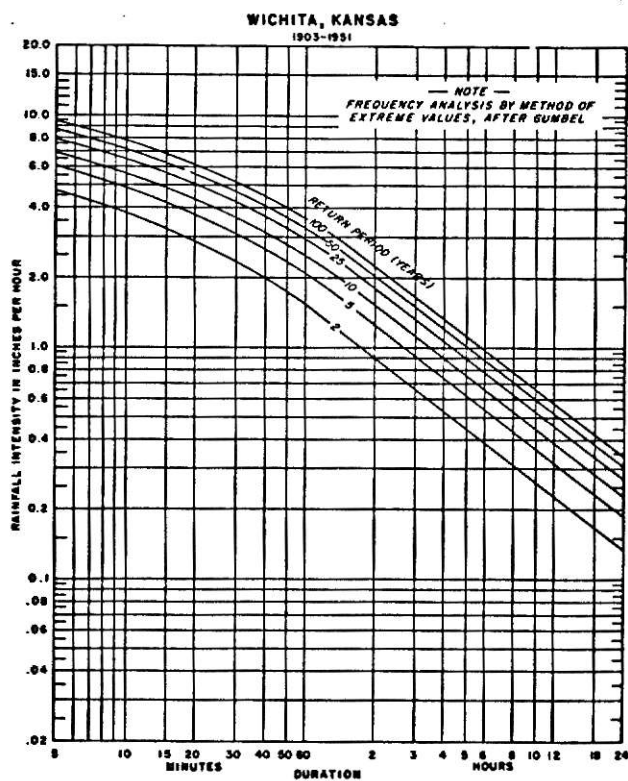


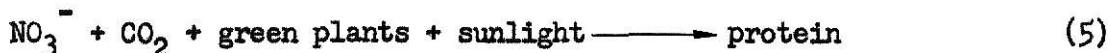
Fig. 3.--A rainfall intensity-duration-frequency curve for Wichita, Kansas. (From Weather Bureau Tech. Paper No. 25, 26)

required by bacteria while stabilizing decomposable organic matter under aerobic conditions. The term "decomposable" indicates the organic matter can serve as food for the bacteria, and energy is derived from its oxidation. BOD is used to measure the pollutorial strength of wastes in terms of the amount of the oxygen required by bacteria to stabilize the decomposable organic portion of the waste material. The BOD measurement must be associated with some time interval to be meaningful. Current practice is to report BOD in terms of a five-day incubation period or as ultimate or total BOD which is generally considered around a twenty-day incubation period. However, waste variations and other factors may affect BOD values (20).

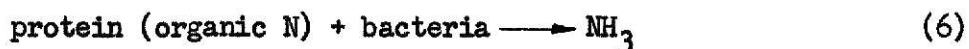
Chemical oxygen demand (COD). COD is a measure of the total oxygen required to oxidize the organic content of a waste material to CO_2 and water. The test is based on the fact that most organic compounds can be oxidized by the action of strong oxidizing agents under acid conditions. A chief limitation of the COD test is its failure to differentiate between biologically oxidizable and biologically inert organic matter. The BOD test is a measure of the biologically oxidizable organic content of a waste. A disadvantage of the BOD test is the time required for measurement, five days. COD can be determined in about three hours. Once the relationship of COD to BOD is established for a particular waste, the COD test can be substituted for the BOD test. A simple ratio, COD/BOD, is the common method of correlating the two measurements (20).

Nitrogen. Nitrogen may be classified as either organic or inorganic. The organic N can be utilized by humans and animals in a protein compound. The inorganic N cannot be utilized by either humans or animals. Plants utilize inorganic N in the form of nitrates. The nitrates are then converted

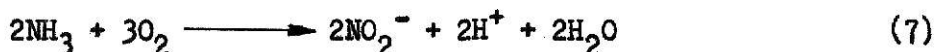
to protein:



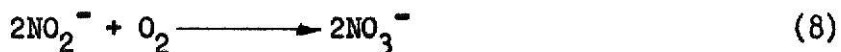
Consequently, humans and animals must obtain N in the form of protein from plants or from animals which have eaten plants. In turn, organic nitrogen compounds are released in the waste products of humans and animals. Herein lies the origin of nitrogen pollutants from the beef feedlot. The organic nitrogen on the feedlot is then converted to ammonia by the action of bacteria:



If oxygen is available, the ammonia may then be converted to nitrites by nitrite forming bacteria:



The nitrites are then oxidized to nitrates by nitrate forming bacteria:



The knowledge of the preceding reactions is the basis for understanding the discussion to follow in a later section.

Phosphorous. Nitrogen and phosphorous are essential elements for the growth of algae. Algal blooms occur when both of these elements are available (20). A variety of nuisance conditions may result from an algal bloom. Conditions which may result include excessive oxygen depletion and degradation of desired aquatic life, and oils produced may cause problems of taste and odor to downstream water users (34).

Solids. The quantities of solids transported by runoff water is measured by total solids (15). Total solids is a measure of suspended solids and dissolved solids without differentiation between organic and inorganic material. Volatile solids is a measure of the organic portion of total solids. It is often expressed as a percentage of the total solids. The loss

in weight of total solids after ignition at 600° C is considered the volatile portion.

Biological indicators. "The microorganisms which exist in any body of water are direct indicators of the condition of that water."(36) Coliform and fecal coliform organisms are used as an index of water-borne disease hazard. "Fecal coliform organisms are more indicative of pollution from humans and animals."(37) The fecal coliform organism is the prime biological pollution indicator to be discussed subsequently.

Research Results on Feedlot Runoff Pollution

Seasonal effects. Miner (1) found runoff to be more heavily polluted during warm weather, low intensity rainfall, and when the lots were already wet prior to the runoff producing storm. He reported runoff from concrete surfaced lots was approximately twice as heavily polluted as that from non-surfaced lots. Higher intensity rainfall causes runoff to start more quickly and carries less organic waste. This reduction in pollution load is related to the reduced contact time between the water and solids in the lot. As higher intensity rainfall continues, channeling occurs in the feedlot with a subsequent greater reduction in pollution load carried by the runoff (15).

Miner et al. (15) reported that due to increased solubilities with temperature, one should expect higher runoff concentration during warm weather as opposed to cold weather. Gilbertson et al. (21) reported concentration of winter runoff (snowmelt) was about ten times greater than general rainstorm runoff. Apparently, a contradiction exists between the results from the two studies.

Gilbertson et al. (21) were studying natural runoff from both rain and

snowmelt. The high winter concentrations were attributed to the soil being near saturation from heavier than normal fall rains and a temperature average for the winter period which was 7.6° F below normal. The low temperatures produced ice accumulations and reduced biological activity. Hence, winter runoff probably transported feces in the excreted condition.

Miner (15) was primarily studying runoff which occurred from simulated rainfall. He did not measure runoff concentrations resulting from snowmelt. Therefore, his results did not reflect factors which evidently are significant during winter runoff.

Swanson et al. (13) stated that even though increased runoff occurs from a feedlot surface as compared to adjacent cropland, the manure pack serves as a protective mulch to keep erosion losses below that of the cropland. They pointed out that the last statement may not be valid when rain falls on a frozen ice and snowpacked feedlot surface which will permit ready movement of organic materials on the surface.

In another article Gilbertson et al. (14) reported that solids transported during the winter thaw averaged about 10 tons per acre-inch, while rainfall runoff transported an average of 1.6 tons per acre-inch. Volatile solids accounted for about 50 percent of solids transported. Winter runoff material contained settleable solids up to 435 ml/l, while settleable solids from rainfall runoff material ranged from 5 to 40 ml/l. The settleable solids were determined after a one hour detention time in Imhoff cones. After ponding and subsequent sampling of runoff material they concluded that settleable solids in fresh runoff can contain up to 80 percent of the original COD in runoff.

The idea of increased runoff concentrations with increased temperature due to greater solubility is applicable to considerations involving dissolved

solids. However, the aforementioned studies (13,14,21) indicate that the increase of suspended solids due to winter runoff is more significant than the reduction of dissolved solids due to decreased temperatures. The increased contact time of snowmelt with the feedlot litter may be another reason for increased runoff concentrations resulting from winter runoff. Another consideration is the reduction in biological activity resulting from colder temperatures (21). One would expect a corresponding hindrance in BOD reduction by microorganisms on the feedlot surface.

Hydrologic effects. Norton (19) developed an equation for predicting depth of overland flow from a feedlot surface. He presented the concept that pollution load is inversely related to the depth of overland flow since the total volume of wastewater in contact with the surface decreases as depth of flow increases. The overland flow equation is:

$$\bar{D}_s = 3/4 \left[\frac{3L_s q v}{L g s} \right]^{1/3} \quad (9)$$

where $\bar{D}_s$ = mean depth of overland flow, ft.

L_s = length of overland flow, ft.

q = rate of overland flow per unit width, CFS/ft.

v = kinematic viscosity of the water, ft²/sec.

L = length of the lot, ft.

g = acceleration of gravity, ft./sec²

s = slope of the lot, ft./ft.

All of the factors on the right hand side of the equation are constant for a given feedlot except q , which is dependent upon rainfall intensity and the overland flow hydrograph. Norton used the overland flow hydrograph developed by Izzard (3) to obtain the flow rate, q , at any time during runoff from a

design intensity storm. Norton experimentally developed an equation to calculate L_s , which is the length of overland flow on the feedlot surface before channeling occurs. With a means to evaluate all the factors in the depth of overland flow equation, mathematical relationships were determined for BOD, alkalinity, and conductivity in terms of $\bar{D}_s$. Figure 4 represents the relationship between BOD and $\bar{D}_s$ determined by Norton's studies (19).

The equation for $\bar{D}_s$ explains why Miner found increased polluted runoff with smaller intensity rains since overland flow depth is reduced with smaller intensity rains. Norton pointed out that feedlot runoff pollution can be reduced by a reduction in feedlot slope, resulting in a greater $\bar{D}_s$. He suggested a minimum slope of 1 percent to prevent poor drainage and subsequent odor problems from anaerobic decomposition.

Runoff BOD. Law (34) stated that the BOD for untreated domestic sewage is approximately 100 to 400 mg/l. Gilbertson et al. (21) made several spot checks on BOD values for feedlot runoff. They found that snowmelt runoff ranged from 1600 to 7900 mg/l and runoff from rainfall ranged from 370 to 600 mg/l.

Miner (1) reported typical BOD concentrations which resulted from runoff from a dirt surfaced lot. The concentrations were 250, 450, and 650 mg/l for winter, spring and fall, and summer, respectively. Miner determined the values by measuring COD and calculating BOD with a COD/BOD ration of 9.5. Also, the runoff was a result of simulated rainfall.

Runoff COD. Gilbertson et al. (21) found the COD of rainstorm runoff to vary from 1300 to 8247 mg/l from dirt surfaced lots. Miner (1) reported a COD range from 1908 to 8900 mg/l from dirt surfaced lots, and the range from concrete surfaced lots was 2760 to 19,400 mg/l. The COD range from winter runoff

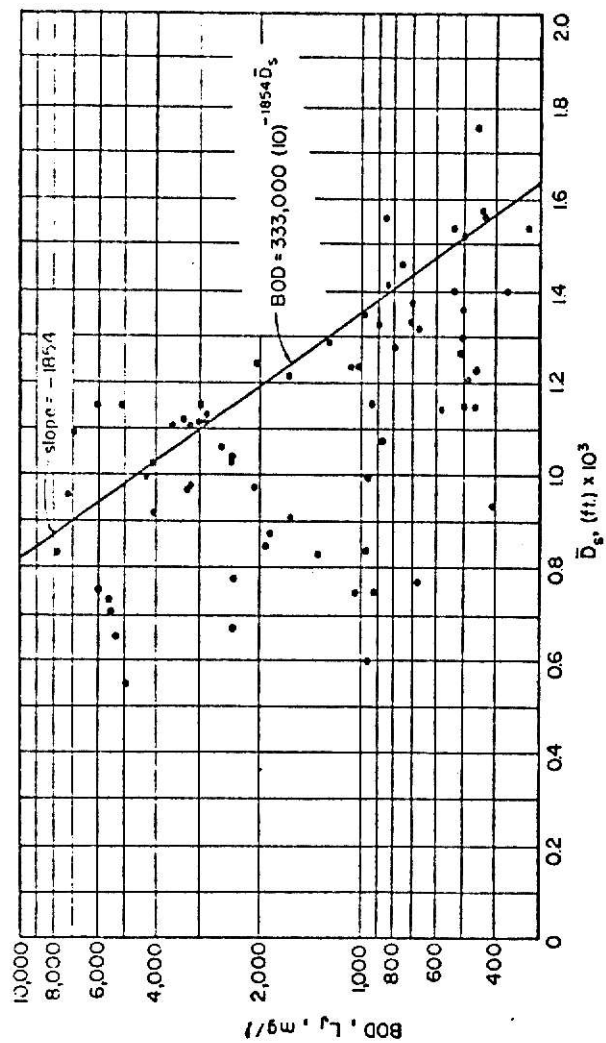


Fig. 4.--The relationship between ultimate BOD and depth of overland flow.
(after Norton, 19)

reported by Gilbertson et al. (21) was 14,129 to 77,804 mg/l.

COD/BOD. Several investigators have reported values of this ratio for cattle wastes. Jex (25) determined the ratio as 8.35 for beef cattle wastes. Miner (1) reported a mean ratio of 9.5 and a standard deviation of 3.2 for runoff resulting from simulated rainfall on a beef cattle feedlot surface. Jeffrey et al. (30) measured the ratio for dairy cattle wastes. After three measurements of the ratio, Jeffrey et al. reported the following values: 9.1, 12.1, and 22.7. Gilbertson et al. (21) found the ratio for runoff resulting from rainfall on a beef cattle feedlot surface to range from 13 to 16. They also reported that the ratio for runoff resulting from snowmelt ranged from 6.1 to 21.3.

Norton (19) explained the variations in the COD/BOD ratio as reported by several researchers as follows: "First the concentration of BOD remaining, from an original concentration of organic matter, decreases with time and, second, the concentration of organic matter initially present could vary with management practices and physical conditions of the feeding operation."

Nitrogen. Three forms of nitrogen of concern are ammonia, nitrates, and nitrites. Miner (1) reported that during cool weather the N was almost exclusively organically bound. During warm weather bacterial activity increased and the N was converted to ammonia, provided that sufficient water was present. Nitrate and nitrite ions appeared only when aerobic conditions existed. Due to the large amount of organic material present in the runoff, aerobic conditions existed only for brief periods.

Ammonia should be considered hazardous in that it is toxic. Concentrations from 0.3 to 75.7 mg/l have been reported toxic or lethal to fish (31). The precise toxic or lethal limit is dependent upon the pH, temperature,

hardness, dissolved oxygen concentration of the water, and fish species.

The nitrate ion is responsible for stimulating algae and other aquatic vegetation. This results in an excessive population of these plants which, in turn, causes a loss in water clarity with accompanying taste and odor problems for downstream water users (1).

Nitrates are also responsible for two types of poisoning. Methemoglobinemia, commonly called blue baby disease, affects infants under two months of age. The nitrates are reduced to nitrites which react with the blood and impair its oxygen-carrying capacity (24). The U.S. Public Health Service has established a limit of 45 mg/l of nitrate in drinking water to prevent this condition (33).

A second form of nitrate poisoning has been observed in animals. Livestock water concentrations of nitrate-nitrogen as low as 5 mg/l may cause subclinical disorders such as loss of milk production, vitamin A deficiency, thyroid disturbance, and reproductive difficulties (38).

The nitrite ion is extremely toxic and must be recognized as a potential hazard. However, it is not found in high concentrations in feedlot runoff (1).

Miner (1) reported nitrogen concentrations of feedlot runoff as ranging from 50 to 1000 mg/l. Gilbertson et al. (21) found total N from winter runoff ranging from 1429 to 5765 mg/l and rainstorm runoff from 65 to 555 mg/l. Miner pointed out that the entire N content of runoff entering a stream or the ground water would eventually be converted to nitrate unless removed. He stated that no economically feasible methods for nitrate removal are available.

George (32) investigated disposal of nitrates by the process of denitrification within the soil profile. The study consisted of a thirteen-week investigation with a laboratory soil profile column. He found that there was

a loss in nitrogen with less than 5 mg/l of nitrates in the water which percolated through the column.

Miner (1) concluded that organic matter and nitrogen were the water quality constituents of primary concern in cattle feedlot runoff.

Phosphorous. As stated earlier, P and N are responsible for algal blooms. The limiting level for P to prevent algal blooms has been established as somewhere near 0.01 mg/l (20). Gilbertson et al. (21) reported P levels ranging from 6.8 to 753.2 and from 13.9 to 46.6 mg/l for winter runoff and rainstorm runoff, respectively.

Solids. Gilbertson et al. (21) reported that as much as 80 percent of the total COD of feedlot runoff can be attributed to settleable solids. The same study evaluated the effects of cattle density and feedlot slope upon the concentration of pollutants in the runoff. The following conclusions were drawn:

. . . Waste concentrations in winter were about ten times that of rainfall-runoff concentrations. Feedlot slope and cattle density did not appear to affect the total materials removed in runoff resulting from rainstorms. Winter runoff, on the other hand, indicated high density lots (100 ft²/head) yielded an average of 4.5 times more total solids than low density lots (200 ft²/head). Volatile solids made up approximately 50% of the total solids in both winter and rainfall-runoff. Material moving from the feedlots averaged 0.58 tons per acre-inch of rainfalls producing runoff on all feedlots studied. Runoff itself transported an average of 1.3 and 1.7 tons per acre-inch for low and high density lots, respectively.

Solids removed in winter runoff averaged 7.0 tons per acre-inch of runoff for low density lots and 20 tons for high density lots.

It may be concluded from this study that a significant reduction in the pollution potential of feedlot runoff can be accomplished by employing methods to retain the solids on the feedlot surface. Means to retain solids on the surface will vary. One method is the use of terraces (18).

A study was made of two methods for removing settleable solids (14). The two methods were labeled the batch system, and the continuous flow system. The batch system actually impounded the flow and reduced its velocity to zero. A continuous flow system consisted of a series of porous dams. Reduction in flow velocity permitted solids to settle out. The batch system was determined to be the least desirable since it required more attention. Cleaning was more difficult with the batch system, and it had a tendency to go anaerobic and produce objectionable odors.

Fecal coliforms FC. The current Kansas standards set on fecal coliforms in waters are as follows (39):

Water Use	Standard
Recreation and Fishing	2000 FC/100ml
Water Supply Intake	2000 FC/100ml
Body Contact Sports	Minimum of 5 samples per 30 days with a log mean less than 200 FC/100ml with less than 10 percent of the samples exceeding 400 FC/100ml

Miner (1) reported median FC densities in feedlot runoff as 130 million /100ml and 33 million/100ml for concrete and dirt surfaced lots, respectively. Obviously, even with a large dilution factor, it would be difficult to meet the above standards if feedlot runoff was released directly to a stream.

EXPERIMENTAL FACILITIES

The equipment for collecting hydrologic information and runoff samples was installed at the site of a commercial cattle feeding operation near Pratt, Kansas. Pratt Feedlot, Inc., is located on an abandoned World War II airbase. The operation can feed as many as 30,000 cattle per day. Two separate areas of the operation were studied for runoff characteristics. The two areas will be referred to as area #2 and area #119.

Area #2

This area consisted of 25 separate pens covering 27.4 acres. The total drainage of area #2 was 32.8 acres, including pens and access areas adjacent to the pens. The 25 lots were numbered from 309 to 333 by the Pratt Feedlot numbering system. All of the lots were 301 feet deep and varied in width from 130 to 200 feet. A feeding area along one side of each pen and 60 feet into the pens was surfaced with concrete; the remaining area was dirt surfaced. The lots had mounds on two sides to provide a dry area for the cattle during wet weather. The mounds were approximately 4 feet above the drainage path down the center of each lot. Lot drainage slopes were about 1.3 percent.

A collecting channel conveyed the runoff from the individual lots to an anaerobic lagoon. The slope of this channel was approximately 0.26 percent. Figure 5 shows a plan view of feedlot area #2.

The total drainage from this area was channeled through a 30-inch Parshall flume equipped with a Stevens Type F water level recorder and a Serco automatic vacuum sampler, PLATE IV. A float device which rose in response to flow activated the water level recorder and the sampler. The runoff was

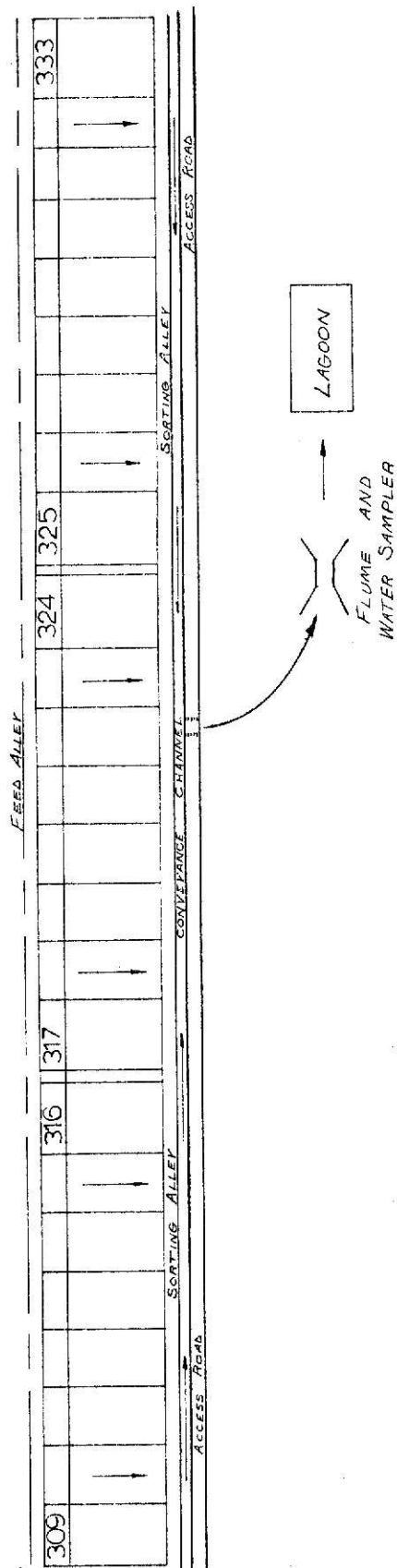
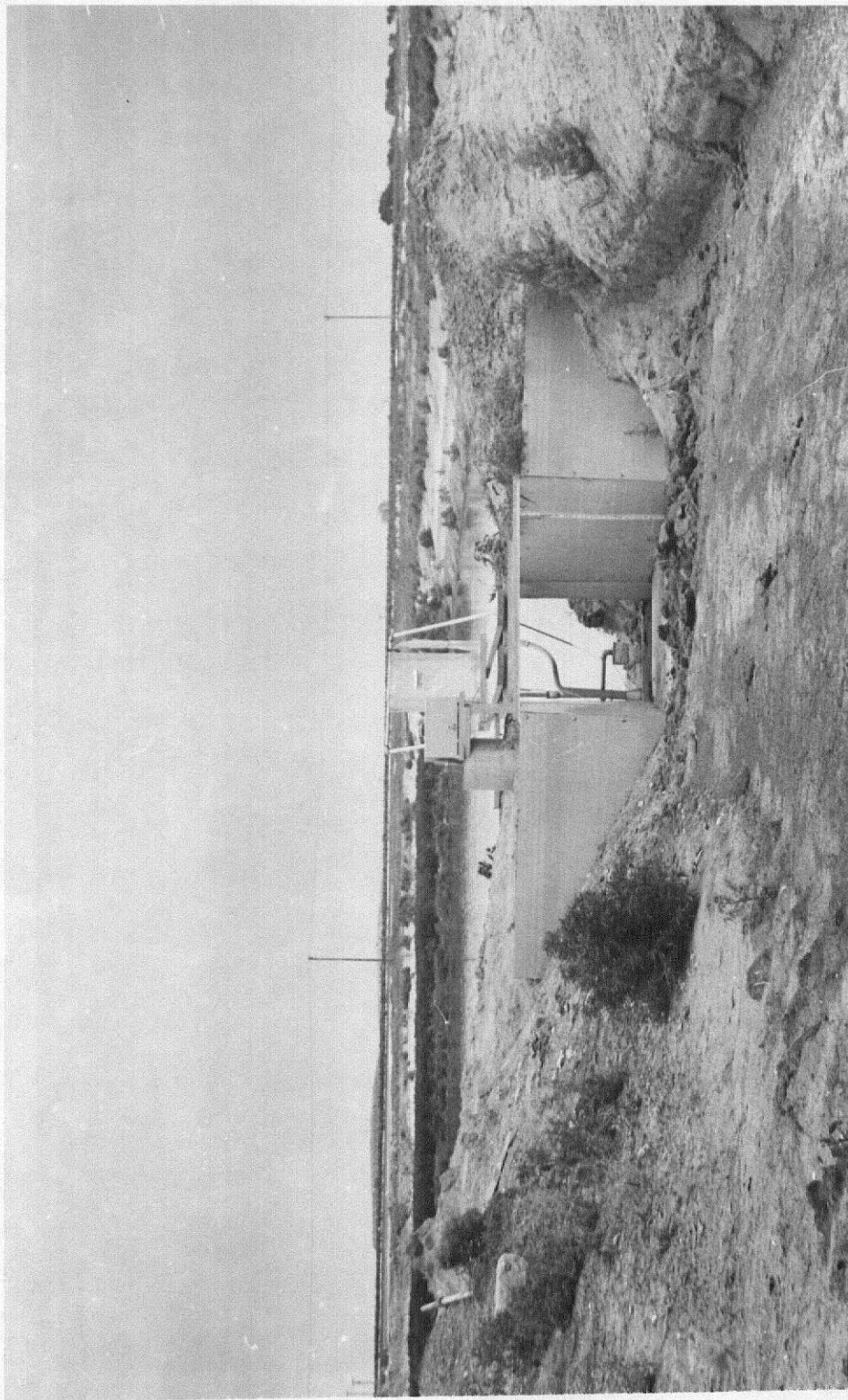


Fig. 5.---Plan view of feedlot area #2.

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NUMEROUS
PICTURES THAT
ARE ATTACHED
TO DOCUMENTS
CROOKED.**

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PLATE IV



A VIEW OF THE PARSHALL FLUME, RECORDER AND SAMPLER FOR AREA #2.

sampled every 10 minutes in response to a vacuum controlled by a time clock. The samples were drawn through individual plastic tubes into plastic bottles. The bottles were inside an aluminum casing. PLATE V shows the sampler arrangement.

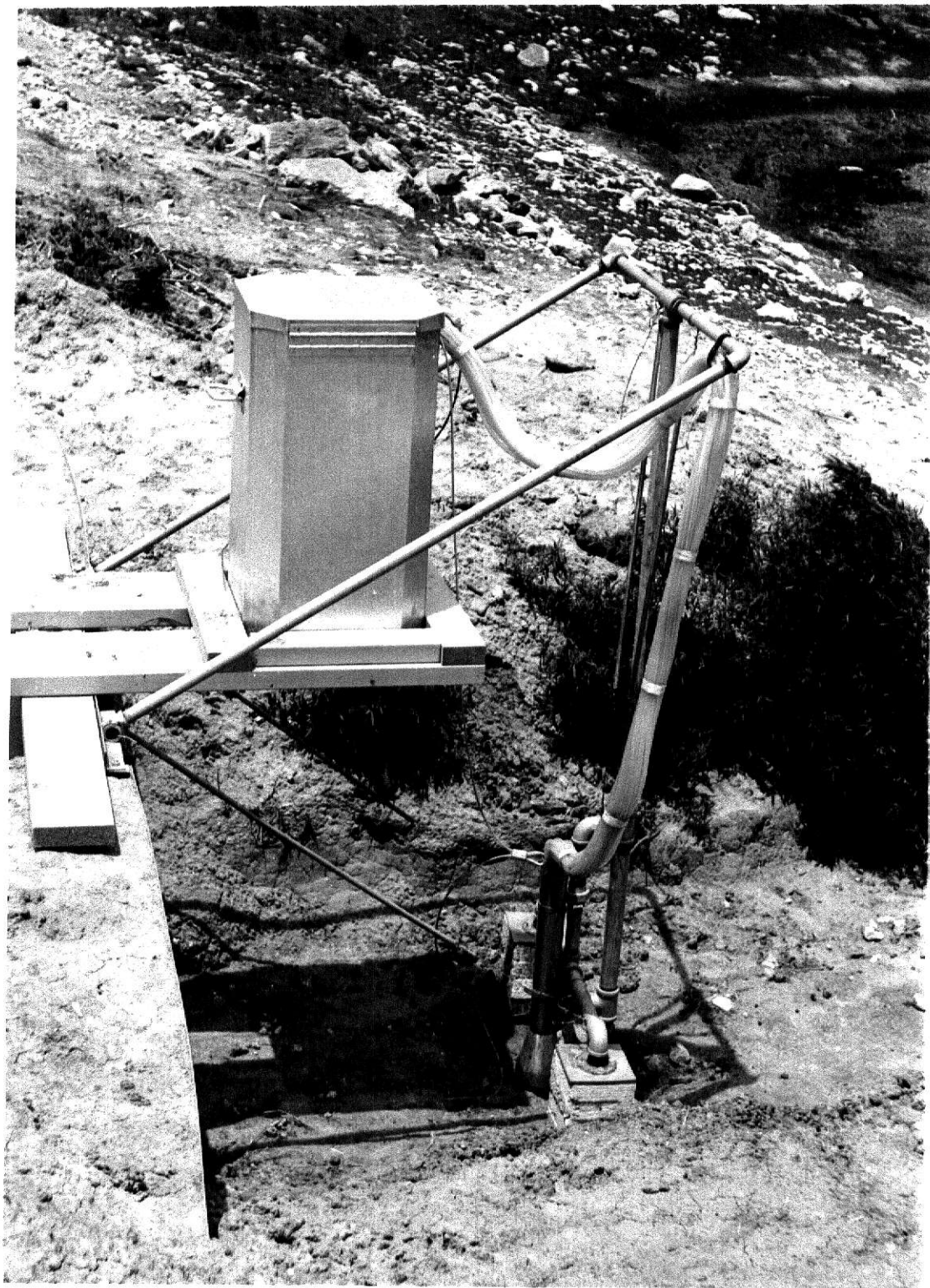
Precipitation falling on the area was measured by three non-recording rain gauges. These gauges were located between pens 314 and 315, 321 and 322, and 327 and 328.

Area #119

Area #119 consisted of one pen, 247 feet deep and 304 feet wide, covering 1.72 acres. The drainage area, including pen #119 and adjacent access areas, totaled 2.03 acres. A feeding area across the front of the pen and approximately 60 feet into the pen was surfaced with concrete; the remaining area was dirt surfaced. The drainage ran diagonally across the lot on about a 1.0 percent slope into an anaerobic lagoon. Runoff was channeled through an 18-inch H-flume prior to reaching the lagoon. The H-flume was equipped with a Stevens Type F water level recorder and a Serco automatic vacuum sampler, PLATE VI. Water samples were drawn off at 10-minute intervals.

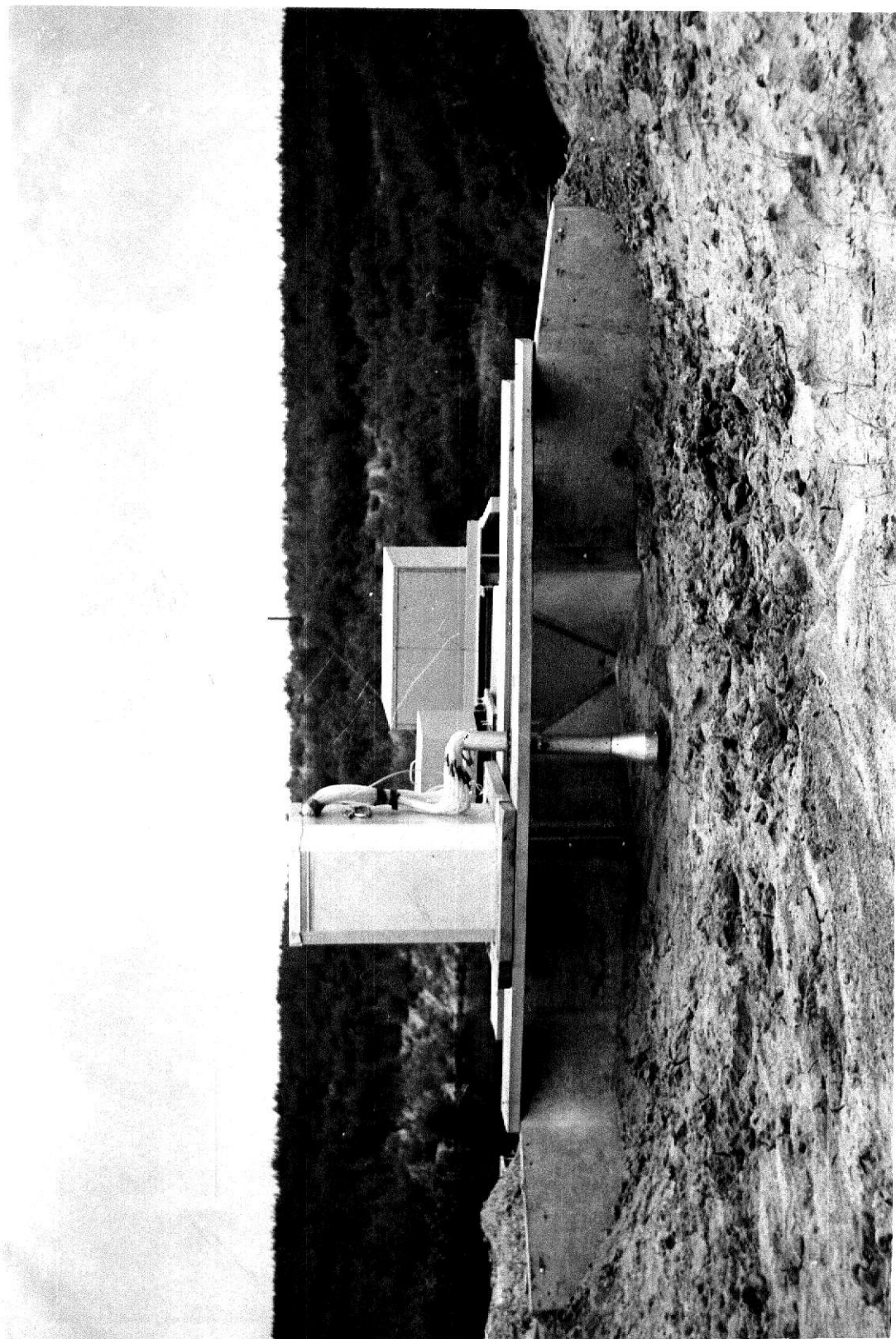
Precipitation falling on the area was measured with a recording rain and snow gauge. The gauge was located about 50 feet outside of the pen. Figure 6 shows a plan view of pen #119.

PLATE V



A CLOSE-UP VIEW OF THE RUNOFF SAMPLER FOR AREA #2.

PLATE VI



A VIEW OF THE H-FLUME, RECORDER, AND SAMPLER FOR AREA #119.

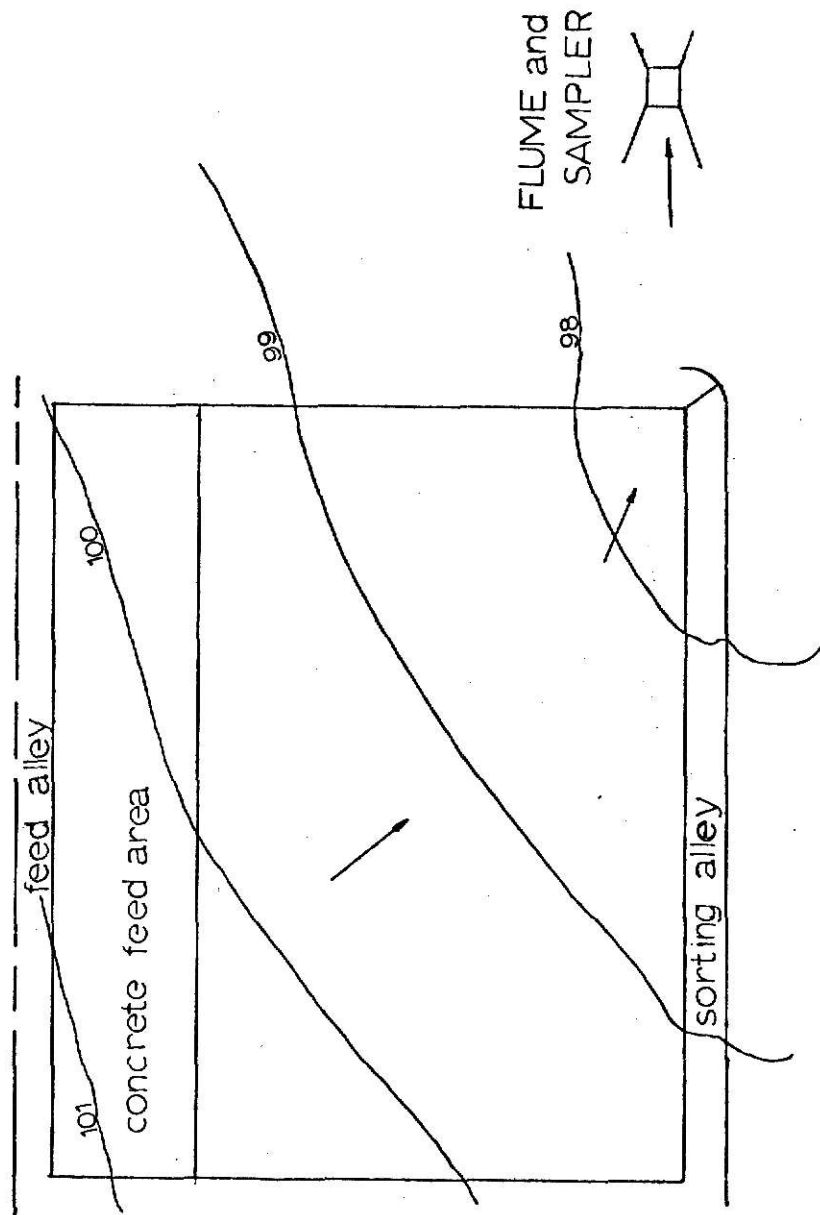


Fig. 6.--Plan view of pen #119.

PROCEDURES

Pollution Parameters

The first objective of this study was to characterize various pollution parameters associated with natural runoff from a cattle feedlot surface. The specific pollution parameters evaluated were as follows: COD, total nitrogen, phosphorous, total solids, and volatile solids.

The runoff samples were packed in ice and transported to Manhattan, Kansas. Laboratory tests were performed according to standard methods (47) at the sanitary engineering laboratory, Civil Engineering Department, Kansas State University.

Runoff Prediction Methods

The second objective of this study was to evaluate available methods for predicting runoff quantity, rate, and pollutant concentrations. The author chose to evaluate one method for predicting runoff quantity, one method for predicting runoff rate, and one method for predicting pollutant concentrations of cattle feedlot runoff.

Runoff Volume

The SCS runoff equation was chosen for prediction of runoff volume. Miner (1) and Bergsrud (4) both proposed the application of this method to feedlots. Prior to this study and after a review of the literature, the author failed to find any attempts to evaluate the ability of the SCS method to accurately predict runoff volume resulting from natural rainfall on a feedlot surface. The SCS equation is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (10)$$

where Q = direct surface runoff in inches

P = storm rainfall in inches

S = maximum potential difference between
rainfall and runoff in inches, starting
at the time of the storm's beginning

$$S = \frac{1000}{CN} - 10 \quad (11)$$

where CN = the runoff curve number

Equation 10 is a quadratic equation and it cannot be used indiscriminately for runoff prediction. A small amount of rainfall will often result in no runoff. The amount of rain necessary to cause runoff is dependent upon the CN of any particular surface. This information may be found in tables (10) or by solving equation 10 for P when Q equals zero. Therefore, a P value that is less than the P to cause runoff should not be substituted into equation 10, because the resulting answer would incorrectly show runoff as other than zero.

The purpose of this portion of the study was to evaluate the SCS runoff equation and to determine the CN for the feedlot surface. A statistical test in conjunction with a regression correlation coefficient was the criterion for decision and evaluation.

Actual runoff. Actual runoff volume for a particular storm was determined by planimetering the area under the runoff hydrograph. The runoff hydrographs, in units of flow rate versus time, were obtained by replotting the depth versus time graphs provided by the Stevens water level recorders. Once the runoff volume was determined for a known feedlot area, the average depth of runoff could be calculated. This procedure yielded the actual runoff which occurred as a result of a known sized storm.

Predicted runoff. Runoff volume was estimated by the SCS equation for each storm which occurred at the Pratt Feedlot from May to October, 1970. Several estimates of runoff for each storm were calculated by substituting different CN's in the equation. Then the procedure was to objectively evaluate the SCS method and to pick the "best" CN.

Evaluation. Theoretically, if the SCS method was always 100 percent correct, a plot of actual runoff versus estimated runoff would yield a straight line with a slope of + 1, an intercept of zero, and all of the points would lie directly on the straight line. An objective evaluation can be derived by consideration of the theoretical relationships just presented. A correlation coefficient as a measure of the degree of scatter of points about a regression line was one criterion for evaluation. A second criterion was to determine if the slope of the linear regression line was significantly other than + 1. This determination was made by use of a t-test outlined by Snedecor (29).

Runoff Rate

The rational formula is widely used for design purposes, primarily because of its simplicity. As pointed out earlier, this method is an oversimplification of a complicated process. The more uniform characteristics of a feedlot surface should reduce those factors affecting runoff flow rates. Therefore, the rational method was chosen to be evaluated for application to a feedlot surface. The objective of this evaluation was to determine a C value for use in the rational equation and to compute a correlation coefficient as a means of rating the method.

In order to evaluate the rational method of flow rate prediction, the time of concentration (T_c) of the feedlot surface was required. This information was necessary to obtain the correct intensity of rainfall that caused

any particular maximum flow rate, since the highest average intensity occurring for a duration equal to the time of concentration, theoretically, will result in the maximum flow rate at the watershed outlet.

Many different methods for estimating T_c are available. The author attempted to determine the T_c for areas #2 and #119. Four methods were applied to both areas for three different storms. Results are tabulated in Appendix II and a brief description of each method may be found there.

The T_c was found to be quite variable for a given area and for different storms. Theoretically, the time of concentration for a given watershed is constant. However, examination of the definition of T_c will point out the discrepancy in the assumption of a constant T_c . Time of concentration is defined as the time required for water to flow from the hydraulic most remote point of the area to the outlet once the soil has become saturated and minor depressions filled (11).

The T_c as defined would be constant, neglecting changes in viscosity due to temperature changes. However, for the purpose for which T_c was needed for this study, it cannot be considered a constant. The original concept of the author was that the intensity to cause maximum flow rate for a given storm could be determined by finding the period equal to T_c during which the most rain fell on the feedlot surface. This theory was invalid because there was no assurance that the soil had become saturated and minor depressions filled prior to the period in which the most rain fell for a duration equal to the theoretical T_c .

Since the theoretical T_c could not validly be used in practice, a slightly different approach was taken to determine the intensity value for use in the rational equation. After examination and comparison of the rainfall charts from the recording rain gauge with the corresponding runoff hydrographs,

a method for determining intensity to cause maximum flow was apparent. The intensity which caused maximum flow was obtained by correlating the time scales of the rain charts with the runoff hydrographs.

In most of the cases for which intensity was determined, very little judgment was required with the method used. However, when the intensity was not readily apparent, it was necessary to exercise some judgment. Any necessary decisions were based on consideration of how much rain had fallen prior to the maximum flow for a duration approximately equal to an average T_c for the feedlot area in question.

Once the intensity value was established for a known flow rate, the coefficient of imperviousness in the rational equation could be calculated.

Runoff Pollutant Concentrations

Norton developed a method for predicting pollutant concentrations in cattle feedlot runoff by correlating depth of runoff with BOD, alkalinity, and conductivity. The author of this study attempted to establish a correlation between average runoff depth and COD. Once a relationship between COD and average runoff depth is established, one should be able to predict other parameters by correlating them with COD. The objective of this portion of the study was to correlate COD with average runoff depth.

The method could be combined with either a basic flood hydrograph (11) or an overland flow hydrograph (3) to predict runoff pollutant concentrations of future rainfall events.

The variables in the depth of overland flow equation were evaluated for feedlot area #119. All of the variables in the equation are constant for a given feedlot surface except the rate of flow. It was necessary to evaluate the effective length of overland flow, L_g , the length of the lot in the

direction of flow, L , and the slope of the feedlot. The effective length of overland flow was calculated from an equation developed experimentally by Norton. The equation is:

$$L_s = 14.5/S_p^{\frac{1}{2}} \quad (12)$$

where L_s = effective length of overland flow, feet

S_p = feedlot slope, percent

An average length of the lot, $\bar{L}$, was obtained by dividing the feedlot area into incremental strips in the direction of runoff flow. The length of each incremental strip, L_i , was measured and multiplied by the corresponding incremental area (A_i). Average length of the lot in the direction of flow was then calculated as follows:

$$\bar{L} = \frac{\sum (A_i \times L_i)}{\sum (A_i)} \quad (13)$$

The incremental areas and lengths in equation 13 were determined for widths of 50 feet perpendicular to the direction of flow.

Feedlot slope was determined by field measurement as 1.0 percent. Effective length of overland flow was 14.5 feet and average length of the lot in the flow direction was 242 feet. The effective width of the area was determined in order to arrive at an equation for depth of overland flow into which the total flow rate could be substituted. Effective width was calculated by dividing the average length of the lot into the total area of the lot. Effective width was 366 feet.

The variables characteristic of area #119 were substituted into Norton's equation which has already been presented in the literature review. The equation applicable to area #119 was:

$$\bar{D}_{s119} = 1.875 \times 10^{-3} Q_1^{1/3} \quad (14)$$

where $\bar{D}_{s119}$ = average depth of overland flow
on feedlot area #119, ft.

Q_1 = instantaneous rate of flow from
area #119, CFS

Once the relationship between D_s and Q_1 had been determined, it was possible to correlate D_s with COD. A correlation coefficient was computed as a measure of the degree of agreement between observed COD and COD calculated with equation 14.

Equation Development and Evaluation

The third objective of this study was to develop and evaluate equations for estimating runoff characteristics. Equations were developed to predict runoff volume, flow rate, and pollutant concentrations. The pollution parameters were COD, total nitrogen, phosphorous, total solids, and volatile solids. All of the equations were evaluated by computing a corresponding correlation coefficient.

All equations were developed by the statistical method of regression (16). Linear regressions were computed on a Wang 700 Advanced Programming Calculator and multiple regressions were computed by an IBM 360 computer. The KSU statistical laboratory supplied the computer program for multiple regression. The program was written to provide deletion of any variables which were not significant at the user specified level. If a variable was deleted, the computer would calculate a new equation without the deleted variable. A 5 percent level of rejection was generally specified.

The data used in the regressions was either collected at the site of the experimental facilities or taken from published climatological data (17).

RESULTS AND DISCUSSION

Pollution Parameters

Runoff pollution parameters were characterized by range, mean, median, and standard deviation. The results were tabulated by feedlot area and the form of precipitation which caused the runoff, either rain or snow. Results are listed in Tables 3-6.

The tabulated results indicate that the mean pollutant concentrations from snowmelt runoff are approximately 2 to $2\frac{1}{2}$ times greater than the mean concentrations of rainfall runoff. Two factors apparently are responsible for the increased concentrations of snowmelt runoff. The first factor is that more solids are removed from the feedlot as a result of snowmelt, and the second factor is that a greater proportion of the solids removed are organic in nature.

The slower runoff process associated with snowmelt is probably at least partially responsible for increased total solids removal from the lot. Precipitation from snow generally has a greater contact time with the feedlot litter and one might expect the increased contact time to partially offset any reduction in dissolved solids due to lower temperatures. Increased total solids in the snowmelt runoff may be due to the same erosion process that causes breakdown of rock formations. For instance, if several inches of snow were to fall on a feedlot surface, the runoff process may occur over a period of several days. During the daytime, water will run off and also soak into the manure pack on the lot surface. At night, the water in the manure pack would freeze and expand. The resulting expansion would probably cause a

TABLE 3
CHARACTERISTICS OF RAINFALL RUNOFF FROM AREA #2

Parameter	Units	Range	Mean	Median	Standard Deviation	Number of Observations
COD	mg/l	14309-15114	6111	5700	2631	85
N	mg/l	962-85	494	462	211	51
P	mg/l	482-19	87	58	89	86
TS	mg/l	17669-2971	7528	6706	2622	63
%VS	%	70.3-38.6	51.3	49.4	7.0	63
VS	mg/l	11437-1429	3891	3444	1627	63

TABLE 4
CHARACTERISTICS OF SNOWMELT RUNOFF FROM AREA #2

Parameter	Units	Range	Mean	Median	Standard Deviation	Number of Observations
COD	mg/l	35,764-7299	13,767	10,300	8087	23
N	mg/l	2337-590	1033	760	617	8
P	mg/l	459-65	209	93	171	12
TS	mg/l	36,684-9282	19,308	12,065	11,425	10
%VS	%	64.8-49.7	57.5	57.5	6.0	10
VS	mg/l	23,551-5253	11,620	6553	7924	10

TABLE 5
CHARACTERISTICS OF RAINFALL RUNOFF FROM AREA #119

Parameter	Units	Range	Mean	Median	Standard Deviation	Number of Observations
COD	mg/l	16,100-861	7596	7055	3255	72
N	mg/l	1580-165	675	600	364	55
P	mg/l	242-9	79	71	42	56
TS	mg/l	19,252-214	8442	9079	5190	48
%VS	%	59.7-12.3	44.6	48.5	12.5	48
VS	mg/l	9552-36	3888	3834	2680	48

TABLE 6
CHARACTERISTICS OF SNOWMELT RUNOFF FROM AREA #119

Parameter	Units	Range	Mean	Median	Standard Deviation	Number of Observations
COD	mg/l	21,700-11,520	16,060	16,160	3566	9
N	mg/l	1860-1080	1450	1440	379	6
P	mg/l	270-122	171	160	55	6
TS	mg/l	21,530-10,744	15,097	14,627	4679	6
%VS	%	63.3-61.3	62.5	62.7	0.8	6
VS	mg/l	13,628-6586	9460	9120	3026	6

breakdown of the manure pack much the same as rock is broken down over a much longer time span. The eroded particles could then be removed in the runoff water the next time runoff occurred.

Colder temperatures tend to reduce the rate of biological degradation of organic materials. Hence, the colder temperatures associated with snowmelt are probably responsible for the increase in the percentage of total solids which are volatile.

Runoff Prediction Methods

Runoff Volume

The SCS equation was applied to nine storms which occurred on area #2 and to ten storms on area #119. Tables 7 and 8 show the results obtained from various CN's and antecedent moisture conditions. Antecedent moisture was considered for each individual storm for a CN of 91 at average antecedent moisture. However, consideration for antecedent moisture conditions yielded a lower coefficient than when antecedent moisture was assumed an average value. Therefore, the other CN calculations were made assuming average antecedent moisture conditions.

The best CN was determined after consideration of the correlation coefficients and the corresponding t values. The hypothesis tested was that the slope of the regression (B) is equal to +1. None of the t values calculated would cause rejection of the hypothesis at a 5 percent level of rejection. Only one of the t values calculated would cause rejection of the hypothesis at a 10 percent level of rejection. The final decision as to the "best" representative CN for the areas #2 and #119 was made by choosing the CN associated with the largest coefficient, provided that the corresponding t value was relatively small. The author chose a CN for area #119 which did not

TABLE 7
DETERMINATION OF THE CN AND EVALUATION OF
THE SCS RUNOFF EQUATION FOR AREA #2

Curve Number and Antecedent Moisture Conditions	Number of Storms Analyzed	Correlation Coefficient	<u>Regression Equation</u>		t * for use in t-test
			Intercept	Slope (B)	
91 I, II, III	9	0.842	0.0875	1.255	0.84
90 II	9	0.933	0.0296	1.075	0.48
<u>91 II</u>	9	<u>0.944</u>	0.00535	0.953	<u>-0.42</u>
92 II	9	0.935	0.01137	0.935	0.49
93 II	9	0.936	0.00150	0.872	-1.03

* w: $t_{0.10} \geq 1.89$ $H_0(B=1)$ vs $H_a(B \neq 1)$

TABLE 8

DETERMINATION OF THE CN AND EVALUATION OF
THE SCS RUNOFF EQUATION FOR AREA #119

Curve Number and Antecedent Moisture Conditions	Number of Storms Analyzed	Correlation Coefficient	<u>Regression Equation</u>		t * for use in t-test
			Intercept	Slope (B)	
91 I, II, III	10	0.377	0.1445	1.081	0.086
90 II	10	0.837	0.0221	1.807	1.93 *
91 II	10	0.835	0.01540	1.59	1.59
92 II	10	0.831	0.00878	1.396	1.20
<u>93 II</u>	10	<u>0.816</u>	0.00628	1.093	<u>0.340</u>

* w: $t_{\alpha/10} \geq 1.86$ $H_0(B=1)$ vs $H_a(B \neq 1)$

produce the largest coefficient but had a more favorable t value associated with it. It was felt that the smaller coefficient was not significantly smaller than the larger coefficients associated with some of the other CN's.

Area #2 was found to have a CN of 91 with a correlation coefficient of 0.944, while area #119 had a CN of 93 with a coefficient of 0.816. The data from both areas was combined and a regression calculated. The combined CN was 92 with a correlation of 0.90.

It was believed that the greater CN for area #119 was due to the lesser travel time for the runoff to reach the measuring flume. In other words, the smaller runoff volume from area #2 may have been a result of channel losses in the conveyance channel to the Parshall flume. The larger correlation coefficient associated with area #2 was possibly a result of the larger area. With a larger area one might expect small effects to cancel out, more than from an area of less than 1/10 its size.

Runoff Rate

Data from area #119 was used to determine a C value for the rational equation. The results follow in Table 9.

The value for C varied considerably from as high as 0.66 to as low as 0.046. A feedlot surface would not be expected to have a constant C value. Cattle are constantly altering the surface characteristics of a feedlot. Lot surface conditions may vary between being hard and smooth to being soggy with many depressions. The author concluded that the rational equation was not intended to be used for flow prediction of any given storm; it is merely a design tool. For design purposes, the C value for a feedlot surface should probably be considered around 0.7. Since the method is solely for design purposes, an attempt to affix a correlation coefficient to it was deemed unnecessary.

TABLE 9
DETERMINATION OF C FOR RATIONAL EQUATION

Date	Max Flow Rate	Intensity	Duration	Coefficient of Imperviousness
	CFS/Acre	In/Hour	Minutes	(C)
5/23/70	0.374	2.32	17	0.16
5/25/70	0.0274	0.60	25	0.046
5/28/70	0.155	0.84	14	0.27
6/11/70 A.M.	0.984	1.50	12	0.66
6/11/70 P.M.	0.0999	1.07	8	0.093
7/27/70	0.112	1.19	20	0.094
8/16/70	0.0349	0.45	20	0.078
8/22/70	0.472	0.84	30	0.56
10/5/70	0.197	0.40	31	0.49

Runoff Pollutant Concentrations

A regression equation was developed from COD data and the average depth of overland flow equation. The equation was:

$$\text{COD} = 7311 \times 10^{-0.1448 \bar{D}_s} \quad (15)$$

where $\bar{D}_s$ = the average depth of overland
flow in feet $\times 10^3$

Thirty-nine observations were used to arrive at equation 15. The correlation coefficient was only -0.28. This small coefficient indicated that less than 8 percent of the variation in COD could be contributed to the average depth of overland flow. As a result of the small correlation coefficient, no further investigation was done on this portion of the study.

Equation Development and Evaluation

Runoff Volume

Area #2. The following equation was developed to predict runoff from area #2.

$$Q_2 = 0.566 + 1.73P + 0.118M_5 - 0.456D - 1.80I \quad (16)$$

$$r = 0.994$$

$$r^2 = 0.988$$

where Q_2 = runoff depth in inches (.0006 - 0.88)

P = rainfall in inches (.12 - 1.60)

M_5 = 5 day antecedent moisture, inches (0 - 1.72)

D = duration in hours (0.33 - 4.41)

I = highest average intensity of the storm for a duration in which at least 80 percent of the total precipitation occurred, inches/hour (.066 - .63)

r = correlation coefficient

The ranges of the data which were used to obtain the equation are given in parentheses. These ranges should be considered before use of the equation since the validity of a regression equation is questionable outside these ranges.

One would expect the effect of rainfall and antecedent moisture to affect runoff positively. Also, one would expect duration to have a negative effect upon runoff since total infiltration increases with time. The author felt that an interaction between intensity and rainfall was responsible for the negative effect of intensity on runoff, since smaller amounts of rain are generally associated with larger intensities.

Multiple regression analysis by computer was found to be quite flexible.

If some doubt exists as to the relationship between an independent and a dependent variable one can investigate the relationship with minimal hand calculations with use of the computer. An instance where this was done in this study was with antecedent moisture. The SCS uses a 5-day period for antecedent moisture considerations. The author attempted to correlate 5, 7, and 10-day antecedent moisture with runoff volume, rate, and pollutant concentrations. Five-day antecedent moisture was generally more highly correlated than either 7- or 10-day moisture. Hence, the process of step deletion at user specified levels of significance, available from the computer analysis, provides for a method to investigate possible relationships without requiring lengthy hand calculations.

Nearly 99 percent of the variation in runoff was explained by equation 16. This high degree of explanation attained by the equation should serve to indicate its potential value. Another advantage of this type of analysis is that if one is willing to accept a smaller correlation coefficient, a simpler equation may be developed. A simpler equation than equation 16 was developed to predict the runoff from area #2. The equation was:

$$Q_2 = 0.57 P - 0.142 \quad (17)$$

$$r = 0.92$$

$$r^2 = 0.84$$

Q and P are defined the same as for equation 16. Equation 17 may be substituted for equation 16, provided that one is willing to accept an r^2 of 84 percent in place of an r^2 of 98.8 percent.

Area #119. The runoff equation for area #119 was as follows:

$$Q_{119} = 0.593 P - 0.128 \quad (18)$$

$$r = 0.79$$

$$r^2 = 0.62$$

Antecedent moisture, average intensity, and duration were deleted from the regression model as they contributed no significant increase in prediction accuracy. However, when all of these factors were in the regression model, an r^2 of about 0.72 was attained. The variables were deleted because they did not meet the user specified level of significance, as measured by a t-test. An alpha of 5 percent was the specified significance level.

The reasons for the smaller significance of intensity, duration, and antecedent moisture upon the runoff volume from area #119 may have been due to the nature of the area. Since area #119 consisted of only one pen, the physical characteristics of the lot as affected by cattle densities and movement may have altered the apparent relationship between runoff volume and characteristics of the storm. The author did not attempt to evaluate effects of cattle densities on the lot upon runoff characteristics. Since area #2 consisted of 25 pens, the physical variations in the area would likely cancel out. Area #119 consisted of only 1 pen, and for that reason, one could expect a reduction in the correlation coefficient due to an inability to measure physical changes in the lot surface.

Runoff Rate

The following equation was developed:

$$q = \frac{0.162 (P_i + 1)^{5.01} I_q^{0.81} A}{(M_s + 1)^{1.73}} \quad (19)$$

$$r = 0.963$$

$$r^2 = 0.927$$

where q = peak runoff flow rate in CFS

P_1 = the rain that fell prior to the intensity that caused q , in inches (0 - 0.65)

I_q = the intensity that caused q , in/hr (0.40 - 2.32)

A = area in acres (2.033)

M_5 = 5 day antecedent moisture, inches (0 - 1.045)

The duration of the storm prior to I_q and the duration of I_q were included in the original model. However, these variables were deleted from the final model due to relative insignificance. The duration of I_q ranged from approximately $8\frac{1}{2}$ to 31 minutes. Therefore, the duration of I_q was enough in all cases to approach some finite time which may be considered a time of concentration.

Prior to obtaining the final equation, the author originally thought that antecedent moisture would be directly related to flow rate. However, the regression model reflected that moisture was inversely related to flow rate. This result caused the author to realize that, due to cattle traffic on the lot, the relationship between antecedent moisture and flow rate is altered. Many surface depressions are made on the lot from cattle hooves during wet conditions, causing increased surface detention and thus reduced flow rates.

Equation 19 accounted for almost 93 percent of the variation in peak flow rate. The rational equation as indicated by results of this study does not even compare with equation 19 for accurately predicting peak flow rates. It is acknowledged that the variables in equation 19 may not be readily attained. Until more information becomes available for assigning recurrence values to the variables in equation 19, engineering judgment and experience may be relied upon to choose acceptable values.

Pollution Parameters

COD. Climatological data and water sample data were used to obtain a

method for estimating COD. COD may be estimated by the following equation:

$$\text{COD} = 46,945 + 18.37 t - 1087 M_5 - 574 T_g + 7.06 W_5 \quad (20)$$

$$r = 0.79, r^2 = 0.62$$

where COD = chemical oxygen demand, mg/l (861 - 13,257)

t = time since runoff began, minutes (0 - 210)

M_5 = 5 day antecedent moisture, inches
(0 - 1.045)

T_g = mean daily ground temperature, °F
(67.5 - 81.5)

W_5 = total wind travel for 5 days prior to the
runoff event, miles (99 - 552)

The ground temperature data was collected at the Hutchinson Experiment Field, at a depth of 4 inches. The wind data was collected at Kanopolis Dam.

Kanopolis Dam is located approximately 78 miles from Pratt in a direction of N 31° E. This was the closest station to Pratt where wind data is recorded. The correlation coefficient would probably have been greater if the wind data had been measured at the site of the experimental facilities. The Hutchinson Experiment Field is about 41 miles from Pratt in a direction of N 59° E. Here again, an increase in the coefficient could probably be realized if the ground temperature were measured at the site of the experimental facilities.

Any attempt to explain the relationship between the variables in equation 20 and COD may or may not be meaningful. The author concluded that the relationships are somewhat dependent upon the range of data analyzed. For instance, COD may in actuality increase for some length of time and then level off or decrease in value. Therefore, whether or not a regression equation reflects either an increase or decrease of COD with time depends upon what range of time water samples are collected. Hence, equation 20 should not be

used without consideration of the ranges of the data which were used in development of the equation.

The one variable which consistently affected COD negatively was ground temperature. Several different equations were obtained from the computer analysis for predicting COD, and ground temperature was consistently the variable which most significantly affected COD. Approximately 40 percent of the variation in COD could be contributed to changes in ground temperature.

Mean daily air temperature was included in the original model to estimate COD. It was found to be considerably less significant than the effects of ground temperature upon runoff concentrations. This result is understandable since the reactions affecting runoff concentrations are in close proximity with the ground.

The author would recommend use of equation 20 as a tool for estimating COD. An estimate of BOD could then be made after a decision was reached concerning the COD/BOD ratio. Other pollution parameters can be estimated from linear regressions.

Nitrogen. An equation was calculated to estimate N once COD is known. The equation is:

$$N = 0.091 \text{ COD} - 137 \quad (21)$$

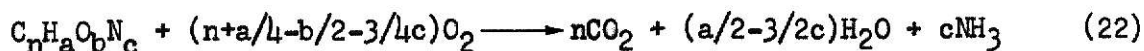
$$r = 0.88$$

$$n = 51 = \text{the number of observations used to establish the equation}$$

One of two conditions or both may be responsible for the relatively high coefficient. First, most of the nitrogen in the runoff may have been in the excreted form, i.e. organically bound. Since COD is a measure of the organic content of a waste, one would expect a high correlation between organic N and COD. A second condition which would result in a high correlation is if a

relatively constant percentage of the total N was organic in nature. If the percentage of N which is organically bound varied considerably, one would not expect a high correlation coefficient. Therefore, the author felt that the N in the runoff was either primarily organically bound and/or that the percentage of the total N which was organic in nature was relatively constant. This line of reasoning may also offer some additional explanation concerning increased COD with decreased temperatures.

As previously mentioned in the literature review, Miner (1) reported that during cool weather the N was almost exclusively organically bound. He also noted that during warm weather bacterial activity increased and the N was converted to ammonia, provided that sufficient water was present. The conversion of organically bound N may be expressed by the following general equation (20):



Equation 22 indicates that if the N has been converted from an organic compound to ammonia, a portion of the oxygen required to degrade the nitrogen compound has been supplied. Therefore, one would expect the COD of feedlot runoff to be reduced when the nitrogen on the feedlot surface is converted to ammonia. This concept may partially explain why the COD was affected negatively by increasing ground temperatures as shown by equation 20.

Consideration of the change in nitrogen forms with temperature led the author to expect that an increase in the ability to predict N content of feedlot runoff could be attained. An improvement in the correlation coefficient could likely be realized by including mean daily ground temperature in the regression model along with COD. This point might be worthy of further study.

Phosphorous. Phosphorous can be estimated as follows:

$$P = 0.036 \text{ COD} - 153 \quad (23)$$

$$r = 0.64$$

$$n = 75$$

Equation 23 explained 41 percent of the variation in P. This relatively low correlation may have been due to variations in the portion of P which was contained in organic compounds. The information in Tables 3-6 in conjunction with equation 23 should provide a reliable estimate of phosphorous in feedlot runoff.

Total solids. The relationship between TS and COD was not highly correlated. This was not unexpected since TS includes both organic and inorganic materials. TS in the runoff is primarily related to management practices aimed towards reducing the amount of material transported. In absence of other means to estimate TS transported, the following equation could be used.

$$TS = 2.74 \text{ COD} - 11,120 \quad (24)$$

$$r = 0.52$$

$$n = 93$$

Also, the tabulated variations in TS (Tables 3-6) could provide a basis for design considerations.

Volatile solids. The organic nature of volatile solids was responsible for a relatively high correlation with COD. The relationship is as follows:

$$VS = 1.08 \text{ COD} - 2132 \quad (25)$$

$$r = 0.84$$

$$n = 93$$

Seventy percent of the variation in volatile solids can be contributed to variations in COD. This is not to say that COD directly affects VS; the

significance is that factors affecting VS are reflected in variations of COD.

Since percent volatile solids were observed to increase with decreasing temperatures, an increase in the correlation coefficient could probably be attained by including ground temperature in the regression model to predict volatile solids.

SUMMARY AND CONCLUSIONS

Runoff Pollutant Concentrations

Results presented in Tables 3-6 indicate that the mean pollutant concentrations from snowmelt runoff are approximately 2 to $2\frac{1}{2}$ times greater than the mean concentrations of rainfall runoff. Two factors apparently are responsible for the increased concentrations of snowmelt runoff. The first factor is that more solids are removed from the feedlot as a result of snowmelt, and the second factor is that a greater proportion of the solids removed are organic in nature. The erosive force of expansion of freezing water may partially explain the increase of total solids in snowmelt runoff. Colder temperatures tend to reduce the rate of biological degradation of organic materials. Hence, the colder temperatures associated with snowmelt are probably responsible for the increase in the percentage of total solids which are volatile.

An equation for predicting chemical oxygen demand of feedlot runoff was obtained. The equation is:

$$\text{COD} = 46,945 + 18.37 t - 1087 M_5 - 574 T_g + 7.06 W_5, r = 0.79 \quad (20)$$

Once COD has been determined, linear regression equations may be used to obtain an estimate of other pollution parameters. Nitrogen was related to COD as follows:

$$N = 0.091 \text{ COD} - 137, r = 0.88 \quad (21)$$

The equation for approximation of phosphorous is:

$$P = 0.036 \text{ COD} - 153, r = 0.64 \quad (23)$$

A close relationship between COD and TS was not found. However, a rough

estimation of TS can be calculated as follows:

$$TS = 2.74 \text{ COD} - 11,120, r = 0.52 \quad (24)$$

A relatively high correlation was established between COD and VS. The relationship is:

$$VS = 1.08 \text{ COD} - 2132, r = 0.84 \quad (25)$$

Runoff Volume

Results of this study indicate that the runoff curve number for the areas studied were 91 and 93 for area #2 and #119, respectively. The Soil Conservation Service runoff equation gave an average correlation coefficient of 0.90 when applied to areas #2 and #119. The method should provide a reliable basis for prediction of feedlot runoff.

An equation was developed from area #2 to predict runoff volume from consideration of four variables. The equation is:

$$Q_2 = 0.566 + 1.73P + 0.118 M_5 - 0.456 D - 1.80 I, \quad (16)$$

$$r = 0.994$$

The equation above was simplified by consideration of only one variable. If only precipitation is considered, the resulting equation is:

$$Q_2 = 0.57 P - 0.142, r = 0.92 \quad (17)$$

Runoff volume from area #119 was related to precipitation as follows:

$$Q_{119} = 0.593 P - 0.128, r = 0.79 \quad (18)$$

The author recommends use of equations 16, 17, and 18, for precipitation amounts less than about 2 inches. For storms exceeding 2 inches, the SCS runoff equation should be used.

Runoff Flow Rate

The rational equation is not an accurate equation for predicting runoff rates from a particular storm. The method may be used to determine maximum

flow rate for a design storm using a rainfall-intensity-duration-frequency curve, provided that an estimate of T_c is available. Kirpich's equation may be used to estimate a T_c .

The Kirpich equation seems to underestimate the T_c for feedlot surfaces at least for the range of slopes under investigation in this study. Therefore, for small slopes, one could consider that the Kirpich equation provides a safety factor when it is used in conjunction with the rainfall-intensity-duration-frequency curves for predicting runoff flow rates. Data and results obtained from this study suggest a value of 0.7 for the feedlot coefficient of imperviousness, C .

An equation was developed from the experimental data to predict maximum runoff flow rates. The equation follows:

$$q = \frac{0.162 (P_1 + 1)^{5.01} I_q^{0.81} A}{(M_5 + 1)^{1.73}}, r = 0.963 \quad (19)$$

The correlation coefficient indicates that this equation could be expected to yield a reasonably accurate prediction of actual flow rates, unlike the rational method. Hence, the author recommends use of the equation for design of feedlot conveyance channels.

SUGGESTIONS FOR FUTURE RESEARCH

Future research to characterize and to develop prediction methods for estimating feedlot pollutant concentrations should include installation of instrumentation to measure ground temperature and wind travel data at the site of the experimental facilities.

Investigation of the application of the regression equations developed in this study to other physical and climatic conditions would be valuable. In addition, an improvement in some of the pollution parameter equations may be attained by including other variables in the models. Specifically, nitrogen and volatile solids concentrations could likely be more accurately predicted if ground temperature were included in the respective equations.

ACKNOWLEDGMENTS

The author is especially indebted to his major professor, Dr. Harry Manges, for his assistance and guidance throughout the course of this study.

The author expresses gratitude to Mr. Carl E. Anderson, instructor of agricultural engineering, for his assistance with the hydrologic aspects of the study.

Thanks also go to the other members who served on the advisory committee, Professor R. I. Lipper and Dr. L. A. Schmid, for their advice and direction.

In addition, the author expresses appreciation to his wife, Louann, for her encouragements and for typing the tentative copy of the thesis.

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APPENDICES

APPENDIX I

Assumptions Involved in the Rational Formula

According to Krimgold (48), the assumptions involved in the rational formula are:

1. The rate of runoff resulting from any rainfall intensity is a maximum when this rainfall intensity lasts as long or longer than the time of concentration, that is, the time required for water to flow from all parts of the watershed to the outlet.
2. The maximum runoff resulting from a rainfall intensity with a duration equal to or greater than the time of concentration is a simple fraction of such rainfall intensity. That is, it assumes a straight line relationship between "q" and "i" and that $q = 0$ when $i = 0$.
3. The expectancy of peak rates of runoff is the same as that of the rainfall intensity for the time of concentration.
4. The relationship between peak rates of runoff and size of drainage area is the same as the relationship between duration and intensity of rainfall.
5. The coefficient of runoff is the same for storms of various expectancies (10 yr., 25 yr., 50 yr., etc.).
6. The coefficient of runoff is the same for all storms on a given watershed.

APPENDIX II

Evaluation of the Time of Concentration for Feedlot Areas #2 and #119

The time of concentration was estimated for both areas #2 and #119 by four different methods. Each of the methods used, for simplicity, will be referred to as methods 1, 2, 3, and 4.

Method 1

The first method used to estimate T_c involved analysis of the runoff hydrograph. According to the SCS (10), in hydrograph analysis T_c is the time from the end of the excessive rainfall to the point on the falling side of the hydrograph where the recession curve begins. The point where the recession curve begins is difficult to determine. For this study the point in question was assumed to be where the plot of the recession limb of the hydrograph became a straight line when the ordinate (CFS) was plotted on a log scale versus the abscissa (time) on a linear scale. This method for establishing the point at which the recession curve begins was based on the theory that the recession curve approximates an exponential rate of decline. A curve of this nature would appear as a straight line on a semi-log plot.

The procedure for applying method 1 involved plotting of the recession limb of the hydrograph on semi-log paper and determination of the points where excessive rainfall ended and where the recession curve began. Determination as to when excessive rainfall ended and the recession curve began was not a clear-cut procedure. The points in question were determined by visual inspection of the rainfall charts and the recession limb plots. Therefore,

method 1 is not an exact determination of the actual T_c ; however, the approximation was probably the best of the four methods used to determine the actual T_c .

Method 2

Time of concentration was estimated by a semi-empirical adaptation of method 1. The procedure was to obtain the slope of the semi-log plot of the hydrograph recession limb. T_c was then calculated as follows:

$$T_c = \frac{0.71}{b} \quad (\text{II-1})$$

where T_c = time of concentration

b = the slope of the straight line portion
of the hydrograph recession limb on a
semi-log plot

The SCS (10) noted that the coefficient in equation II-1 is an average that applied in many, but not all, cases. They further state that the coefficient will differ for watersheds with channel losses, and that the value may be checked by determining T_c by method 1, computing b , and taking the product $b (T_c)$ as the coefficient. A check was made on the coefficient for both area #2 and #119. The value 0.71 yielded essentially the same average T_c from the three hydrographs analyzed for area #119 by both methods 1 and 2. The coefficient was adjusted to 0.98 for area #2 in order to obtain agreement between the mean T_c determined by methods 1 and 2. This correction was thought necessary due to channel losses in the conveyance channel which collected runoff from the individual lots in area #2.

Method 3

T_c may be estimated from consideration of the watershed approximate slope. This method was developed by Kirpich (49). The procedure is as

follows:

1. Find the length (L) of the longest waterway from the watershed outlet to the ridge, in feet.
2. Obtain the difference in elevation (H) between the watershed outlet and the farthestmost point, in feet, but omit drops due to gully overfalls, waterfalls, etc.
3. Use the following equation to estimate T_c , in minutes:

$$T_c = 0.0078 L^{0.77} S^{-0.385} \quad (\text{II-2})$$

where $S = H/L$ = the watershed gradient
in feet per foot

Method 4

An average T_c can be obtained using the time from beginning of rise of a simple runoff hydrograph to the time at which flow rate peaks (10). The relationship presented by the SCS is:

$$T_p = T_c^{\frac{1}{2}} + 0.6 T_c \quad (\text{II-3})$$

where T_p = the time to peak

T_c = the time of concentration

Solution of equation II-3 is a trial and error procedure; however, a plot of the relationship is available for graphical solution (10).

Summary of T_c

The values obtained for T_c for three storms on areas #2 and #119 are given in Table II-1.

An interesting observation was that for the storm in which the most moisture was retained on the lot, the T_c was the smallest value as determined by method 1. Also, the T_c was inversely related to surface retention for all of the storms analyzed by method 1. This condition was notable since it

TABLE II-1
 T_c IN MINUTES FOR AREAS #2 AND #119
 BY FOUR METHODS AND THREE STORMS

Date of Storm	Method 1	Method 2	Method 3	Method 4	Inches of Precipitation Retained On the Lot
Area #2					
5/28/70	23	38.6	23.7	81	.64
6/1/70	53	33.2	23.7	36	.54
8/15/70	63	68.0	23.7	56	.30
Ave. T_c	46.3	46.7	23.7	58	---
Area #119					
6/11/70	21	8.2	5.2	4.8	0.22
8/15/70	19	22.7	5.2	3.6	0.30
10/5/70	6	15.4	5.2	9.6	0.37
Ave. T_c	15.3	15.4	5.2	6.0	----

demonstrates that actual T_c approaches a smaller theoretical T_c as the theoretical conditions are approached. In other words, T_c is reduced in accordance with how much the soil has become saturated and minor depressions filled. This observation was further noteworthy since method 1 was considered to be the best of the four methods for evaluation of the actual T_c .

HYDROLOGIC AND WATER QUALITY CHARACTERISTICS
OF BEEF FEEDLOT RUNOFF

by

WILLIAM JOSEPH FIELDS

B. S., Kansas State University, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

The cattle industry in Kansas has undergone a change in production techniques in the last fifteen years. Economic benefits from economy of scale have proven to be the stimulus in a change from producing cattle for market in scattered small lots to producing thousands of cattle for market in large commercial feedlots. Such large concentrations of cattle have proven to be a major pollution threat to the state's water resources.

Facilities to investigate the quantity, rate of flow, and pollutant concentrations of feedlot runoff were installed at a large commercial feedlot near Pratt, Kansas.

Basically, three objectives were set for the study. These objectives are as follows:

1. To determine the quantity and variation of various pollution parameters.
2. To evaluate available methods for predicting runoff quantity, rate, and pollutant concentrations.
3. To develop and evaluate equations for estimating runoff and water quality characteristics.

Runoff pollution parameters characterized were COD, total nitrogen, phosphorous, total solids, percent volatile solids, and volatile solids. The results were reported with differentiation between snowmelt runoff and rainfall runoff. Mean concentrations of snowmelt runoff were observed to be approximately $2-2\frac{1}{2}$ times greater than the mean concentrations of rainfall runoff.

Available methods for predicting runoff volume, flow rate, and pollutant concentrations were evaluated for application to cattle feedlots.

The Soil Conservation Service runoff equation was evaluated for pre-

dicting runoff volume. The runoff curve number was found to be 91 and 93 for an area of 32.8 acres (area #2) and 2.03 acres (area #119), respectively. The rational method was evaluated for predicting runoff flow rates. A recently developed method for predicting pollutant concentrations in feedlot runoff was evaluated for application to full-scale operations. The method involved establishing a relationship between depth of overland flow of the runoff with some pollution parameter. Both the rational method and the pollutant concentration prediction method were found to be rather poor for predicting runoff rates and pollutant concentrations, respectively.

Equations were developed from the experimental data to predict runoff volume, rate, and pollutant concentrations. The following multiple regression equation was developed to predict runoff volume from area #2:

$$Q_2 = 0.566 + 1.73 P + 0.118 M_5 - 0.456 D - 1.80 I, r = 0.994$$

where Q_2 is rainfall, P is precipitation, M_5 is 5-day antecedent moisture, D is storm duration, I is storm intensity, and r is the correlation coefficient.

Runoff from area #119 may be calculated as follows:

$$Q_{119} = 0.593 P - 0.128, r = 0.79$$

An equation to predict maximum runoff flow rates was developed. The equation was:

$$q = \frac{0.162 (P_i + 1)^{5.01} I_q^{0.81} A}{(M_5 + 1)^{1.73}}, r = 0.963$$

where P_i is the precipitation which fell prior to the intensity (I_q) which caused q and A is area of the feedlot.

Chemical oxygen demand can be estimated as follows:

$$\text{COD} = 46,945 + 18.37 t - 1087 M_5 - 574 T_g + 7.06 W_5, r = 0.79$$

where t is the time since runoff began, T_g is mean daily ground temperature,

W_5 is wind travel 5 days preceding the runoff event.

Other pollution parameters were correlated with COD. The nitrogen equation was:

$$N = 0.091 \text{ COD} - 137, r = 0.88$$

Phosphorous can be estimated by the following equation:

$$P = 0.036 \text{ COD} - 153, r = 0.64$$

Total solids could be roughly estimated as follows:

$$TS = 2.74 \text{ COD} - 11,120, r = 0.52$$

The equation developed to predict volatile solids was:

$$VS = 1.08 \text{ COD} - 2132, r = 0.84$$