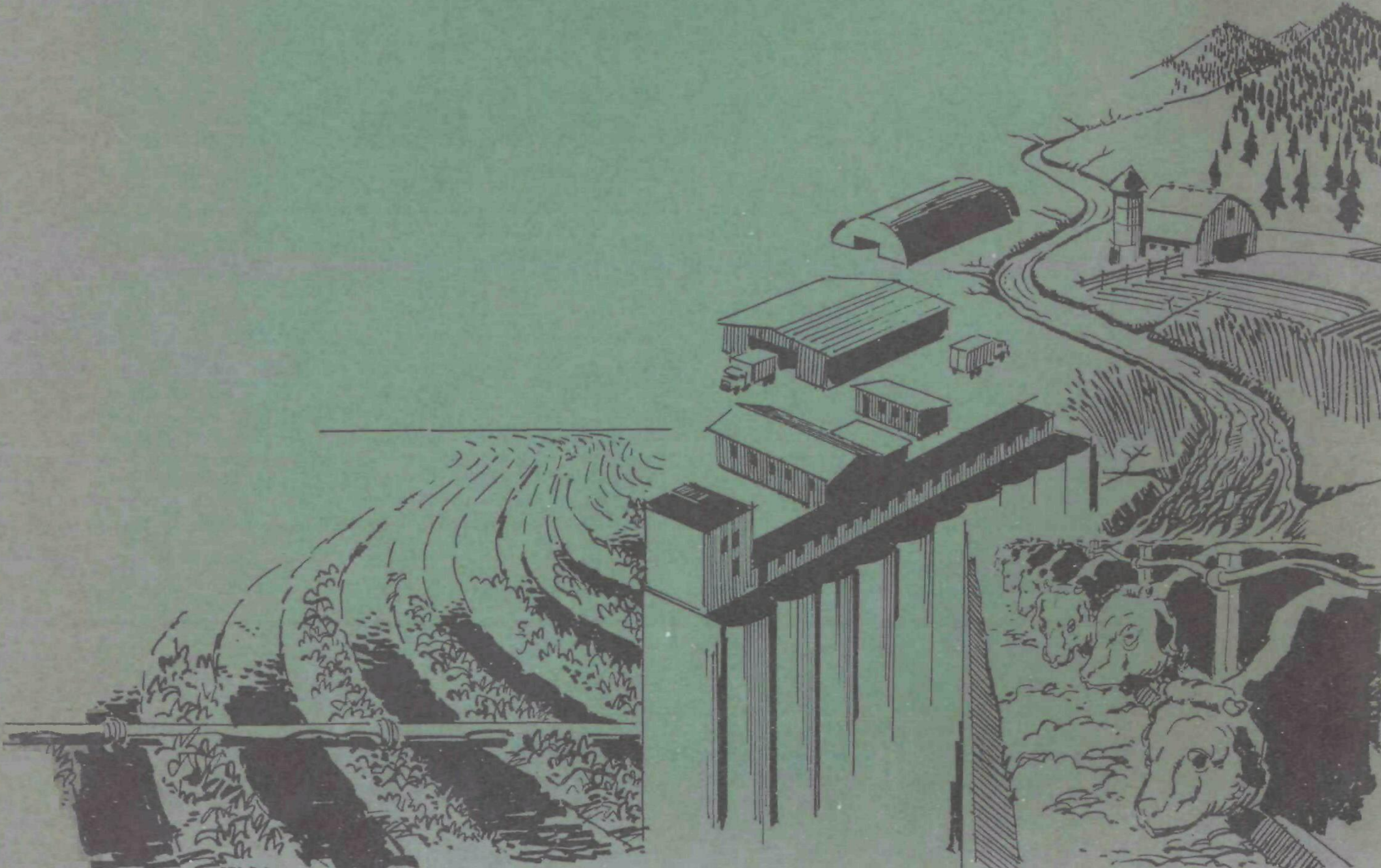
EVALUATION OF BEEF CATTLE FEEDLOT WASTE MANAGEMENT ALTERNATIVES



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EVALUATION OF BEEF CATTLE FEEDLOT WASTE MANAGEMENT ALTERNATIVES

by

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ABSTRACT

Alternative beef waste management systems were examined to determine minimum cost systems for effective waste disposal. Design and cost information was obtained from feedlot visits and the literature. A computer program was developed for use with a Conversational Programming System (CPS) for calculating the sizes of equipment and facilities and for estimating the facility and machinery operating and investment costs.

For open feedlots, two waste management systems, solid and runoff-carried, were considered. The total system investment cost for a 20,000 head unpaved feedlot with pollution control was approximately $420,000 with an operating cost of $0.133 per animal day (not including feed mill and storage, office or land costs). The pen facilities were about 65% of the total investment cost, the runoff control system about 10% and the solids handling about 25%

Confinement buildings with slotted floors using slurry handling methods or with solid floors using solid handling methods offer a high potential for completely controlling the animal waste and abating pollution. A promising system for near optimum pollution control is a cable scraper system underneath a slotted floor for daily removal and disposal of the wastes. A manure irrigation system costs about one-half as much as mechanically conveying the slurry to the fields. In semi-arid and arid areas, evaporation lagoons offer another ultimate disposal alternative.

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CONCLUSIONS

1. Uncontrolled wastes from beef cattle feedlots constitute a serious threat to the quality of the surrounding environment. The most immediate concern is the contamination of receiving waters by rainfall runoff which comes in contact with cattle manure. Of great importance and increasing concern are the odors associated with the cattle feeding operation and the storage and disposal of the wastes.

2. At this time, there have been no practical treatment systems successfully demonstrated for liquid feedlot wastes that will produce an effluent suitable for discharge to a stream. Essentially all the current waste management systems use the soil as the ultimate disposal site for both liquid and solid wastes.

3. The most common open-feedlot waste management system utilizes ditches and detention ponds to collect and store runoff from the pens; manure is mechanically removed from the pens from one to three times per year; and both the stored runoff and manure are spread on cropland. Diversion terraces may be used to divert outside rainfall runoff around the feedlot.

4. Areas, principally in Western United States, where the moisture deficit (evaporation minus precipitation) is greater than 10 inches, have a high potential for using evaporation for ultimate disposal of liquid wastes. An evaporation pond area of approximately one-third the size of the total feedlot will be needed in a region of a 40-inch moisture deficit.

5. Paving open feedlots reduces the pen surface area and runoff control structures sizes to about one-third of the area and sizes required for unpaved feedlots.

6. Settling basins (debris basins) located before a detention pond should be a part of the runoff control system as the basins prevent a high percentage of solids from reaching a detention pond; the solids are easily cleaned from the settling basins with conventional solids handling methods.

7. Confinement buildings offer a high potential for pollution control, especially in high rainfall and cold weather regions. Capital costs are higher than for open feedlots, but land areas are reduced, rainfall runoff structures are unnecessary and wastes may be removed either as a

semisolid or as a slurry. A slotted-floor building with daily removal of waste or an oxidation ditch system reduces the potential for odor problems.

8. A slurry hauling system utilizing soil injection for handling liquid wastes from storage pits provides an optimum system for abatement of odors and water pollution, but is more expensive and slower than surface spreading.

9. A manure irrigation system for pumping a slurry or waste water for field application costs about one-half as much as mechanically hauling and spreading a slurry within one-half mile of the feeding facilities.

10. The application of cattle wastes to the soil has been based primarily on the nitrogen requirements of the crop. In most cases, the feedlot operator would prefer to load the soil as heavily as possible without damaging the crop or causing long-term damage to the soil. Little information is currently available concerning the maximum or optimum loading rates or the long-term effects of such loading.

11. Ultimate disposal of feedlot waste on agricultural land should be encouraged. Under the most common loading rates (approximately 200 lb N per acre), approximately three-eighths acre per head and one-twelfth acre per head capacity are required for disposal of slurry and solid wastes, respectively.

RECOMMENDATIONS

To protect the quality of receiving waters waste management should be an integral part of the design and operation of all cattle feedlots. Obviously, the most effective and economical waste management facilities are those incorporated during feedlot construction.

The main emphasis of this investigation was the assimilation of design, efficiency and cost information on waste management alternatives that are currently available to the cattle feedlot operator. Most of these current waste handling, treatment and disposal designs are based primarily upon empirical relations. In many instances, precise design criteria and basic information was lacking, especially on the design of settling basins and on land required for ultimate disposal. Nevertheless, information presented herein should serve as guidelines to the feedlot operator and design engineer in comparing pollution control alternatives.

Costs calculated in this analysis are based primarily upon Oklahoma prices for materials and equipment and may not be compatible with all areas of the United States. The costs will change with time and estimates are obviously dependent upon the accuracy of the field surveys and manufacturers' quotes. Other factors that were difficult to determine were the life of the machines, dead time of equipment during waste handling operations, and maintenance requirements.

Some alternative handling, treatment and disposal methods, such as composting, refeeding, and anaerobic-aerobic treatment, were not included in the analysis primarily because they were not observed under commercial conditions or design and cost information was unavailable.

The key waste management problems currently facing the cattle feedlot operator include the ultimate disposal of runoff-carried wastes and solid wastes, and control of odors from feedlots and waste disposal areas. Although the subject of little research, odor control is probably the most technically and economically difficult of these problems for open feedlots.

Additional research is needed in developing practical and economical liquid waste treatment processes, especially for high rainfall areas, that will produce an effluent suitable for stream discharge. Since land is probably going to continue as the ultimate animal waste disposal point for the foreseeable future, further information is needed on the effects of high solid and liquid waste loading rates on soil properties, ground waters, and rainfall runoff.

CHAPTER I

INTRODUCTION

During the decade of the 60's, the number of fed cattle marketed increased from 13 million in 1960 to 25 million in 1970 as illustrated in Figure 1 (68). The rate of increase has been over one million per year. This increase is due to increases in the United States population and also to an increased preference for beef as a food item.

Accompanying this increase in numbers of fed cattle is a proportional increase in waste produced. For 1970, the annual production of waste probably exceeded 85 million tons for the animals during the finishing period. The trend in cattle feeding has been toward confining the cattle in smaller areas, either in open-feedlots or in confinement buildings during the finishing period. This has resulted in concentrating the waste in small areas producing a higher pollution potential than under the smaller scale and less confined feeding before the early 60's.

The major beef feeding areas are the North Central region, the southern Great Plains and desert Southwest. Table 1 lists the number of fed cattle marketed in 22 major beef feeding states for 1969. Iowa marketed the most fed cattle with over four million, followed by Nebraska, Texas, California, Colorado, Kansas and Illinois with all marketing over one million fed cattle during 1969.

THE PROBLEM

The disposal of wastes from a large beef feedlot is a major problem. For a 10,000 head lot, the manure production approaches 1/2 million pounds per day. Researchers have found that beef manure production is about 6% of the body weight per day (51). Thus, a 1,000 pound animal produces about 60 pounds per day of wet manure at 85% moisture content. Some of the moisture is evaporated and some of the organic material undergoes decomposition by bacterial action on the feedlot.

It has been estimated that one ton of solid waste material per animal has to be removed from an open feedlot at the end of the feeding period. This represents a large amount of waste that has to be removed annually. Thus, a 10,000 head capacity lot with two and 1/2 turnovers per year would have an annual solid waste handling load of approximately 25,000 tons.

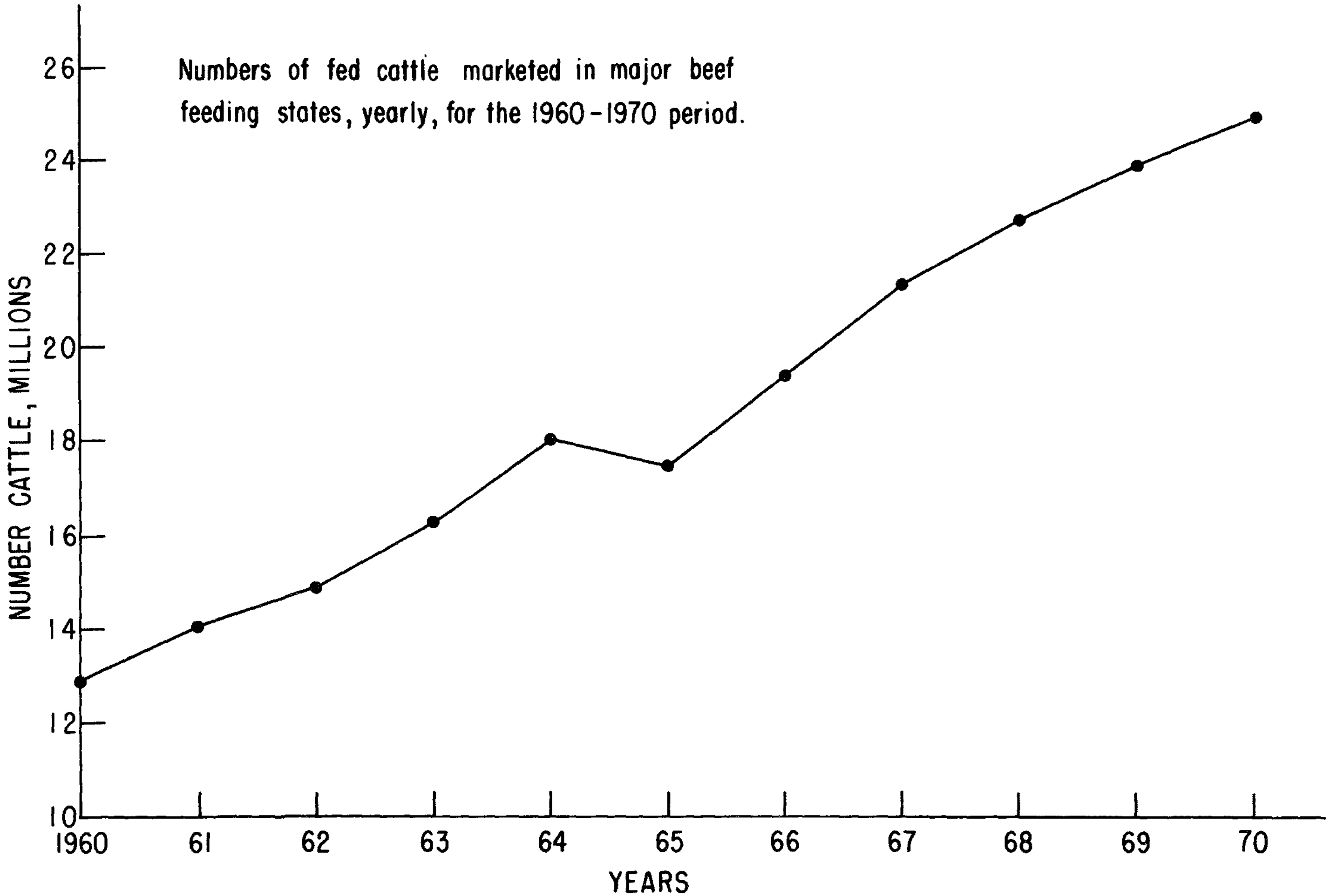


Figure 1. Number of fed cattle marketed yearly in major beef feeding states for the 1960-1970 period (Crop Rep. Bd, SRS, USDA, 1971)

Table 1. Number of Fed Cattle Marketed in 22 Major States, by Quarters, 1969

- 1,000 Head -

State	Jan.-March	April-June	July-Sept.	Oct.-Dec.	TOTAL
Pennsylvania	27	42	38	24	131
Ohio	93	150	124	67	434
Indiana	96	144	158	113	511
Illinois	282	308	344	282	1216
Michigan	52	71	76	45	244
Wisconsin	52	62	48	50	212
Minnesota	208	160	205	230	803
Iowa	1002	1086	1177	1237	4502
Missouri	198	161	193	168	720
South Dakota	153	123	105	155	536
Nebraska	936	846	785	794	3361
Kansas	429	427	418	400	1674
Oklahoma	137	110	113	139	499
Texas	660	651	673	722	2706
Montana	65	37	41	34	177
Idaho	112	116	114	96	438
Colorado	464	463	425	419	1771
New Mexico	93	97	97	73	360
Arizona	198	222	209	218	847
Washington	85	85	104	75	349
Oregon	45	42	46	40	173
California	530	417	527	583	2057
All States	5917	5820	6020	5964	23,721

In terms of BOD population equivalent, a 10,000 head feedlot has a pollution potential of a city of approximately 150,000. Animal waste not controlled and permitted to enter streams, such as from rainfall runoff or snowmelt, can cause stream pollution, result in fish kills, upset the ecological balances in the stream, and seriously degrade the water for further domestic or recreational uses. A potential also exists for pollution of underground water by percolation of contaminants through the soil to the ground water. However, as mentioned by Rademacher (76), the population equivalent values are continually based on the total animal waste production with little regard for the fact that only part, perhaps 5 to 10%, of the waste actually enters surface and ground waters. As the practice of confined feeding of animals increases, the percent of the potential pollutants getting into the stream could increase if pollution abatement is not practiced.

Rainfall runoff from a feedlot may carry high concentrations of oxygen-demanding materials, solids, nutrients, and disease organisms into surface waters or the leachate may carry pollutants into the ground water. Rainfall runoff may contain pollutant concentrations 10 to 100 times those of raw municipal sewage; and uncontrolled access to streams can result in oxygen depletion, fish kills, and other long-term, undesirable ecological conditions for many miles downstream. Scalf, et al., (77) reported that direct runoff from an open feedlot contained variable concentrations of organic matter, solids and nutrients one order or magnitude higher than raw municipal sewage. They also determined the chemical conditions in a farm pond receiving feedlot runoff at the time of a fish kill in the pond. They found the pond to have a higher conductivity and oxygen demand and greater concentration of solids, chlorides, nitrogen and phosphorus at the time of the fish kill.

Finding solutions to abate pollution from feedlots presents a tremendous challenge to engineers and feedlot designers. The characteristics of the feedlot wastes are different than most municipal wastes, therefore, it is difficult to use traditional municipal waste treatment processes on animal waste. Animal waste has a higher solids concentration and presents a higher pollutional strength than municipal wastes. Also, there is a high lignin content in most cattle wastes, which decomposes very slowly. In addition, shock loadings resulting from rainfall runoff from open feedlots cause severe strains on a waste treatment system. Most of the conventional municipal type treatment systems are expensive and require a high degree of sophistication in facilities, equipment and trained personnel.

Rademacher (76) has said that while investigations have shown that animal wastes are amenable to municipal waste treatment processes, the treatment results have usually been unsuccessful because of a lack of understanding of characteristics of the waste, the magnitude of the problem, and economic constraints currently imposed by society. Animal waste may contain even after treatment higher pollutional parameters than domestic sewage does before treatment. Rademacher, therefore, suggests that a residual concept of waste treatment be used. Residual treatment is that degree of treatment which reduces pollution to a prescribed level or residual. This residual would be determined for each situation and depend on the classification of the stream, other waste sources discharging into it, and other factors. No one treatment system will be the ultimate solution for all animal production units. A variety of management and treatment systems will have to be developed.

Feedlot Laws and Regulations

With the advent of water quality standards for many of the streams and because of observed fish kills downstream from feedlots, several states have enacted feedlot laws and regulations. Currently, there are differences between the feedlot laws of the various states as indicated in Table 2. As animal waste management technology progresses, there will probably be few differences between the states' laws and regulations. The major concern of the regulations will be to prevent water pollution and to control dust and odors within acceptable limits.

Currently, most of the states with feedlot laws and regulations require that a feedlot be licensed or registered with a state board whenever the capacity is above a set figure for a confinement feeding operation. Most of the states make attempts in their regulations to prevent pollution of streams arising from feedlot runoff sources. Most of the states suggest building diversions around the feedlot and channeling the feedlot runoff into ponds or lagoons. There are differences between the various states as to how to design the capacity of the detention structure. Primarily these structures are based upon determining a design rainfall from either a 5 year 48-hour storm 10 year 24-hour storm or 25 year 24-hour storm. The Texas Water Quality Board also suggests that the total pond capacity can be determined by using approximately 3/4 of the average monthly rainfall occurring during the rainy part of the year.

Some of the states require that the retention pond be

Table 2. Summary of Feedlot Laws and Regulations for Beef Feedlots in Various States

State	Regulatory Agency	Licensing Requirement	Resume of Guidelines and Regulations
Arizona	The Livestock Sanitary Board	Required for over 500 head	Feedlot Categories: A - Feedlot near cities or residences B - Rural areas, but affecting streams and highways C - Rural areas, not near streams or highways Performance Standards: A - Clean pens 3 times per year, use deodorants, control insects, keep stacked manure to minimum B - Clean pens once per year, prevent contamination of water, control dust C - Clean pens once per year, prevent contamination of water
Colorado	Water Pollution Commission, Colorado Dept. of Health	No licensing, but pollution abatement must be practiced	Engineering report by professional engineer required prior to construction of runoff or treatment facilities Retention pond--volume based on 10 yr 24 hr storm, must be pumped out within 15 days after storm

Table 2. Continued

State	Regulatory Agency	Licensing Requirement	Resume of Guidelines and Regulations
			Evaporation pond--only where annual evaporation exceeds annual precipitation
Kansas	Kansas Board of Health	Permit required for over 300 head	Retention pond--volume to retain 10 yr 24 hr storm, minimum 2 cells, capable of pumping ponds within 5 days after storm
Iowa	Iowa State Dept. of Health	Permit required when: 1. over 1,000 head confined 2. distance between feedlot and watercourse is less than 2 ft per head capacity 3. runoff can enter property of others	Retention pond--2 inches of runoff storage when irrigation regularly practiced or 3 inches of storage volume for settling basins and lagoons for evaporation removal
Nebraska	Environmental Health Services, Dept. of Health	Permit required when: 1. over 300 head	Register 60 days before beginning construction Regulation based upon stream water

Table 2. Continued

State	Regulatory Agency	Licensing Requirement	Resume of Guidelines and Regulations
			quality standards which feedlot runoff cannot degrade further
		2. feedlot within 500 feet of watercourse	Runoff control facilities designed by Soil Conservation Service or consulting engineers, 10 yr 24 hr storm
		3. any operation with water pollution potential	
South Dakota	S.D. Commission on Water Pollution	Permit required where water quality standards may be lowered	
Oklahoma	State Board of Agriculture	License required for over 250 head	Water discharge must be in conformity with stream water quality criteria Retention pond--volume to retain 2 day 5 year storm, waste should be removed periodically to insure adequate capacity
Texas	Texas Water Quality Board	Permit required when wastes may be discharged into or adjacent to waters of the state	Use "designed" retention structures, suggest pond capacity by 3/4 of average monthly rainfall occurring during rainy part of year or 25 yr 24 hr storm, suggest supplemental ponds for cleaning periods

pumped out within 10 days to 15 days after a storm in order to insure adequate volume for any subsequent storm events. Also, the solid waste material has to be handled in such a way as to prevent the streams from being polluted. Other waste material, such as dead animals, and general sanitation also comes under the jurisdiction of most of these control agencies.

Economic Considerations

In many of the Great Plains states and some of the Corn Belt states, along with Arizona and California, the beef feeding segment represents a major portion of the agricultural economy of those states. When prices are favorable, good returns on the investment can be made in a beef feeding enterprise. However, prices fluctuate considerably both for price of beef and for grain prices. In general, the beef feeding industry is considered to be a very low margin industry with only a few dollars profit being made on each animal.

Price fluctuations are the major cause of income variability in cattle feeding, according to a study on cattle feeding in the United States by the USDA (31). Net returns from cattle feeding are largely dependent upon achieving two favorable margins: (1) a feeding margin, which is the difference between the cost of beef and the price received for the gain put on cattle, and (2) a price margin, which is the difference between purchase and selling prices per hundredweight.

The price margin is a good indicator of variability in income from cattle feeding over time. However, a negative price margin does not necessarily indicate a loss nor does a positive price margin necessarily reflect a profit if it is offset by a poor feeding margin.

By comparing prices of choice slaughter steers at Chicago with average prices of all feeder steers at Kansas City 5 months earlier, Gustafson and Van Arsdall (31) determined the extent of variation. Negative price margins prevailed in 26 months of the period 1960-1968. Positive price margins prevailed in 82 months of the period. The maximum positive and negative price margins were $8.08 and -$2.57.

Martin, et al., (33) examined the feeding costs and returns from selected cattle feeding records in Illinois for the period 1952-1967. They found returns per $100 of feed fed were high enough to cover all costs of production in only four years for the period. In four other years, the returns above feed costs were not enough to cover cash non-feed costs, excluding labor. During the remaining eight years the returns above feed costs were sufficient to cover cash non-feed costs and to provide a partial payment for labor and overhead.

Engineering Considerations

The design of a waste management system for beef feedlots has both economic and engineering considerations. Economic in the sense that the system should be constructed at minimum cost that will effectively abate pollution from a particular feedlot waste. Engineering in the sense that the design of the waste management system should be done on the basis of sound engineering design principles. Some of these principles have been practiced for many years by agricultural, civil, sanitary and hydraulic engineers. In some cases, new concepts may have to be developed to fit a particular feedlot.

In the design of a feedlot, engineers have to consider many aspects. They have to consider the feedlot layout from the feed handling, cattle handling and waste handling viewpoint. All of the various systems within a feedlot operation have to be integrated in the final plan. Formerly, very little attention was given to the waste handling design and the most attention was given to the design of feed handling and cattle handling systems.

It is the intent of this publication to review some of the alternatives for the design of the waste management systems for both beef confinement building feeding facilities and open feedlot feeding facilities. It is realized that each feedlot is unique and therefore, an engineer, or feedlot designer, should have some waste management alternatives available that he may recommend to the prospective feedlot owner. This report contains information on the various alternatives and their fixed and operating costs. It is hoped that from the typical designs and general information that the feedlot designer will be able to use this information for selecting and designing a particular feedlot waste management system.

OBJECTIVES OF THE RESEARCH

The objectives of the research reported in this publication were:

1. To develop beef feedlot design criteria that will minimize pollution from runoff wastes and to facilitate handling of solid and liquid animal waste.

2. To examine alternative feedlot waste disposal systems to determine minimum cost systems for effective waste disposal.

PROCEDURE

To achieve these objectives, the basic procedure was to:

1. Determine the feedlot design criteria.

2. Develop engineering design equations and program them for the computer.

3. Evaluate the alternative systems to determine the minimum cost systems for feedlot waste disposal.

Analysis of the engineering design requirements for feedlots was made by examining the literature, observing feedlot operations, performing operational analysis of waste handling systems and from personal conversations. From these design requirements, preliminary design of feedlots was made to include various concepts aimed at enhancing the removal of feedlot wastes. Equations and procedures were developed to calculate the sizes of equipment and facilities needed for the waste handling systems.

Field Observations

A considerable amount of time was spent in traveling to beef feeding facilities in various Western and upper Midwest areas where beef feeding operations are prevalent. The purpose of these visits was to inspect existing waste management systems that were in use in various parts of the United States. A list of the feedlot visits and major points of interest are noted in Appendix A. Visits to the upper Midwest concentrated primarily on viewing confinement beef building facilities and waste management systems. The visits in the Southern High Plains and Southwest plus the states of California and Washington concentrated mainly on observing waste handling and feedlot design for open feedlots.

On the feedlot visits, information was obtained on the sizes of the facilities and nature of construction, waste handling, treatment and ultimate disposal methods, design criteria used for the waste management system, performance of the system, and cost information. Information was not always available for all of the items on the questionnaire but from all of the feedlots visited a composite was acquired. Some of the information was related almost exclusively to a particular geographic area, such as the desert

Southwest, whereas other information was of a general nature and could be applied at more than one geographic location. From these feedlot visits, much information was obtained about feedlot design and the operation of a feedlot as a production facility.

Analysis of Alternatives

Analysis of the various alternatives for handling the feedlot wastes was done by analyzing the field observations and utilizing the computer to generate design information and to perform calculations for comparing the costs of the various systems. The computer was especially useful in performing the design calculations for some of the facilities, such as detention structures. It was also helpful in determining the sizes and numbers of the pieces of waste handling equipment needed.

The computer program developed in this study was based upon a procedure and computer program developed by Paine (71) for estimating the facility, machinery, labor and capital costs for a livestock operation. Paine's economic analysis of livestock production systems did not include waste management systems. In this study, the program was converted for use on a Conversational Programming System (CPS) so that programming and data analysis could be done at a terminal located in the Oklahoma State University's Agricultural Engineering Department. The terminal was connected to the IBM 360/65 digital computer located at the University's Computer Center.

Cost information was obtained from the field visits, from manufacturers' literature and from engineering estimation procedures. Where design information could not be obtained easily, or relatively new technology was being developed, the design and cost information sometimes had to be made by estimates. Occasionally, some assumptions had to be made in the design of the facilities. The sizes and numbers of the pieces of equipment, sizes of facilities, land area for ultimate disposal, and initial fixed and operating costs were determined for the various alternative systems.

CHAPTER II

WASTE HANDLING ALTERNATIVES

The selection of a waste management system is dependent upon the type of production facility and upon the physical form of the waste material. In handling beef animal wastes, there are three physical forms encountered:

1. Slurry--where the feces and urine are combined together with or without additional water

2. Solid Waste--where the solid fractions of the waste material are collected on the feedlot surface or on solid floors of confinement buildings

3. Runoff-carried Waste--where rainfall runoff carries solid and liquid animal waste off the feedlots

For any of the forms of waste, there are three other considerations that have to be made. First, the handling system and its components have to be chosen. Second, the method for treating the waste to reduce its pollutional strength has to be considered as an integral part of the handling system. Third, the ultimate disposal of the waste material has to be considered and should be a prime concern.

The choice of a waste handling system is basically a choice between a liquid oriented system and a solid system. Liquid slurry handling systems have been quite popular for confinement barn facilities. Of course, runoff control systems from open feedlots are a liquid handling systems. Solid handling systems are used for both open feedlots and certain types of confinement feeding facilities.

In this chapter, some of the choices available for waste handling systems will be explored. The various alternatives will be presented for both open feedlots and confinement buildings. Treatment and ultimate disposal of the waste will also be considered but only in general terms.

WASTE HANDLING SYSTEMS FOR OPEN FEEDLOTS

Solid handling systems and runoff-control systems are the two major systems used in open feedlot waste handling. Most open feedlots are unpaved. However, paved feedlots offer the possibility of a liquid flush system and slurry handling techniques. Slurry handling techniques will be discussed under confinement building systems.

Solids Handling Systems

As illustrated in Figure 2, several alternatives for the handling of solid wastes from an open feedlot are presented. The most prevalent method is by mechanically removing the solid materials from the feedlot periodically, such as once or twice per year. In addition, no removal and plowing the manure deeply into the soil are two unique alternatives that have been used.

Mechanical Removal--The type of equipment selected for removing the material from the lot surface depends greatly upon the physical nature of the solid waste material. Some of the obvious factors affecting the removal of the material from the lot surface are:

1. moisture content
2. animal density
3. length of time from previous cleaning
4. amount of rainfall and intensity
5. slope of the feedlot surface
6. size of the pens
7. feedlot capacity
8. hauling requirements and ultimate disposal
9. temperature
10. evaporation rate
11. wind
12. solar radiation
13. soil type

Some of the environmental factors listed above affect the physical manner by which moisture is lost from the solid material and also degradation of the material due to biological action. Some of the factors are related to the feedlot design which is primarily dictated by local climatic conditions and capacity of the feedlot.

In removing the solid waste from the feedlot surface, the first step is scraping the material from the surface. Some of the methods of scraping the feedlot surface are:

1. tractor with front-end loader
2. commercial loader with bucket
3. tractor with ripper and mounted blade
4. patrol scraper
5. rotary scraper
6. large earth moving scrapers

For some of the scrapers, particularly the first four, the material is windrowed or piled in the center of the pen for subsequent pickup with a commercial loader or front-end

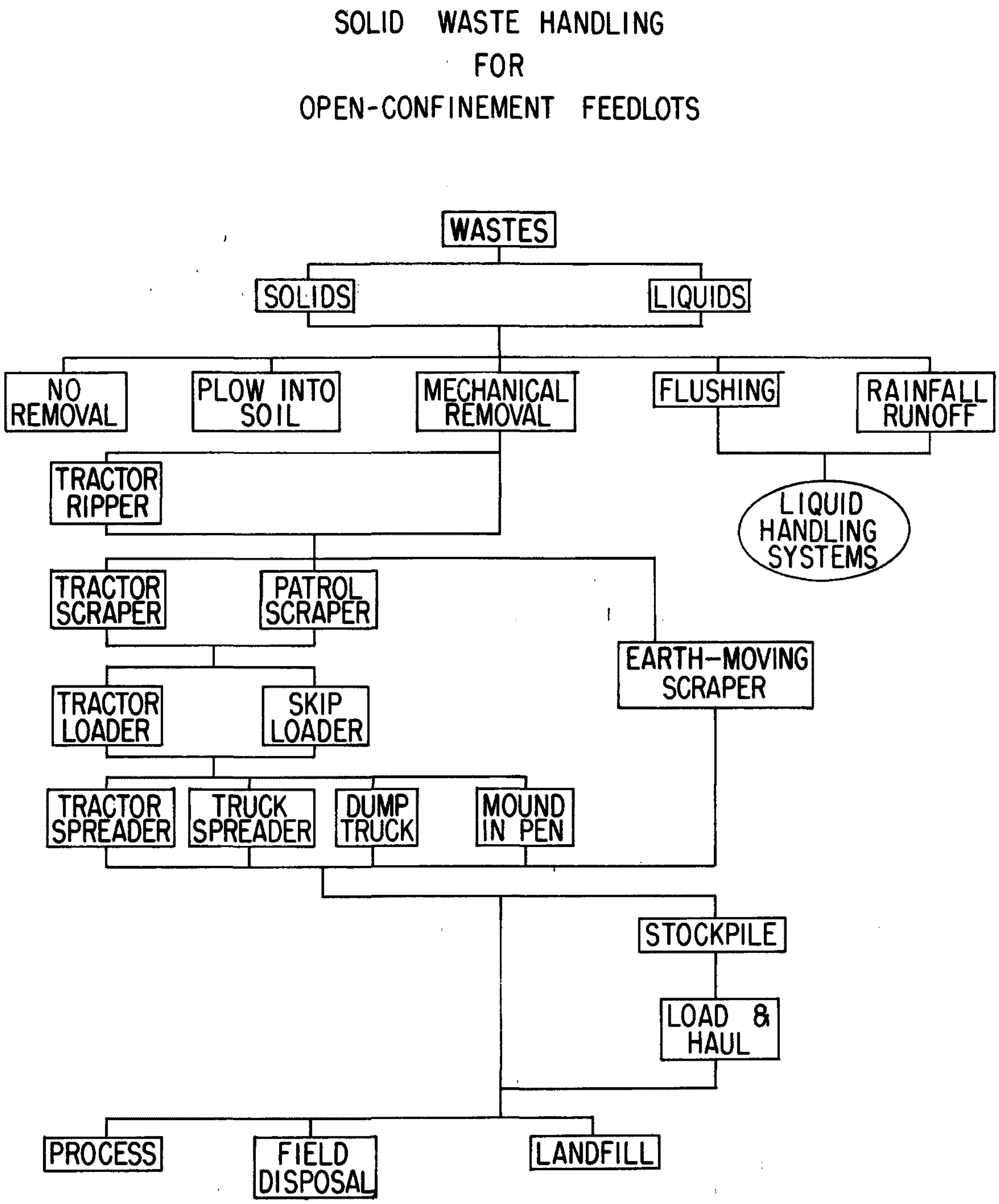


Figure 2. Alternatives for handling solid wastes from open feedlots

loader with tractor. Stockpiling in the center of the pen provides a temporary storage area and also in many cases a mound for which the cattle will be able to rest and keep dry. These mounds are sometimes formed in the fall of the year for use during the winter months and then are removed during the summer months. Other operators build a mound from the first year's manure production and leave the mound to serve as a permanent resting area for the cattle. When manure is stockpiled in a separate location, more than one handling is required. The most efficient hauling method is immediately hauling the waste directly to the point of ultimate disposal. However, most farmers prefer to have the solid waste material stockpiled for several months so there is less likelihood of viable weed seeds being transmitted to the fields.

After the solid waste material is scraped and possibly windrowed or temporarily stockpiled in the center of the pen, it is ready for loading and transporting. Using a tractor and front-end loader or commercial loader, the material can be placed into one of the following:

1. dump truck
2. truck spreader
3. tractor and spreader

Most of the larger open feedlots use dump trucks or truck spreaders. Trucks can transport the material to a stockpile location, directly to a field location, or to a processing or treatment point, such as a digestor. Feedlots, utilizing the tractor and spreader system, generally haul directly to the fields. Some operators prefer a truck spreader for placing the material into a stockpile because it breaks up the chunks and makes the material easier to remove. Bacterial action occurs in the stockpile which helps decompose the material.

Some feedlots use large earth moving equipment for pen cleaning. They are capable of performing several operations with one piece of equipment. If the feedlot pen sizes are large enough, these larger pieces of equipment can enter the pens, scrape the pen surface and load in one operation. The material is then hauled to a stockpile area or in some instances, hauled directly to fields. However, hauling directly to the fields may require considerable travel distance to and from the fields. Large earth moving pieces of equipment represent large investments. Therefore, they have to be used for the cleaning of large feedlots on an almost continuous basis. Most of these pieces of equipment are used by road building contractors or manure hauling firms for manure hauling. These manure hauling firms can service several large feedlots and therefore make efficient time use of their equipment.

Many feedlots contract to have the waste material scraped, loaded, and hauled from the pen surfaces. In most cases, the manure is given to the contractor. The contractor then performs removal operation and sells the material to farmers or orchard operators. The general rate of charge to the farmers is about $2.50 per ton of material hauled within a five mile radius of the feedlot. A few feedlots receive $.25 per ton for the material. Some feedlots require that farmers with whom they contract feed grain, haul manure back to their farms for ultimate disposal on the fields.

Characteristics of Solid Waste Material--To design solid waste handling equipment or processes and to determine the costs for handling the material, the engineering properties of the solid waste material must be known. Unfortunately many of these properties are not known or are highly variable for solid waste coming from open feedlots.

There are many variables affecting the physical characteristics of the solid waste. Rainfall runoff carries some of the solid wastes off from the feedlot surfaces. Cattle may trample the manure into the soil and cause a mixing action. Therefore, some soil may be removed when the feedlots are cleaned. Bio-degradation of the solid waste material will take place under favorable temperature and moisture conditions. Increasing the density of the cattle in the feedlot causes an increased amount of manure to be deposited upon the feedlots, and in most cases, makes the feedlot surfaces damper. When feedlot surfaces become dry, they become dusty. There is some odor associated with the dust carried off by the wind from the feedlots. Odors are prevalent when the feedlot surfaces are moist and temperatures are high enough for bacterial action to occur.

Some typical amounts of solid wastes removed from feedlots with about 6% slope located near Lincoln, Nebraska (20) and Pratt, Kansas (50) are presented in Table 3. The dry matter removed in tons per day per animal is presented in the table. The moisture content is also given so that the total weight of the material removed including the moisture, can be calculated by the following expression:

Table 3. Solid Waste Removal from Feedlots

Feedlot Location	Days Accumulated	Date of Removal	Animal Density (ft^2/animal)	Dry Matter Removed (tons/day/animal)	Moisture Content (% w.b.)
Eastern Nebraska	112	Nov. 7	100	.00429	52
	112	Nov. 7	200	.00286	54
	203	June 27	100	.00713*	33
	203	June 27	200	.01005*	40
South Central Kansas	163	Feb. 25	250	.00789	39
	290	Aug. 21	261	.00683*	34
	287	Oct. 7	238	.00794*	24
	153	Nov. 14	208	.00521	39

*Values based upon pen capacity rather than total number fed during two feeding periods

$$TW = \frac{100\ D}{100-MC} \quad \text{where } TW = \text{total weight, tons/day/animal}$$

MC = percent moisture content

D = dry matter removed, tons/day/animal

The amounts for the longer time periods of 200 days or more represent the accumulation from two pens of cattle before cleaning. A comparison of the solids removed from an unpaved feedlot in eastern Nebraska versus the slope of the lot is shown in Figure 3.

A rule of thumb of approximately one ton of material per animal per feedlot, has been commonly used as the amount of solid waste material that has to be removed from an open feedlot. Based upon the Pratt, Kansas feedlot data for a 150 day feeding period, the amount of dry material removed per animal ranges from approximately 0.75 tons/animal to about 1.2 tons/animal. If one considers that the moisture content of the material is approximately 40% wet basis, then the range in total weight of the solids removed per animal is from 1.2 tons to 2.0 tons per animal. Some of the variation in the data was probably due to cattle being in the pens for more than one feeding period before the material was removed, permitting more mixing of the soil and feces. Also, when lots are in very sloppy conditions, mixing of soil and manure by cattle activity is increased. Soil mixing is greater on steeper slopes, 6 to 10%, than on lower slopes, such as the 3 to 6% slopes. The Nebraska studies indicated that up to 95% of the dry material removed from the lot was soil. Also, it has been shown by McCalla, et al., (55) that 55% of the fecal organic matter is biologically degraded on the lot itself.

Grub (26) found that if the accumulated waste is kept moist, either as a result of maintaining a high density of animals in the feedlot or due to weather conditions, biological degradation of the waste proceeded at a rate proportional to its temperature. As long as the moisture content of the waste exceeded about 40% w.b., a 10°C rise in temperature roughly doubled the rate of which degradation occurs. During dry weather, when the organic mass contained as little as 2% w.b. moisture, very little biological or chemical activity occurred.

Mielke, et al., (58) found little evidence of pollution of the ground water in the proximity of a level feedlot in the Platte River Valley near Central City, Nebraska. The feedlot was located over a permeable silt loam soil with a fluctuating high water table. The stocking rate was about 400 square feet per head during the winter months. About

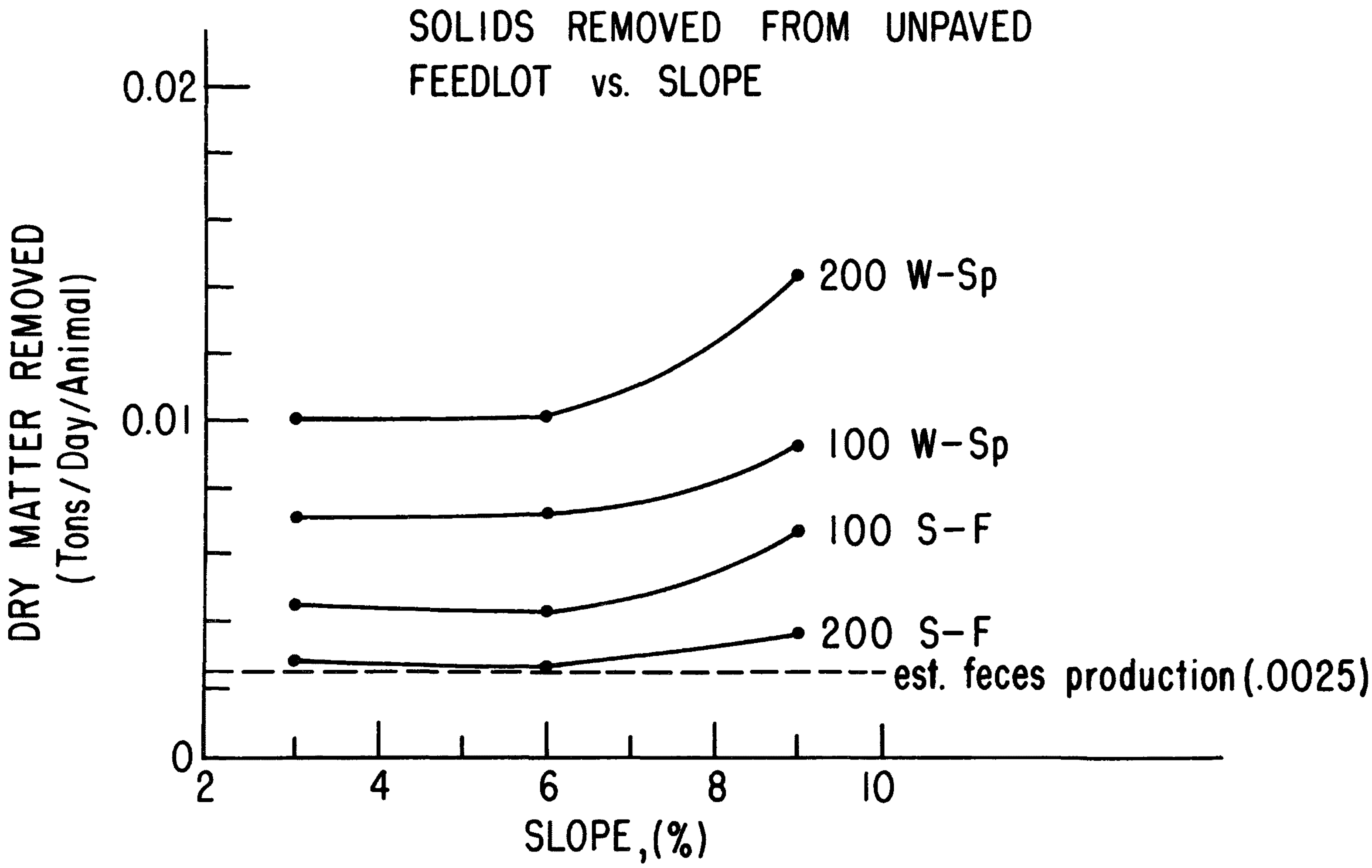


Figure 3. The effect of slope on the removal of solid wastes from an unpaved feedlot in eastern Nebraska

one foot of organic matter had accumulated on the lot between 1950 and 1969 despite no cleaning of the feedlot surface. Most of the water that reached the lot from precipitation and animal waste was lost by evaporation and very little surface runoff occurred from the feedlot. The manure pack and the soil surface interface apparently provided an effective barrier to water movement. A laboratory study showed that 90% of the nitrogen initially in the manure or added in urine was lost to the atmosphere during spring and summer climatic conditions.

Apparently, aerobic conditions exist on the air-surface interface of the feedlot waste. However, anaerobic conditions exist deeper in the manure pack. The increase in oxygen demand in the manure pack then results in soil and fecal organisms reducing nitrates. Stewart, et al., (81) found that a beef feedlot infrequently cleaned showed low nitrate concentration, whereas a frequently cleaned dairy corral exhibited nitrate accumulations in the soil profile Apparently, under the aerobic conditions, carbonaceous materials are rapidly oxidized to carbon dioxide; microbial cells are synthesized; and nitrates, sulphates, and inorganic phosphate tend to accumulate. Under anaerobic conditions, denitrification occurs with wet soil conditions and a considerable amount of the nitrogen may be lost to the atmosphere along with other anaerobic decomposition products.

McCalla, et al., (56) investigated the manure decomposition and fate of breakdown products in soil. In laboratory tests they found that after three weeks of decomposition, 90% of the nitrogen added initially in the manure or subsequently in the urine was lost to the atmosphere with a stocking rate of 50 square feet per animal. About 50% of the volatile solids were lost in four months. Application of animal waste to the surface or incorporation in the soil is followed by further decomposition. Three-fourths or more of the organic materials are decomposed in the first year.

Equipment and Labor--There is a lack of useable data for evaluating the economics of handling solid animal wastes. Fairbank (18) reviewed the operation of a large commercial feedlot cleaning operation that scrapes, hauls, and spreads solid wastes from feedlots in southern California. They use spreader trucks costing about $30,000 each and capable of carrying 15 tons. Additional transports carry up to 56 yards per load. They seldom haul the waste more than five miles from the feedyard to a field. They clean, haul, and spread for about $.75 per ton.

In the Southern High Plains region, many of the large feedlots contract to clean the lots and haul the waste. The feedlots generally give the waste material to the contractors and the contractors then market the material to farmers. The general rate is about $2.50 per ton for delivery within a five mile radius of the feedlot.

Webb (91) reported on an economic analysis of feedlots of 1,000, 5,000, and 10,000 head capacity. He analyzed the various operations around a feedlot including the waste handling operation. He found that the annual costs per head of capacity for the mounding operation only in the pen cleaning operation was $.15, $.09, and $.09 per head for 1,000, 5,000, and 10,000 head capacity respectively. For cleaning pens, he found approximately 800 feet, 1500 feet, and 2500 feet travel distance were required respectively. He also gave a breakdown of the ownership and operating cost for the equipment used for mounding and cleaning pens for the three sizes of lots.

An analysis of the cost and number of pieces of equipment for solid waste handling operations determined by this study will be presented in Chapter VI. Various systems will also be compared for various feedlot sizes.

Runoff-Carried Waste

Runoff control from feedlots should be an integral part of the feedlot design and operation. If uncontrolled, the feedlot runoff proceeds to the adjacent water courses carrying the waste material in solution or suspension. Analyses of feedlot runoff by various investigators have shown that runoff is characterized by high biochemical oxygen demand (BOD), high chemical oxygen demand (COD) and high contents of other pollution indicators. It is difficult to apply domestic or municipal waste treatment techniques to runoff wastes because of the intermittent nature of the flow which is based upon rainfall or precipitation events and also because of the extremely high solids content in the waste material.

Handling Alternatives--Alternatives for the handling, treatment and disposal of runoff-carried wastes are illustrated in Figure 4. The system consists of the pen drainage system, collection and transport drains, solids settling area for some systems, holding or treatment area, and ultimate disposal, chiefly by irrigation or evaporation.

There are many variables which influence feedlot runoff. Such factors include the size of the lot, the density of

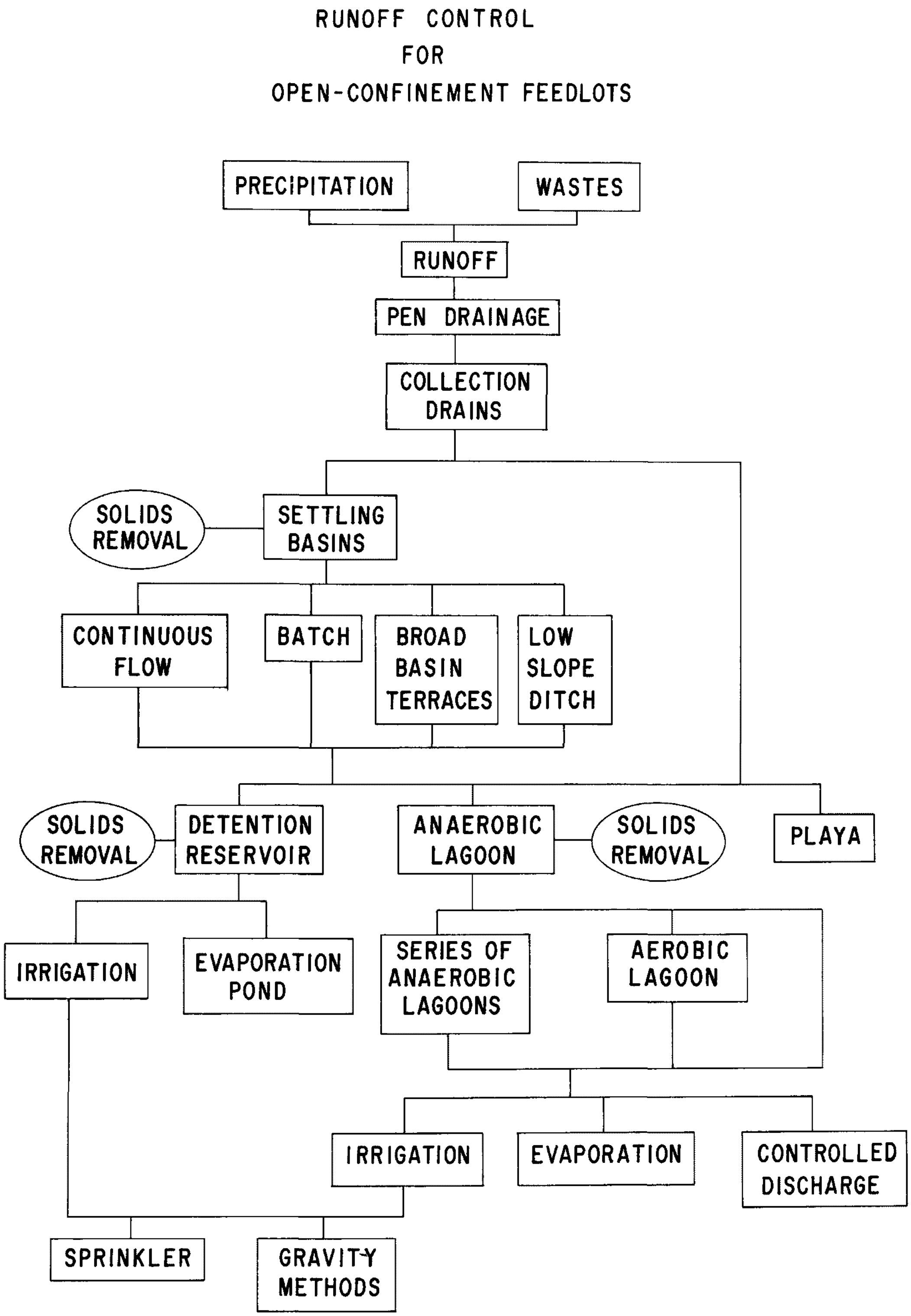


Figure 4. Alternatives for the handling, treatment and disposal of runoff-carried waste

livestock in the pens, the cleanliness of the lot, general topography of the area, the location of the lot with respect to receiving stream, the amount and intensity of rainfall, and the nature of the drainage basin.

Pollution control, therefore, requires a system which prevents feedlot runoff from entering the stream, treats the runoff before releasing it to the stream, returns the waste to the land, or some combination of these methods, according to Crawford (15). The solution for runoff control consists essentially of retaining the runoff and returning the collected runoff to crop land by irrigation. The design of a feedlot runoff control facility requires knowledge of the hydrology of the geographical area and the application of hydraulic principles to the specific lot.

Precipitation and evaporation are two climatic variables that should be known for the particular site. The site selection of the feedlot is a very major consideration when designing the collection and runoff control facilities. It is suggested that diversion terraces be constructed around the feedlot to prevent runoff from adjacent land traversing the feedlot and thus requiring greater collection and disposal facilities. The design and operation of the individual pens in feedlots influence the design and operation of runoff control facilities. Of particular importance is the cleanliness of the pen. A regular program of solids removal will lessen the amount of solids flushed into internal drainage facilities and overall runoff control facilities and reduce the amount of dissolved organics in a liquid runoff. However, it should be pointed out that according to some studies a thin layer of manure should be left on the lot surface during cleaning operations in order to reduce the possibility of movement of nitrates and other pollutants into the ground water.

A number of considerations enter into the location and design of the retention facilities. Some of these considerations are the availability of a suitable site, the terrain, the feedlot runoff conveyance system, accessability and allowance for expansion. The optimum capacity of the retention facility will be determined essentially by the size of the feedlot, climatic conditions, and terrain. It is suggested that each set of retention facilities should include two or more settling basins as the first stage of control for the retention of solids flushed from the feedlot surface. Properly designed basins make the removal of the solids that have been flushed from the feedlot surface easier than cleaning the bottom of a large volume pond. When the collected runoff is stored for any appreciable length of time, odors will arise from the decomposition. At present, the most effective method of odor control is the rapid removal of stored liquid.

Feedlot Hydrology--Due to the many variables affecting runoff and their wide variations, particularly the climatic variables such as precipitation intensity, it has been difficult to predict the characteristics and quantity of runoff from an open feedlot. Several researchers are attempting to determine the runoff characteristics from beef feedlots in various beef producing areas, principally in Kansas, Nebraska, Colorado, and western Texas.

In Kansas, Lipper (48) found that cleaning lots reduced runoff pollution for no more than two weeks following cleaning. Accumulating manure in packed mounds in the lots over extended periods had little effect on the nature of the runoff. Pollutant concentrations were approximately twice as great from a concrete lot as for an unsurfaced lot. Factors contributing to high concentrations were warm weather, lower rainfall rates, and feedlot surfaces already wet before rainfall began. For design purposes their hydrologic observations indicated that Soil Complex Numbers of 94 and 91 for the concrete lot and for soil surfaced lots using the Soil Conservation Service Design Manual could be used to relate runoff rates to rainfall amounts.

Grub et al., (25) studied the effect of feed, design, and management on the control of pollution from beef cattle feedlots located in west Texas. If the accumulated organic mass on the feedlot floor is slightly damp when precipitation begins, it can readily absorb a large quantity of rainfall at a rapid rate. If it is dry and tightly compacted, it provides a relatively impervious barrier to the initial penetration of moisture. Thus, a high intensity rain falling on a dry lot surface may result in rapid runoff and consequent removal of large quantities of organic matter from the feedlot surface, while the same intensity of rain falling on a damp lot might cause little or no runoff.

Another study in west Texas by Wells, et al., (92) found that a concrete lot retained an average of .38 inches of rainfall for each precipitation event. This amounted to approximately 0.5 inches of moisture retention for an inch of accumulated mass during the spring period. During the fall period, concrete surface lots had approximately 0.45 inches of rainfall retention per inch of precipitation in lots when all-concentrate ration was fed and 0.57 inches of retention per inch of precipitation in the lots when 12% roughage was fed. The dirt lot retained approximately three times as much rainfall during the spring as did the concrete feedlot. However, during the fall period (a high rainfall period) the concrete and soil lots had nearly the same retention.

Norton and Hansen (67) investigated cattle feedlot water quality hydrology in northeastern Colorado. They found that for short term rainfall durations of from 2 to 8 hours infiltration to the ground water was extremely small and could be neglected on determining the total runoff from cattle feedlots. Additional support for this conclusion was found when manure was observed to have a dry hard crust 2 to 4 inches below the surface of the manure after the runoff had ended.

Swanson, Mielke, and Lorimor (85) have reported on hydrologic studies for evaluation of the pollution potential of feedlots in eastern Nebraska. They examined the annual water balance of the feedlot surface and characterized the water leaving the feedlot. They found that runoff in the late summer and early fall may not be expected from rainfalls of 0.5 inches or less unless earlier rainfall had occurred within the previous 72 hours. From 15 rainfall events totaling 12.40 inches of rain they found 5.45 inches of runoff resulting over the four month summer-fall period. They found that: (1) infiltration on an established beef feedlot appears to be restricted to water storage in a manure pack, (2) the runoff from a feedlot is a function of the area of the lot, (3) annual runoff from a beef feedlot may be 2 or 3 times that of adjacent crop land, (4) despite increased runoff in comparison to adjacent crop land, the protective mulch of the manure pack keeps erosion losses below those of the crop land. Observations of other feedlots by these researchers indicated that long, steep slopes in a feedlot create high velocity over-land flow causing scouring just as on uncultivated field slopes.

Gilbertson, et al., (20) reported on the effect of animal density and surface slope on characteristics of runoff, solid waste, and nitrate movement on unpaved beef feedlots. They found runoff from feedlots from rainfall and snow melts was highly variable. Runoff appeared to be more dependent on rainfall than on feedlot slope or cattle density. Runoff from the eastern Nebraska feedlots resulted when there were storms producing rainfall greater than 0.4 inches. Feedlots with 100 square feet per head averaged a runoff of 81% of the precipitation (in the form of snow) resulting from the winter thawing. Runoff from low density lots of

200 square feet per head yielded an average of 54% of the snowfall. For an individual storm, runoff was about 70% of the rainfall, while the annual runoff was 40% of the accumulative rainfalls, including snow.

Detention Reservoir Design--The amount of feedlot runoff to be retained in reservoirs can be determined by using the Soil Conservation Service method for estimating the amount of direct runoff from rainfall (69). The procedure is roughly as follows:

1. Determine the drainage area (DA). Ideally this drainage area should include just the feedlot area and not include other outside drainage areas. Thus, a diversion terrace should be installed around the feedlot to divert outside waters.

2. Determine design storm rainfall (P). The design storm rainfall depends upon the state laws and regulations governing the design of the retention structures as indicated in Chapter I. The most common design storm rainfall is the 10-year 24-hour storm. However, Oklahoma uses the 5-year 48-hour storm as indicated in Figure 5. (88).

3. Determine the runoff (Q), in inches. The runoff can be estimated by the following equation:

$$Q = \frac{(P-0.352)^2}{P+1.41}$$

where Q = inches runoff
P = inches precipitation

This equation is based upon the SCS method of estimating the amount of direct runoff from rainfall for their classified conditions of antecedent condition III, soil group D, land use farmstead, and S = 1.76, where S is a dimensionless factor. This equation closely matches experimental results found at Nebraska, Kansas, and Colorado. It takes into account some storage on the feedlot surface by storing approximately .4 of an inch on the feedlot surface. This curve is shown in Figure 6. For rainfalls over 1/2 inch, a quick rule of thumb, based upon the Nebraska data is:

$$Q = P \times 0.7$$

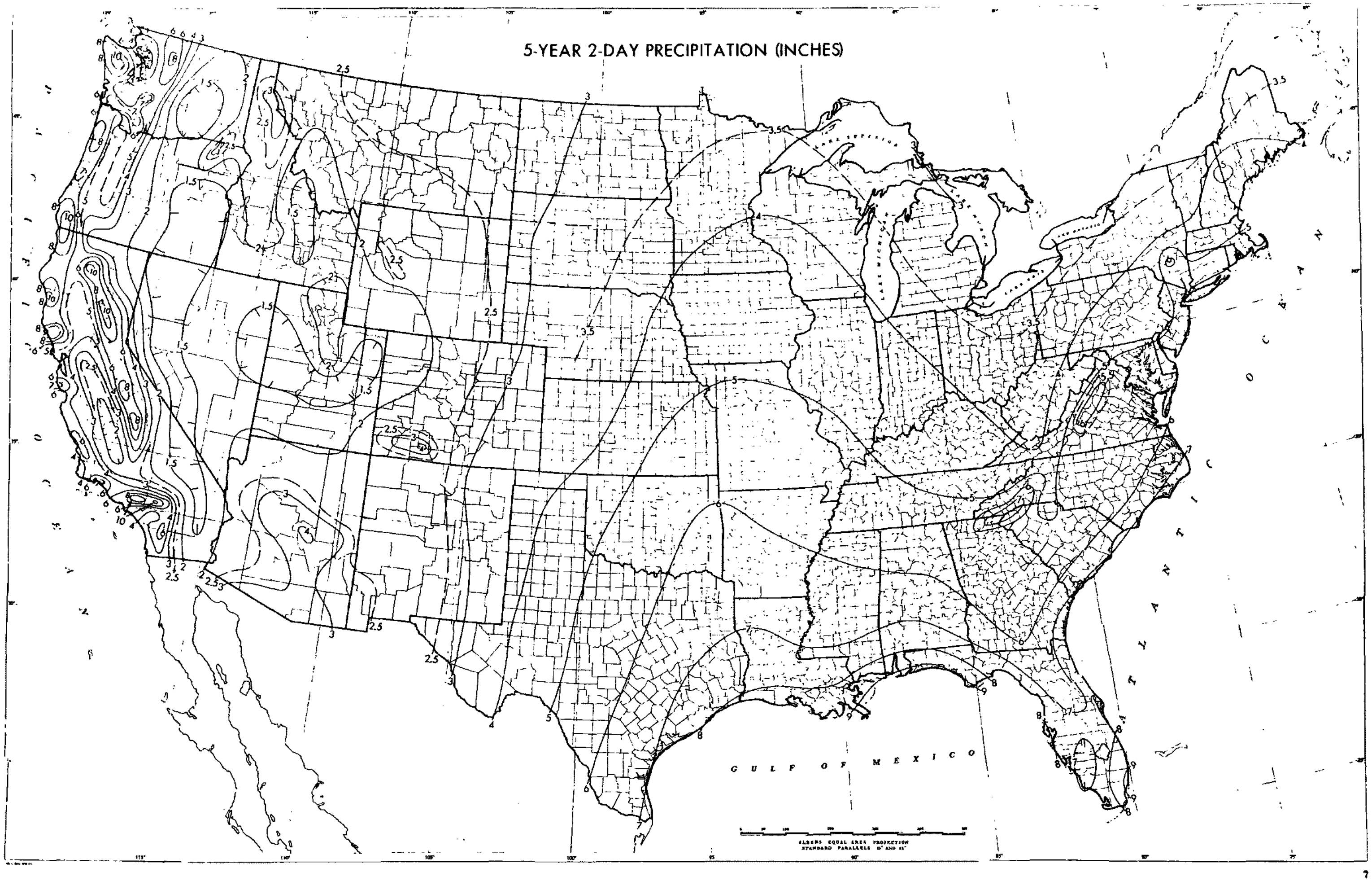


Figure 5. Two-day precipitation for five-year return period in the United States (Tech. Paper 49, Weather Bureau, 1965)

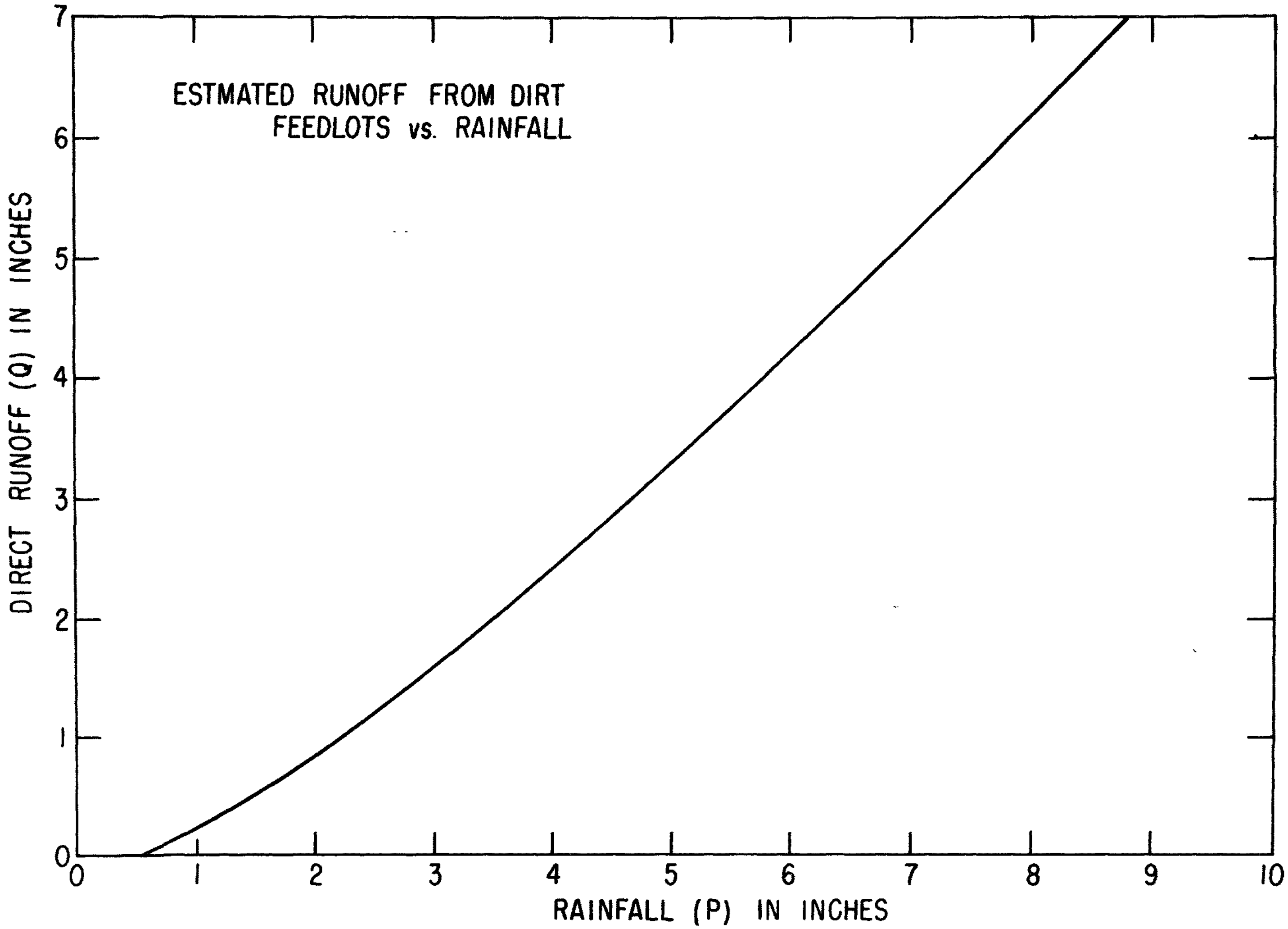


Figure 6. Feedlot runoff-storm precipitation relationship

4. The volume to be retained by the runoff detention structure can be calculated by the following expression:

$$V = \frac{Q \times DA}{12}$$

where V = acre feet

or,

$$V' = 3,630\ Q \times DA$$

where V' = cubic feet

5. Design the spillway. The spillway design is based upon the peak discharge. An SCS design manual for small structures can be used. The spillway design depends upon the slope of the drainage area, land use, soil group, drainage area, and rainfall intensity.

Settling Basins--Based upon the Nebraska results, a settling area can be designed for open dirt beef feedlots using the following procedure (21). To determine the design volume for a settling area, one has to have knowledge of the amount of settleable solids in the runoff. Also, a certain volume of water or liquids in the settling area has to be contained to slow up or detain the runoff to permit the solids to settle out. A suggested design criteria is to add the volume of the settleable solids to the volume of a one inch runoff for the feedlot area. The steps then are as follows:

1. Determine the settleable solids accumulated.
   A. Determine the drainage area, A.
   B. Determine the design rainfall, DR, 10-year one-day or 5-year two-day.
   C. Determine the runoff from the drainage area, R.
      R = A x DR x 0.70

      where R = acre inches
      (also the SCS method could be used for determining runoff as explained in the previous section)
   D. Determine the solids (ST) in runoff.
      ST = R x 1.3 tons/acre inch

      where ST = tons
      For winter conditions use 7.0 tons/acre inch.

E. Determine the settleable solids, (SS).
$SS = ST \times 0.50$

where SS = tons
(The Nebraska results found approximately 50% of the settleable solids settled out in a basin.)

F. Determine the volume of the settleable solids, (V_{SS}).
$V_{SS} = SS \times 32.05$ cubic feet per ton

2. Determine the volume of the one-inch runoff for the feedlot area.

$$V_F = \frac{A}{12}$$

where V_F = cubic feet
A = square feet

3. The design value for the settling basin volume is then:

$$V = V_{SS} + V_F$$

It should be noted that this is only an approximation and may be suitable only for areas similar to eastern Nebraska. This empirical procedure may not apply to other geographic areas where the nature of the rainfall or other conditions could be considerably different.

Gilbertson et al., (22) developed two experimental systems for removing settleable solids from outdoor beef cattle feedlot runoff. One system is called a batch system and the other system is called a continuous flow system. The systems are illustrated in Figures 7 and 8.

For the batch system the components are a primary settling basin and a secondary basin. All runoff from a given storm event is trapped within the primary settling basin and detained, allowing the heavier solids to settle to the bottom of the basin. The supernatant is pumped from the primary basin into the secondary basin for longer detention times. The continuous flow system consists of a series of porous dams. The porous dams reduce the velocity of flow sufficiently to allow the heavier particles to remain in the settling channel while the liquids flow by gravity to a liquid storage pond. The porous dams are constructed of crushed rock and planking, with cracks between the planking.

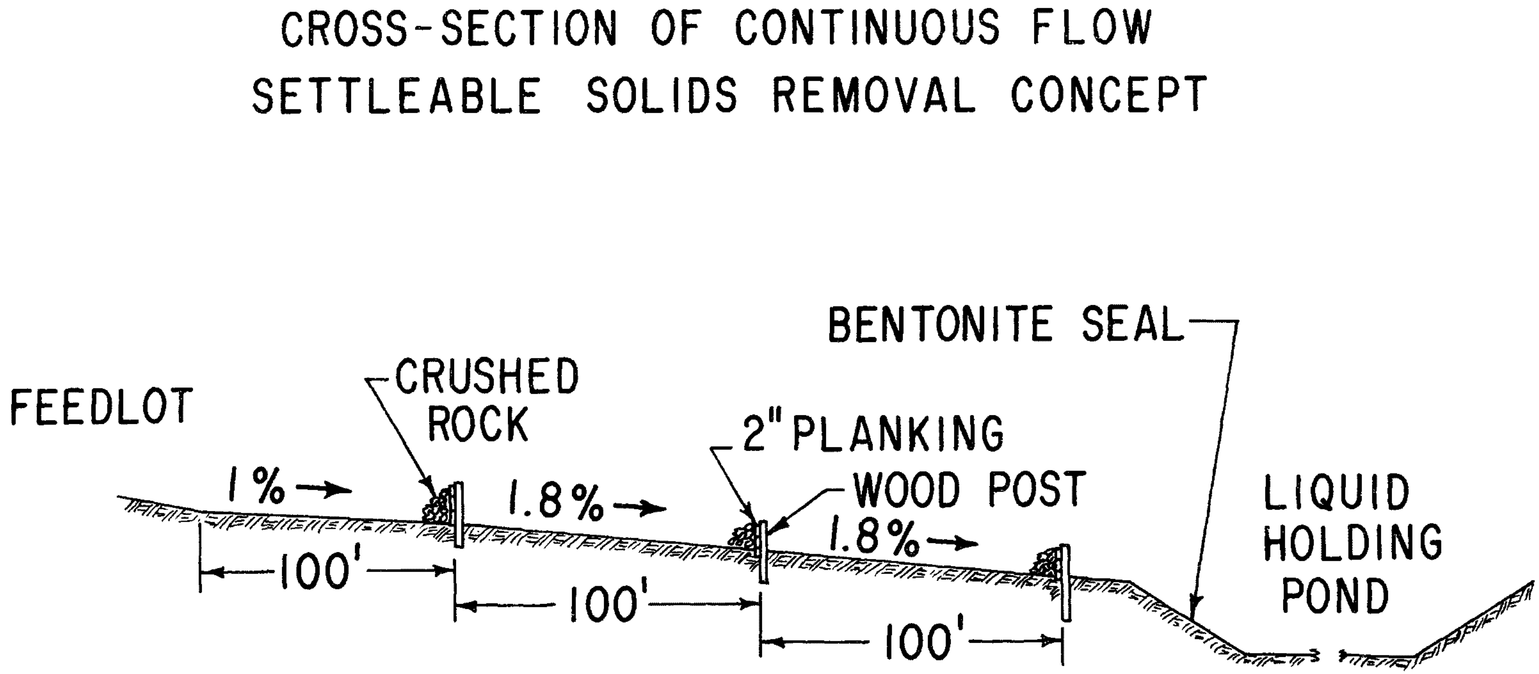


Figure 7. Schematic of continuous flow concept for removing settleable solids in runoff (Gilbertson, et al., 1970)

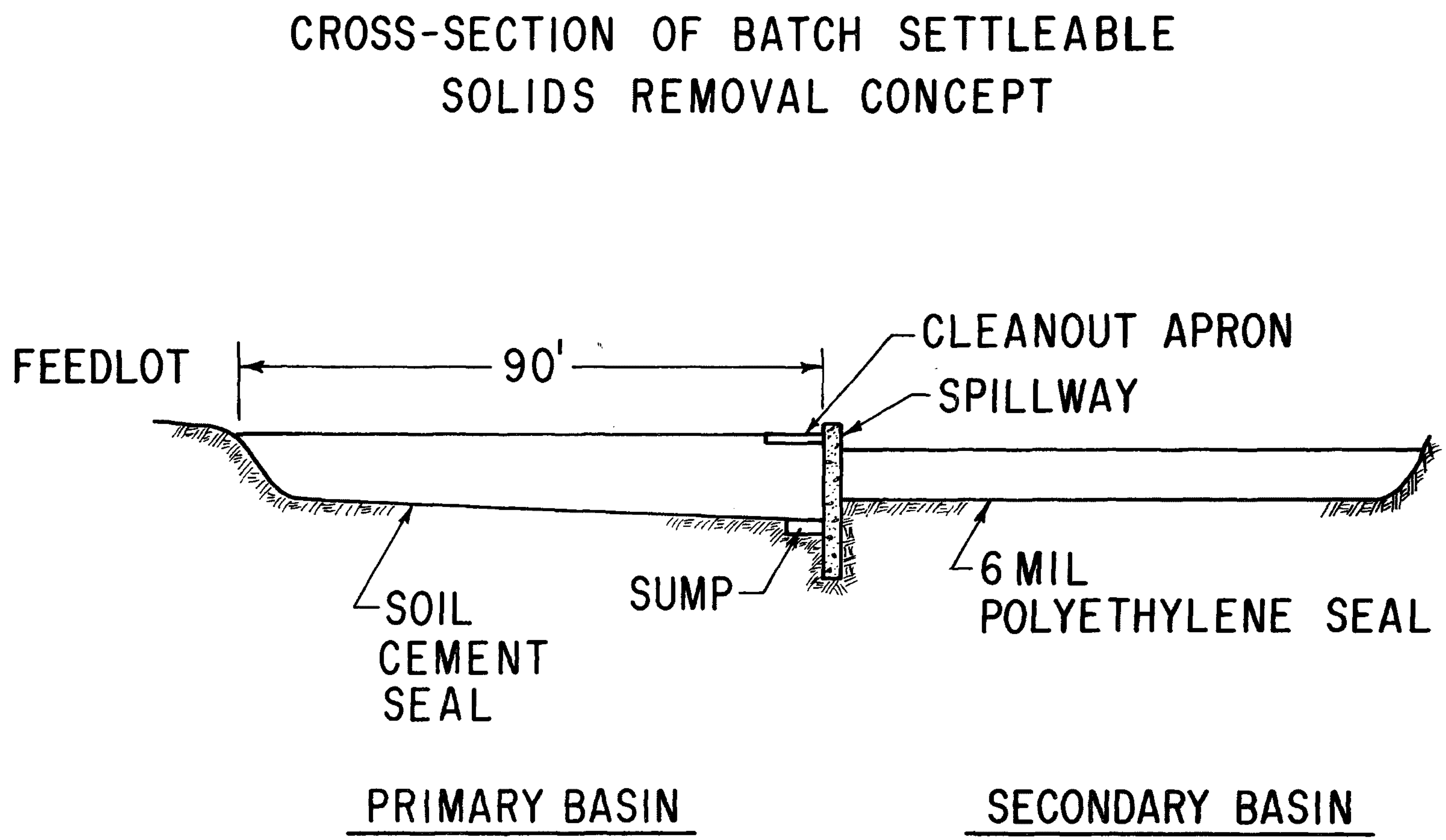


Figure 8. Schematic of batch collection basin for removing settleable solids in runoff (Gilbertson, et al., 1970)

The batch system removes the settleable solids efficiently; however, the system is difficult to maintain. The primary settling basin must have sufficient capacity to prevent direct overflow to the secondary basin. Also, removing the accumulated solid, with the primary settling basin requires specialized equipment, such as a drag line bucket.

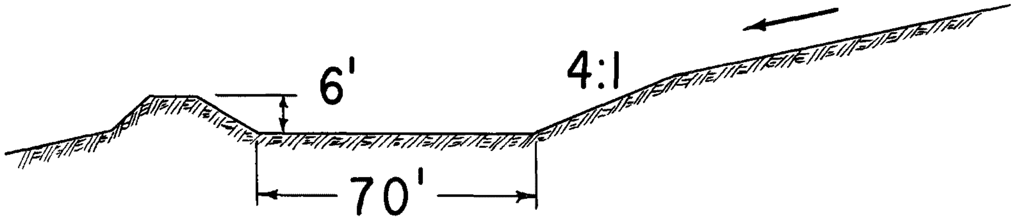
The continuous flow concept is a low maintenance method of controlling the settleable solids content of the runoff reaching the liquid detention ponds. A series of three porous dams in the settling channel of the continuous flow system remove about 50% of the total solids transported. The first dam removes 80% of this total. Front end loaders on tractors are utilized to clean the settling channel. Odors are not detected as readily from the continuous flow system as from the batch system. The settling of solids during the winter months present problems for both methods.

Swanson (84) developed a broad basin terrace concept of runoff control for eastern Nebraska, Figure 9. One lot with a 15% slope and a single basin was constructed where the feedlot had been in existence for more than 20 years. The basin was designed to have a capacity for the storage of 12 inches of runoff from the lot plus one foot of free board. This storage would be adequate for the total runoff in a normal year. However, storage was not planned for a long period since the effluent was to be pumped and distributed on adjacent crop land. The base of the broad basin terrace was approximately 70 feet across with a 4 to 1 slope going into the basin on the feedlot side. A six foot height at the lower terrace was constructed for this basin. These basins were constructed inside the lots and provided areas to push snow if necessary. Also, there was no problem with weed growth around the basin. Experience has shown that the basins dry out rapidly after drainage.

The side slopes of the basins and terraces have been of value as a bedding area for the cattle and for protection from the wind in cold weather. Some operators left the runoff in the basins during hot weather to provide an area where the cattle could stand and be comfortable. Apparently this reduced death losses when temperatures were above 100°F. In some cases, however, the basins have all of the moisture removed by evaporation during certain years. However, during other years the runoff may have to be pumped to another holding pond or possibly used in irrigation. A two inch accumulation of solids in the basin in one year was observed.

Another runoff control system was observed under construction in the fall of 1970 at the Farr Feedlots, Greeley,

SINGLE BROAD BASIN TERRACE



MULTIPLE BROAD BASIN TERRACE

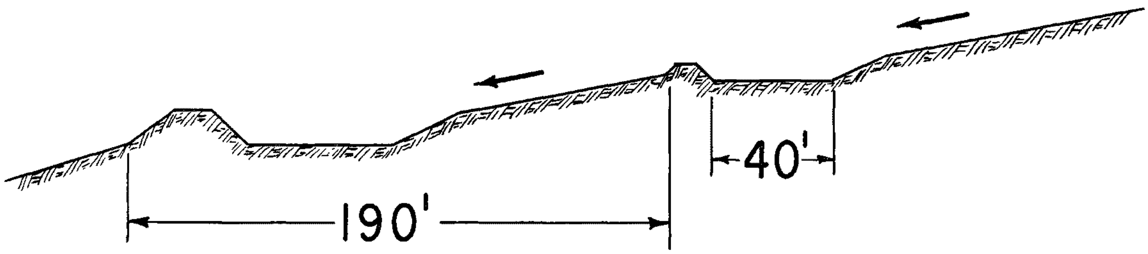


Figure 9. Schematic of broad basin terraces for detaining runoff from feedlots

Colorado. This system was designed by a consulting engineering firm. Drainage occurs between the mounds in the pens with the material flowing to a collection ditch located at the lower end of each of the pens. The collection ditch was designed with a 0.15% slope. This low slope was designed to permit rather low velocities of the runoff to occur and therefore to permit some of the solids to be settled out in the ditch. This ditch then traveled several hundred feet to retention structures. The ditch and the retention structures were designed to have the solids removed from the ditch within 10 to 14 days after a rainfall event, depending upon weather conditions. The runoff liquid in the detention structures was used on corn crop land by irrigation.

Systems--The choice of the runoff control system will depend upon local regulations, local climatic conditions, terrain, soil structure, water table and nearness to streams or bodies of water. Some of the alternatives are illustrated in the flow diagram of Figure 4.

The first phase in the selection of the drainage system is to determine the pen drainage design. There are various alternatives available as illustrated in Figure 10. Some of the methods have the runoff flow into a ditch that is formed in the pen and then the ditch may carry the runoff through not only that pen, but several pens in a row to a main collection ditch. If this system is used, the two choices that seem to work best are those that have the drainage ditch located approximately 30 feet behind the feedbunk and feeding slab or located at about the third point from the rear of the pen. The drainage ditch permits the pen to be well drained and also leaves some dry areas as resting places for the cattle. Another method permits the runoff to flow against the concrete feedbunks and then follow the feedbunks downhill. With this method, solids accumulate along the feedbunk. Thus, cleaning of the slab near the feedbunks has to be accomplished after the rainfall runoff events. Another system permits runoff to go through the working alley at the rear of the pens. Solids and liquids collect in the working alley, however, and create more undesirable working conditions.

The next major consideration is the collection ditch. Essentially, two choices are available here. One, design the collection ditch with a low slope so that solids will settle out, or two, design it with a higher slope so that many of the solids will be carried along. In cases where solids are carried along, a settling basin, a continuous flow settling using porous dams, or a batch settling system is desirable.

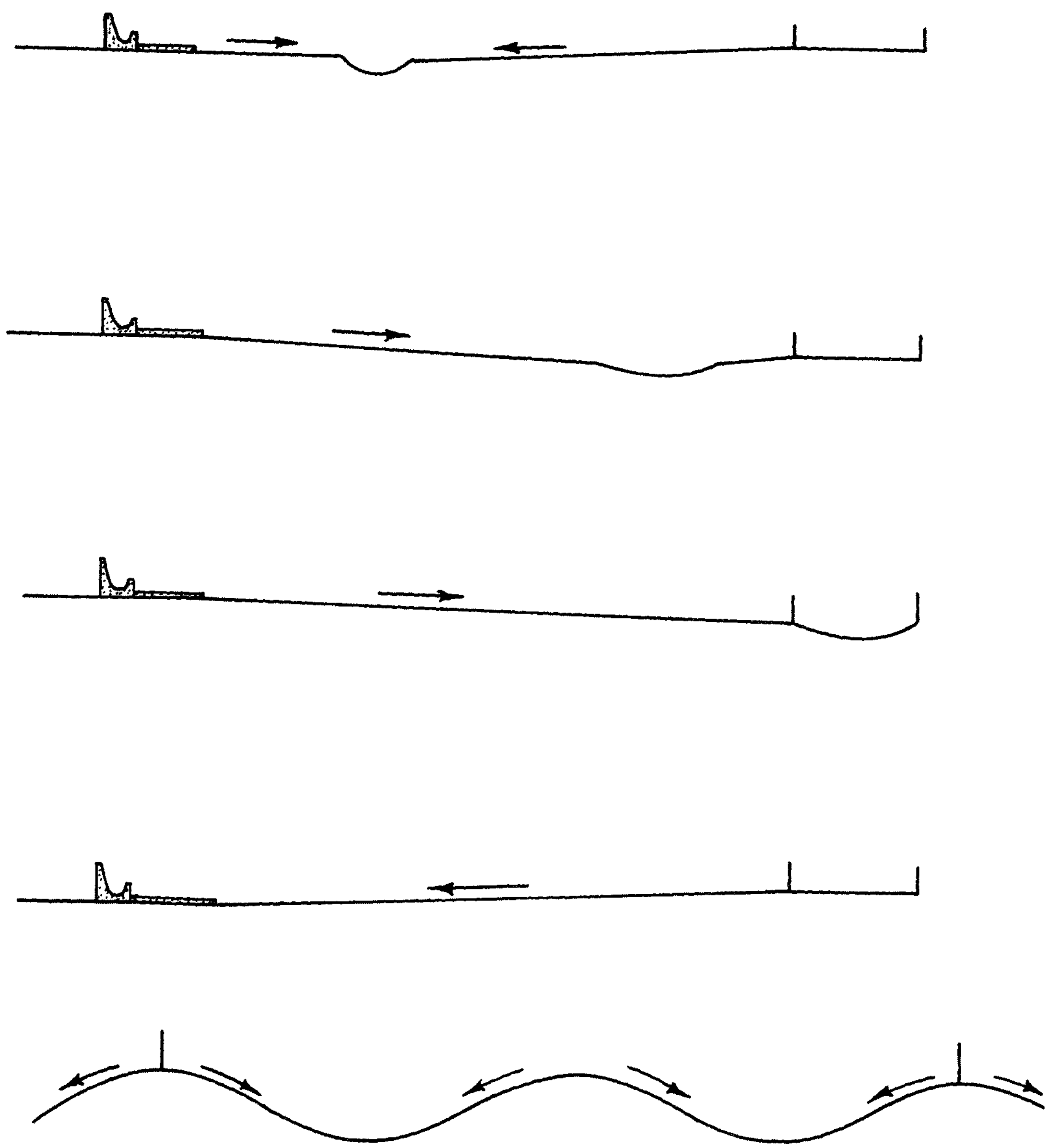


Figure 10. Schematic of pen drainage systems

After the collection system has been designed, one has a choice of using a settling basin or having the runoff go directly to a detention structure or possibly to a playa, or to anaerobic lagoons. A playa is a wet weather lake that has no outlet. These are located predominately in the southern High Plains area of Kansas, Oklahoma, Texas, and New Mexico. Playas usually contain some water during rainy seasons but are dry during the dry seasons. Thus, much of the liquid runoff evaporates from the playas. Apparently, from studies done by Lehman, et al., (48) in west Texas, there is little movement of nitrates or other possible pollutants through the soil surface of a playa into the water table. Lagoons for runoff control systems encounter operational problems because of slug loading arising from infrequent rainfall events. This type of loading upsets the biological balance within the microbial population of the lagoons. Thus, serious odors may arise from anaerobic lagoons. Anaerobic lagoons work best when fed on a regular basis, such as daily loading. Aerobic lagoons require considerable surface area and therefore generally have been unacceptable.

One of the suggested systems for controlling runoff from the open feedlots is that of providing a settling area for the solids and then having the liquids from the settling area proceed on to a detention structure or reservoir. Irrigation of crops with the liquids in the detention reservoir can then be done. With this method a high percentage of the solids are removed before the runoff enters the detention reservoir. The solids can be removed from the settling basins with conventional solid waste handling equipment. Evaporation and irrigation would remove the liquid portions of the runoff. Some states suggest removing the contents of the detention reservoir within a reasonable period of time, such as 10 to 15 days. This also recuces odors. The aim is to keep all of the material on the land and prevent any runoff from reaching public waters.

WASTE HANDLING SYSTEMS FOR CONFINEMENT BUILDINGS

The waste management system for confinement buildings depends greatly upon the floor type. The two general floor types are slotted floor and solid floor. Within these two categories, there may be minor modifications, such as partially slotted floor or totally slotted floor or in the case of a solid floor it may be a partially paved or a totally paved floor.

There are essentially three different systems for handling the waste material. The first is a solid handling system similar to the solid handling systems for the open confinement feedlots. The second system is a slurry handling system where both the feces and urine are combined to form the slurry without the addition of water. Third, liquid-flush systems may be used where water is used to remove and transport the waste material to a storage pit. A liquid flush system is used primarily with concrete solid floor systems.

Solids Handling Systems

The traditional solid floor systems have the cattle housed either on a dirt floor or a paved floor. Bedding is used in the resting area. For dirt floors, a concrete slab is generally located near the feedbunk, which is generally scraped periodically to remove the waste material from the area.

Schulz (78) presents some data from various sources on the amount of manure produced for cattle fed in confined feedlots with bedded solid floors. With about a 50% hay diet the average total excrement per day for an animal on full feed is 69.1 pounds and for a 20% roughage diet is about 35 pounds (Tables 4 and 5). For yearlings fed over 140 days on a paved floor in an open shed and adjoining paved lot, the average manure production was approximately 0.5 tons per head per month.

The alternatives for handling the solid waste material are indicated in the flow chart of Figure 11. Essentially, the steps involve scraping into a pile or loading directly into a spreader. For confinement barn facilities, the tractors and loaders are generally smaller than those used in open-type feedlots. The most common method is to use a front-end loader with a tractor and dump the material into a spreader that is pulled by a tractor. It is also possible to use a commercial type of loader in some of the confinement buildings where the loader is small enough to get around easily within the building or small lot. Truck spreaders or dump trucks may also be used for hauling the material.

There are three possible ultimate disposal alternatives for the material: processing, such as drying or composting, field disposal, or stockpile. The most prevalent method of disposal is to haul the material to the fields periodically. Generally it is hauled and spread in the fields during the spring of the year prior to tillage operations for planting corn or other crops. The material may also be hauled in the fall or throughout the summer if the hauling operation does not interfere with cropping practices. Stockpiling is

Table 4. Effect of Character of Ration on Amount of Manure Produced
Schulz (78)

Ratio of hay to corn to linseed meal	Average feces per day* (lb.)	Average urine per day* (lb.)	Total Excrement per day (lb.)
1:1:0	57.1	12.0	69.1
1:3:0	44.2	13.1	57.3
1:5:0	26.7	8.0	34.7
1:4:1	22.3	14.3	36.6

*For animals on full feed.

Approximately 15% less manure will be recovered from dirt floors than concrete floors.

Table 5. Manure Obtained from Cattle Fed on Paved Floor in Pen Shed and Adjoining Paved Lot Schulz (78)

Calves	Average Days Fed	Total Period (tons)	Per Month (tons)
Full fed with silage	229	1.82	0.23
Full fed with dry roughage	235	2.18	0.30
Full fed with ear corn silage	231	2.16	0.28
Wintered without grain	132	1.59	0.36
Yearlings			
Fed over 140 days	150	2.24	0.45
Fed under 101 days	91	1.52	0.51

WASTE HANDLING
FOR
SOLID FLOOR SYSTEMS

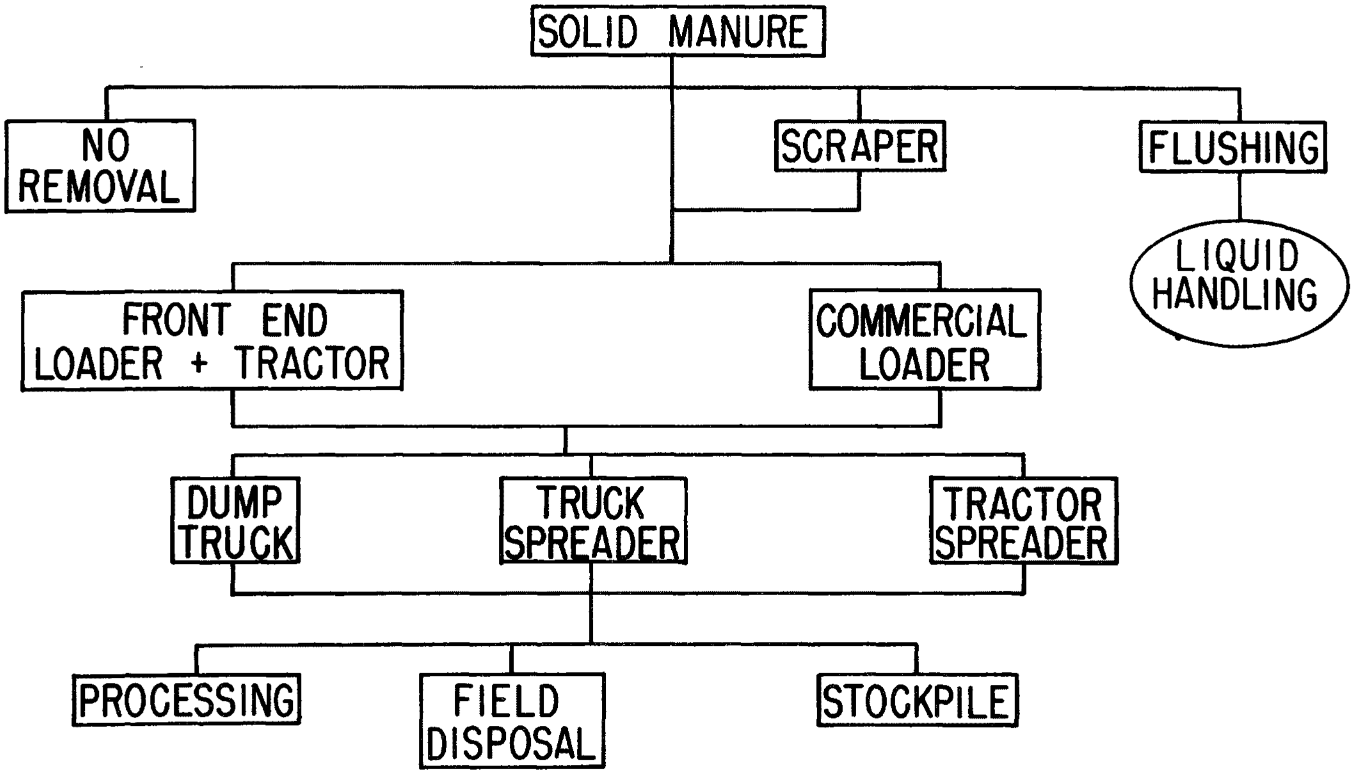


Figure 11. Alternatives for handling solid wastes from solid floor confinement barns

another possibility, but generally is only for a short term. During the warmer months, fly problems and other health problems may arise from stockpiled manure.

Slurry Handling Systems

Slurry handling systems are used primarily where slotted floor systems have been installed. The size of the pit underneath the slotted floors depends primarily upon the frequency of removal of the slurry, number of animals, and whether it is a partial or totally slotted floor. In most cases attempts are made to prevent extra water from entering the pit. The two major types of storage pits are: 1. a deep storage pit for storing the slurry for several months at a time and 2. a shallow pit for storage of the material for only a day, or at most a few days at a time. The latter system is primarily where a cable scraper is used to remove the slurry wastes on a daily basis.

Many of the pits for confinement buildings in the upper Midwest are designed for an 8 to 10 foot depth underneath a totally slotted floor or a partially slotted floor. Farmers estimate that the pits fill at the rate of about one foot per month for a totally slotted floor. For beef animals it can be assumed that approximately one cubic foot per day of manure is produced at a density of about 60 pounds per cubic foot and a moisture content of 85% wet basis for a 1,000 pound animal (32). This does not account for possible evaporation from the manure pit. The slurry for this type of confinement operation is generally removed two times per year, March-April and October-November. These times coincide with before and after the corn growing season in the upper Midwest.

The various alternatives for handling the slurry wastes from these deep storage pits are presented in Figure 12. The two choices for removing the slurry from the pit are to use a pump or to have a gravity flow system. Most use a chopper pump that is driven by a tractor. This pump can agitate the material in the deep storage pit which should not be over 40' by 40' dimension for good mixing. With the dimensions greater than 40' by 40' there have been problems associated with not getting solids from the corners. Mixing should be done for three-quarters of an hour to two hours prior to pumping the material into tank wagons. This insures adequate mixing of the solids that have settled out in the pit. Tank wagons are designed to haul the slurry to adjacent fields and spread on the surface or bury the liquid material into the soil by means of a plow device.

WASTE HANDLING
FOR
SLOTTED FLOOR SYSTEM
WITH STORAGE PIT

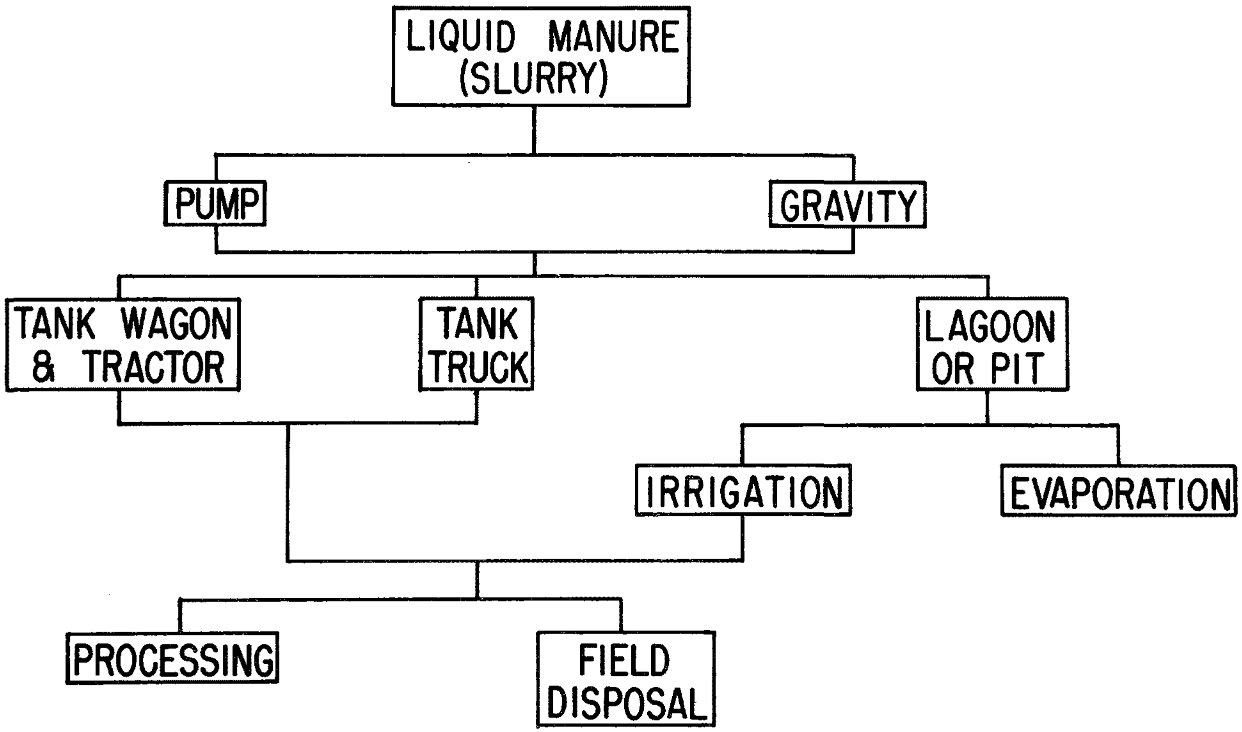


Figure 12. Alternatives for handling slurry wastes from slotted floor barns with deep pits

Filling the approximately 1500 gallon tank wagons is accomplished in 60 to 70 seconds using the manure pumps. Tank trucks could also be used to haul the material to the point of ultimate disposal. Instead of removing the material by tank trucks or tank wagons, the material could be pumped to a lagoon or pit for subsequent removal by an irrigation system or possibly by evaporation. Some systems, particularly for dairy installations, have pumped the slurry daily from a pit to grass land for distribution with a big gun type of sprinkler irrigation nozzles. However, for the dairy installations extra water is mixed with the slurry because of the washing operations around a dairy. Therefore, the manure has been diluted considerably from the normal slurry that would be found under a slotted floor. A few attempts have been made to process the slurry waste by drying or other means. Since the slurry contains about 85% water, a dryer would have to remove a tremendous amount of water to get the material into a form so that it can be handled with solids handling equipment. Thus, other means for de-watering the slurry and separating the solids are more feasible and require less energy than drying with heat.

A cable scraper system located in a pit from one to two feet deep underneath the slotted floors appears to be an increasingly popular method for manure removal. The cable scrapers are similar to those used in poultry installations. They scrape the material towards one end of the building where it collects in a cross conveyor or pit. From a pit at the end of the building or a central collecting pit for several buildings, the slurry can be pumped into tank wagons for field application or to other temporary storage locations. The cable scrapers are operated daily, so there is no major buildup of manure. Because of the daily removal, there appear to be fewer odor problems and fly problems than with some of the other handling systems, such as the solid handling system for confinement buildings or even for the deep pit storage system. When deep pits have their contents removed, considerable odors develop.

The alternatives for handling of the material from a slotted floor system using a mechanical scraper are illustrated in the flow chart of Figure 13. After the scraper has moved the material to the collection pit, there are several choices for further handling. Again it can be pumped directly for irrigation to a field or pumped to a lagoon for treatment or possibly go through a solids separation system where the liquids can then be pumped to a lagoon or a tank wagon for removal. The solids can be spread onto a field or composted. Another choice is to pump directly to the tank wagon and then

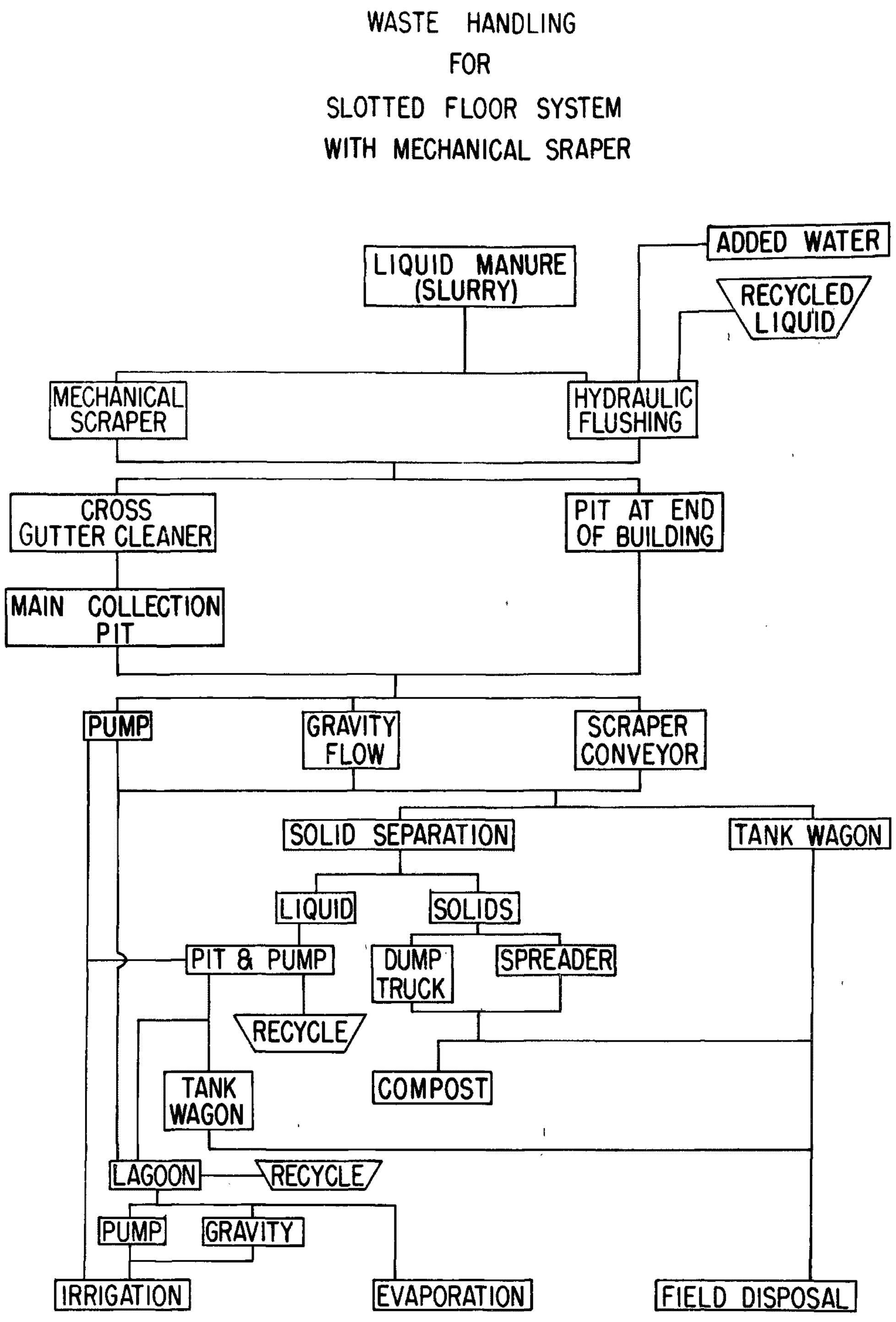


Figure 13. Alternatives for handling slurry wastes from slotted floor barns with shallow pits and mechanical scraper

transport the material to the field.

It is also possible to use hydraulic flushing systems instead of mechanical scrapers. With an hydraulic system, water has to be added, or possibly some of the liquids can be recycled for flushing. Recycled liquids could come from a lagoon or after solid separation has occurred. Pratt et al., (74) reported on a water reuse system for flushing down the floors of an experimental beef confinement building. The liquids could effectively be used to flush the waste material; however, the water remained rather dark in color after several different methods were attempted to upgrade the quality of the effluent. Also, odors were still prevalent. It appeared that recycled water would have to have some additional water added to it to keep the odors down and to recover some of the losses due to evaporation.

Liquid Flush Systems

Liquid flush systems for beef confinement buildings with solid floors are not prevalent in the upper Midwest or the colder climates, but offer possibilities for warmer climates. Liquids may have a tendency to freeze in some of the more open buildings. Also, when weather gets cool, conditions would be created where livestock may remain damp, particularly for solid floor systems.

Some of the alternatives available for a liquid flushing system for paved feedlots are illustrated in the flow diagram of Figure 14. A flushing system requires the addition of fresh water, reuse or low grade water. In areas where water use may be critical, a reuse system could be used. Disadvantages of liquid flush systems are: 1. additional water has to be added to make the waste material more fluid and easier to handle by pumps and 2. the additional water has to be handled, treated and disposed.

Liquid flushing methods around dairies sometimes consist of a low level dam which contains the wash water. When the dam is dropped or lowered, the water flushes down an alley picking up the solid waste material. This method has been used for some dairies where the cattle remain in the free stalls and deposit the manure in an alley. Another method utilizes pumps with high pressure spray nozzles permanently installed or with an operator directing the flow of the spray to flush the waste.

A feedlot near Devine, Texas, with an estimated capacity of 12,000 cattle, uses a flushing type of cleaning system (3). The feeding pens are 260' by 100' with a 2% slope. The

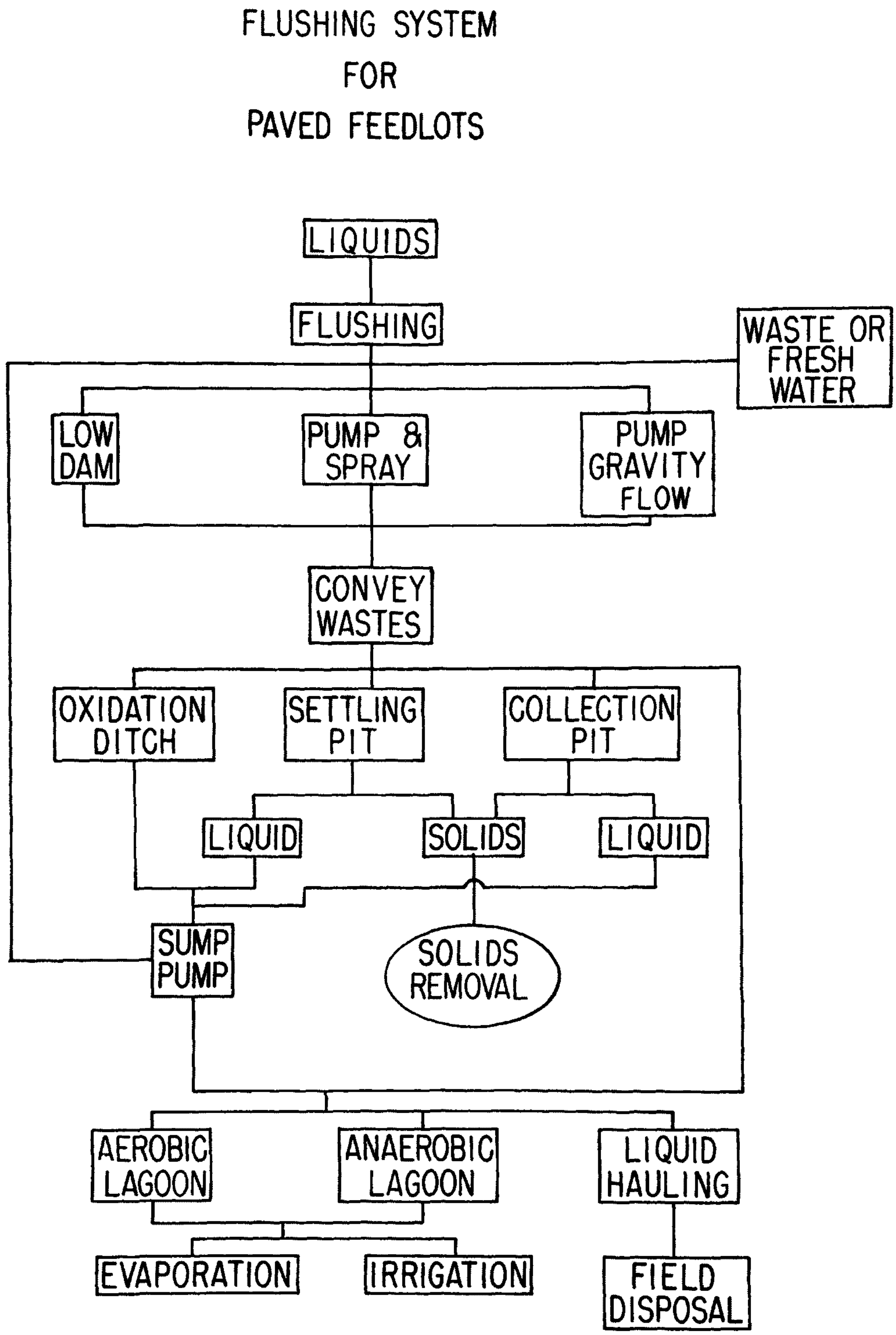


Figure 14. Alternatives for handling flushed wastes from paved feedlots

waste is flushed into a 12 inch underground sewer line at the lower end of each pen and through a 36 inch main to a half million cubic feet capacity concrete reservoir. A crushing device and pumps convert all of it into a slurry which is pumped to the fields through eight inch mains with an outlet station every 400 feet. The waste is sprayed on the coastal bermuda grass fields immediately after each cutting and is followed by six to seven hours of sprinkling with good quality irrigation water to drive the waste down to the root zone.

CHAPTER III

TREATMENT ALTERNATIVES AND DESIGN

Treatment is considered as any operation which improves the quality of the material either in a physical, chemical, or biological manner. In Chapter II, treatment of the waste was considered as an integral part of the waste management system. This chapter considers treatment alternatives and the design of treatment facilities in greater depth.

LIQUID TREATMENT SYSTEMS

The two basic biological treatment methods are aerobic treatment and anaerobic treatment. Aerobic bacteria break down the organic material when there is a sufficient supply of oxygen available. Anaerobic bacteria utilize the oxygen in the organic matter without the presence of dissolved oxygen.

Aerobic Treatment

Miner (61) discusses the aerobic metabolism process. Under endogenous metabolism, cell maintenance exists at all times but becomes predominate when there is just enough food to keep the microorganisms alive. Under these conditions, ammonia is converted to nitrate, the oxygen consumption rate levels off, and mineralization is increased due to the destruction of volatile solids. The resulting accumulation of solids are fixed solids and nonbiodegradable volatile solids.

The maintenance of from one to two milligrams per liter of dissolved oxygen in the waste liquid is sufficient to maintain aerobic conditions. Experiments with municipal wastes have shown that the air requirements for oxidation are satisfied when sufficient air is supplied to keep the solids in suspension. Nitrogen and phosphorous are required for bacterial growth and these two nutrients are normally present in animal waste.

Aerobic treatment for the removal of biodegradable organic matter from liquid waste is an odorless process and consists of two phases operating simultaneously. One phase is biological oxidation resulting in emissions of carbon dioxide, water and energy. The second phase utilizes the energy from the oxidation phase for synthesis of new cells, as shown by the following simplified equation:

$$\text{microbial cells} + \text{organic matter} + O_2 \rightarrow CO_2 + H_2O + NH_3 + \text{more cells}$$

With long detention times there will be a solids residue buildup (sludge) that ultimately must be disposed of. The sludge accumulation rate in municipal activated sludge systems is about 11% of the BOD removed per day. If nutrients are supplied continuously, the cycle is in a continuous process with all phases (acclimatization, exponential growth, and endogenous metabolism) occurring simultaneously.

Aerobic Lagoon--Aerobic lagoons may be divided into two classifications, dependent upon the method of aeration: oxidation ponds (naturally aerated lagoons), and aerated lagoons (mechanically aerated lagoons). In an aerobic lagoon, the biodegradable portion of the organic wastes is stabilized and the sludge is mineralized to such an extent that objectionable odors are eliminated. An oxidation pond is usually a shallow basin three to five feet deep for the purpose of treating sewage or other waste water by storage under climatic conditions that promote introduction of atmospheric oxygen and that favor the growth of algae. If oxidation ponds are properly constructed and hold the waste for sufficient time, then destruction of coliform organisms and a satisfactory reduction of BOD_5 occur. An oxidation pond should have considerably larger surface area than either the oxidation ditch or the aerated lagoon.

Loading of oxidation ponds of about 45 pounds BOD_5 per acre is a commonly used design figure for municipal wastes. The pond volume recommended for beef animal raw wastes is six cubic feet per pound of livestock (43). The size requirement can be reduced up to one-half by removing the settleable solids. Because of the extremely large surface area required for animal wastes, oxidation ponds have not found favor with livestock producers.

In aerated lagoons, oxygen is furnished by some type of mechanism that beats or blows air into the water. Satisfactory aerobic treatment of dairy and swine wastes has been obtained in aerated lagoons that have a volume of approximately 50 times the daily manure production. However, if the aerated lagoon is considered as a final or longtime storage of the waste residues, a much larger size is needed. For beef cattle the recommended size is 0.76 cubic feet per pound of animal for an aerated lagoon receiving the raw waste with 800 day detention time. For continous operation a mechanical aerator that will provide an oxygenation capacity of 1.5 times the total daily BOD_5 loading is the minimum recommended size. If the operation is to be intermittent (off in the extremely cold months), the aerator should have an oxygenation capacity of at least twice the daily BOD_5 loading. The rate of decomposition is slowed as the temperature decreases. Below 45°F, bacterial action is greatly reduced and below 35°F there is little activity.

For the aerobic lagoons, daily flushing is recommended to prevent odor production and shock loading in the system. The actual layout of the lagoon will depend upon the available area, however, a round or oblong shape is recommended. Lagoons should be located in a rather tight preferably clay soil to prevent leakage and sub-surface water contamination. The oxidation ponds may require solids removal after several years and weeds should always be kept under control to prevent mosquito breeding and other nuisances. Aerobic lagoons have been used principally to further treat wastes from anaerobic lagoons.

Oxidation Ditch--The oxidation ditch was developed during the 1950's in the Netherlands as a low-cost method of treating untreated sewage emanating from communities and industries. The oxidation ditch is a modified form of the activated sludge process and may be classified as an extended aeration type of treatment. During the last few years, this system has been adopted by many livestock producers, primarily swine operators, for treating animal waste water.

The oxidation ditch is made up of two principle parts--a continuous open-channel ditch, usually shaped like a race track, and an aeration rotor that supplies the oxygen and circulates the ditch contents. The oxidation ditch offers the following advantages over some of the other possible treatment methods:

1. Being an aerobic process, it is nearly odorless, with only a slight ammonia or earthy smell emitted.

2. It has some ability to handle shock loads.

3. It requires little attention and maintenance.

4. The process may be combined with a labor saving slotted floor system requiring no extra pumping or hydraulic systems to move wastes from the collection pit to the treatment plant.

Research is currently being conducted on oxidation ditch treatment of beef animal waste in various climatic locations at Illinois, Minnesota, and Oklahoma (43, 63, 46). Foaming appears to be a problem at times during startup and during cold weather operation. Foaming usually results from insufficient aerobic bacterial action. Once the aerobic bacteria population is established, foaming subsides.

Because of the high humidity and corrosive gases in the air surrounding the rotor, problems with rotor bearings have been prevalent. Evaporation of the liquids is a problem that should be considered during hot weather.

Oxidation ditches designed for approximately 30 cubic feet of liquid per pound of daily BOD_5 added operate satisfactorily if the suspended solids in the ditch are kept below 25,000 to 30,000 milligrams per liter by periodic or continuous sludge removal. Adequate velocity must be maintained in the ditch to keep the solids suspended. Normally this is considered to be a minimum of one foot per second. Generally, the liquid depth in the ditch is limited to about 18 inches and the total channel length is limited to about 300 feet. Most rotor designs can transfer about 1.5 pounds of oxygen per hour per foot of rotor in the water at standard conditions and at 100 rpm and six inches immersion. The cost of the rotor itself, is about $250.00 per foot of rotor for the nominal six to eight foot length. The major operating cost is the power required to operate the motors, usually two to five horsepower motors. Daily operating cost is approximately $.02 per pound of BOD_5 added if the rotor supplies 1.9 pounds of oxygen per kilowatt hour and the power cost is $.02 per kilowatt hour.

The design procedure for an oxidation ditch, based upon Jones, Day and Dales' publication (43) is:

1. Determine the number of animals (N) and their maximum size to be housed in the building.

2. Determine the minimum liquid volume (V) in the oxidation ditch.

   Minimum volume = number of animals times 1.5 BOD_5 pounds per day per 1,000 pounds of animal times 30 cubic feet per BOD_5 per day.

   $V = N \times 1.5 \times 30 = 45 \times N$ cubic feet
   (assuming the animals weigh 1,000 lbs.)

3. Determine the oxidation ditch liquid depth (D). Surface area (S):

   $S = N \times A = N \times 25$
   (assuming $A = 25\ ft^2$/animal)

   $D = \frac{V}{S}$ (ft)

$$D = \frac{45N}{AxN} \text{ or } \frac{45}{A}$$

where N = number of animals

4. Determine the daily oxygenation demand, X (pounds per day).

   $X = 2 \times$ daily BOD_5 loading $= 2 \times 1.5 \times N = 3 \times N$ pounds per day.

5. Determine rotor length (L) required for oxygenation.

   a. Immersion depth (d) of rotor should be,

      $$d = \frac{D}{4} \text{ to } \frac{D}{3}$$

   b. The oxygenation capacity (XC) can be determined in pounds of oxygen per day per foot of rotor length, Figure 15.

      $$\text{Rotor Length (L)} = \frac{\text{daily oxygenation demand, X}}{\text{rotor oxygenation capacity, XC}}$$

   c. The maximum immersion depth can be determined from,

      $$d = \frac{1}{3} \times \frac{V}{S}$$

6. Determine the blade immersion depth (d_p) required for pumping. Assume the minimum velocity equals 1.25 feet per second. The flow rate, Q, in cubic feet per second per foot of rotor can be determined as follows:

   $$Q = \frac{\text{ditch width, W x ditch depth, D x 1.25 ft/second}}{\text{rotor length, L}}$$

   $$Q = \frac{1.25 \times W \times D}{L}$$

   $d_p = 1.82\ (Q - .1)$, inches

   Blade immersion, d', should be the largest of d or d_p

7. Determine the number of rotors needed by assuming the maximum distance between rotors equals 180 feet.

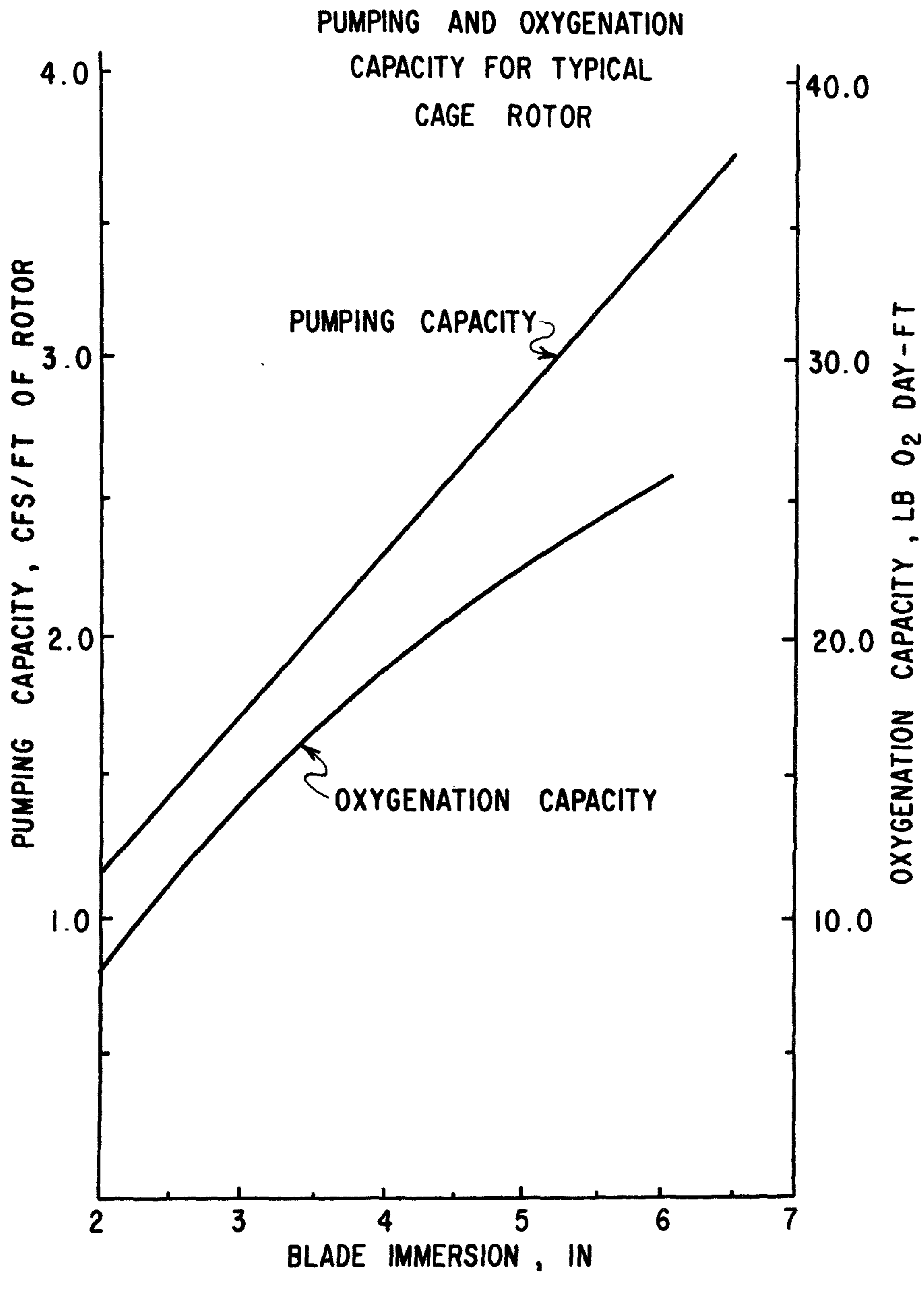


Figure 15. Pumping capacity and oxygenation capacity versus rotor blade immersion depth

a. Number of rotors, NR = length of rotors, L, divided by rotor width, RW,

$$NR = \frac{L}{RW}$$

For eight foot slats, a rotor width of seven feet would normally be used.

b. Number of rotors, NRL = ditch length, $\frac{DL}{350}$

$$NRL = \frac{DL}{350}$$

Use the larger of the numbers of NR or NRL.

8. Determine the power requirements and operating costs.

a. For a selected blade immersion depth, one can find the rotor power, RP, in kilowatt hours per foot per day. Using the information for Figure 20 of Jones, Day, and Dale (43), an equation dependent upon the blade immersion depth, d', can be expressed as follows:

$$RP = 5.44 + 1.56d'$$

b. The total power, TP, can be determined by the following expression where total length of the rotors is TL.

TL = (NR or NRL) x individual rotor length
TP = TL x RP

c. The cost can then be determined, assuming $.02 per kilowatt hour, by the following expression,

$$C = 0.02 \times TP$$

Newtson (66) states that three factors are necessary to construct an oxidation ditch system to minimize foam. These factors are ditch design, aerator design, and operating techniques. Moore, et al., (63) found the dissolved oxygen level in a batch type oxidation ditch was maintained above zero during the winter operation for a completely confined warm building operation. No odors were evident from the liquid and the pollutional strength was reduced but the effluent was still not suitable for discharge into a water course. Solids loading averaged 5.1 pounds per day per animal for 36 animals. They found a solid reduction of 34%

achieved for a 148 day period.

Spray-Runoff

Spray-runoff soil treatment is an adaptation of spray irrigation where the grass covered treatment area is leveled and sloped so that runoff flows evenly over the surface at a predetermined rate. Biological reduction of the waste is accomplished by a high population of microbes that colonize the wet surface of the grass and soil particles. Spray-runoff systems have been used to treat cannery wastes (47, 88) and have removed about 90% of the volatile solids, oxygen demanding organics, and total nitrogen with once per day spraying at Paris, Texas. Changing the spraying schedule from once per day to three times per week improved the phosphorus removal from about 50% to 88%. Operating costs for cannery wastes have been about $0.05/1000 gallons of waste water treated.

A spray-runoff system shows promise as an economical method to treat animal wastes. Such a system has been installed to treat runoff wastes from a feedlot at McKinney, Texas.

Anaerobic Treatment

Anaerobic processes are those that take place in an environment devoid of molecular oxygen (61). Chemically bound oxygen is commonly used for energy production in these processes. The oxygen may be bound with sulfur in sulphate ions, with nitrogen in nitrate ions, with carbon and hydrogen in various organic compounds, or with carbon alone in carbon dioxide. A heterogeneous population of bacteria is present which hydrolizes organic matter and metabolizes the products to organic acids, alcohols, sulphides, amines, and carbon dioxide, in the acid forming phase. The basic attraction of the anaerobic process is its ability to decompose more organic matter per unit volume than its aerobic counterpart. For this reason alone, the anaerobic process deserves consideration for the initial stabilization of strong organic wastes.

A characteristic of anaerobic digestion is the production of methane as a principle end product. Other gases are also emitted, including carbon dioxide and hydrogen sulfide, and intermediate products evolved as gases which may be toxic and odorous. Depending upon the nature of the waste constituents, organic solids may be liquified by 40 to nearly 100%. Inorganic solids may not be reduced by anaerobic digestion.

An anaerobic system is a good method for pretreatment ahead of an aerobic system. The combined anaerobic-aerogic system offers a high degree of treatment in a more economical manner than the exclusive use of an aerobic system.

Anaerobic Lagoons--Anaerobic lagoons have found widespread application in the treatment of animal waste because of their low initial cost, ease of operation, and perhaps more importantly, a lack of alternatives. Anaerobic lagoons have developed by a trial and error process from municipal aerobic waste-stabilization ponds. Anaerobic lagoons have proved to be useful for manure storage in northern climates during winter months when spreading is not feasible and in the central and southern United States has provided significant organic decomposition as well as manure storage.

Loading rates may vary from 0.001 to 0.01 pounds of volatile solids per cubic foot daily. This range in values is primarily because of variability of the climates. In the design of a lagoon, one should be guided by the climatic conditions in which it will operate. For moderate Midwestern climates, a lagoon loading rate of five pounds of volatile solids per 1,000 cubic feet appears reasonable. For central United States, Miner (61) suggests a lagoon capacity of 1,500 cubic feet per head for cattle weighing 1,000 pounds. He also suggests that the required capacity be increased up to 50% in areas of severe winters or when infrequent removal is important. Warm winter climates may justify decreases of 25%. The Midwest Plan Service (7) recommends a lagoon size of approximately one cubic foot for each pound of livestock.

Some of the design features for an anaerobic lagoon are:

1. Depth. Depth of 12 to 14 feet or more appears to be satisfactory as long as it does not permit percolation of contaminants into the ground water. Deeper lagoons provide greater temperature stability and minimal surface area for evaporation and the escape of odors.

2. Sealing. To perform satisfactorily, lagoons must not show appreciable seepage. In certain locations, soil additives such as bentonite clay and various polyphosphates should be used to create an impervious seal to prevent contamination of the ground water.

3. Shape. Circular or rectangular lagoons appear to work satisfactorily. For a rectangular lagoon a length to width ratio of 3:1 or less should be used.

4. Dike slope. Dike slopes of 3:1 should be used, with at least a two foot freeboard. Dikes may also be constructed so that machinery, such as tractors and mowers may be able to operate on them.

The width of a lagoon should be limited to about 50 feet if a drag line is to be used for cleaning the lagoon.

5. Inlets and outlets. Raw manure should enter away from the edge of the unit and preferrably near the center. A submerged inlet is desirable to aid mixing and to avoid the winter freezing problems. To avoid pollution, all overflow from an anaerobic lagoon should go into an aerobic lagoon or other secondary waste treatment system for further decomposition. A trickle tube will handle normal overflows. An emergency spillway should be constructed.

6. Surface grading. The area around a lagoon should be shaped to prevent surface runoff from entering the lagoon. Diversion terraces should be constructed to achieve this purpose.

7. Fencing. Lagoons should be fenced for the protection of children or livestock.

Many lagoons are operated so that no discharge is necessary. Thus, water is lost by evaporation and seepage which must equal the average raw waste inflow. Miner (61) presents an equation, taking into consideration minimal seepage:

$$A\,(E-R) = PQ$$

where R = annual rainfall rate, inches per year
E = evaporation rate, inches per year
Q = daily waste flow, gallons
P = conversion factor, 0.0134
A = surface area of lagoon, acres

This expression is useful in predicting the size of a lagoon required for evaporation of incoming water during an average year. In areas of high rainfall, it is not feasible to design a lagoon for evaporation of all incoming water. In such instances, outlets must be provided and plans made for proper disposal of the effluent. Effluent may be spread on nearby land as enriched irrigation water.

Information on the bottom width and length of a lagoon as influenced by side slopes and depth of the lagoon is presented in Figure 16. This information is useful in determining the surface area of a lagoon for possible evaporation design. Also, the amount of material that has to be removed can be calculated for lagoons located on rather flat land. The equation for determining the volume of the lagoon is:

$$V = b\,l\,h + (sl + sb)\,h^2 + 4/3s^2h^3$$

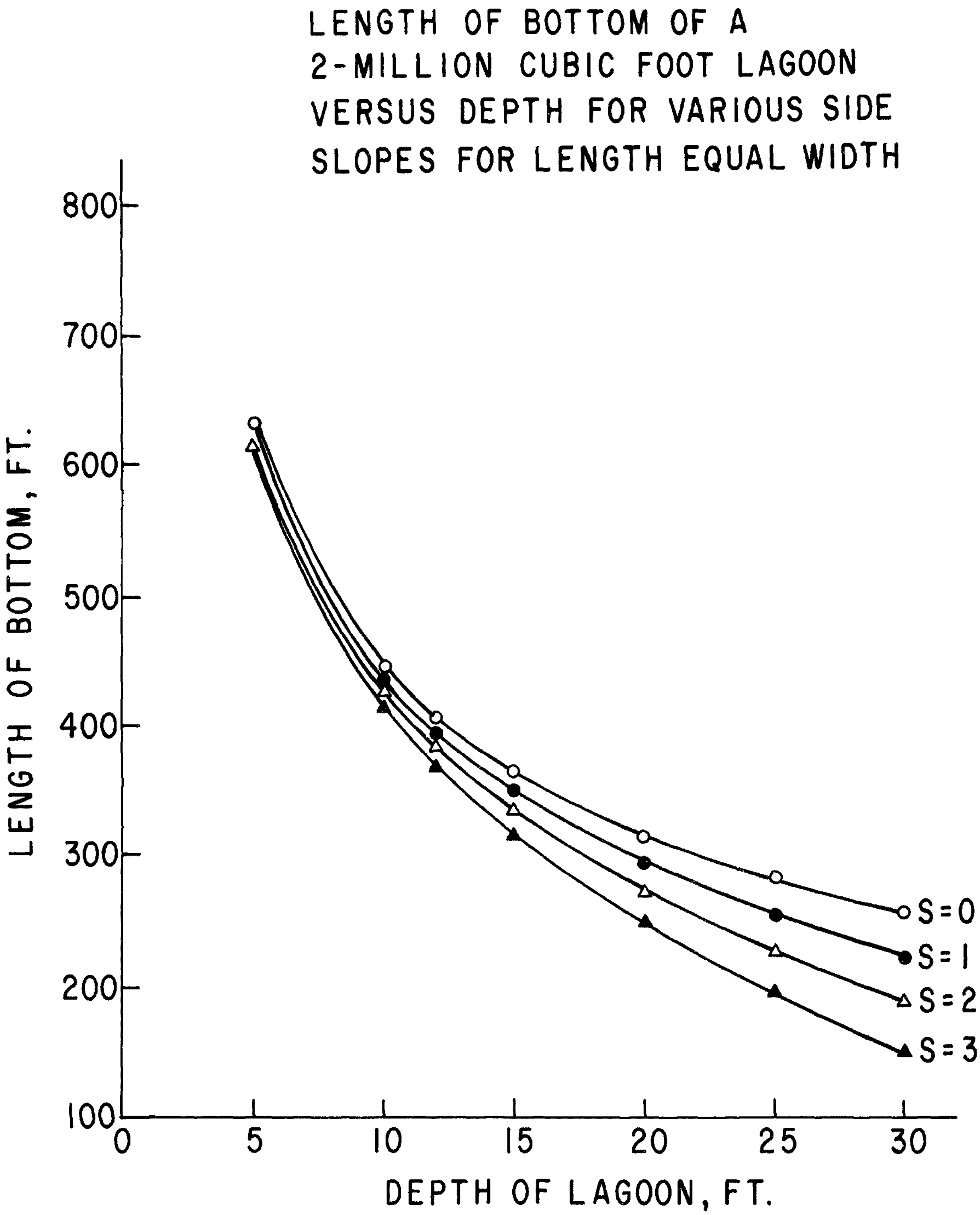


Figure 16. The effect of depth and side slope on the bottom length of a 2 million cubic foot lagoon

where V = volume, ft^3
b = width of base, ft
l = length of base, ft
h = depth of lagoon, ft
s = side slope, horizontal distance/vertical distance

A schematic drawing, illustrating the various dimensions, is presented in Figure 17. In Figure 18, the relationship between surface area and depth for a two million cubic foot lagoon is displayed.

Another formula, used by the SCS for estimating pond volumes, is:

$$V = \frac{D}{6}\,(\text{area top} + \text{area bottom} + 4(\text{area of midsection}))$$

where V = volume
D = depth

The areas are assumed to be parallel.

Waste Storage Tank Design

A waste storage facility may be a separate tank or it may be a part of the livestock building. The confinement buildings with a slotted floor could have deep storage pits underneath the slotted floor. Also, flushing systems for solid floors could use a storage tank facility.

The size of the container will depend on the way a livestock operation is managed, the length of time between emptyings, and the kind, number, and the size of the animals (82). The tank storage capacity can be determined as follows:

Storage Capacity = (number of animals x daily manure production x storage period in days) + dilution or transport water

The approximate daily manure production for a 1,000 pound steer is 1.0 cubic feet, or 7.5 gallons, at 80-90% water on a wet basis. This value does not include any dilution water but it is suggested that extra water be added to bring the percent water to about 90% for easier handling. Storage capacity of up to 180 days is recommended for colder climates to avoid application on frozen ground. Cropping practices, distribution methods, and climate affect the storage period.

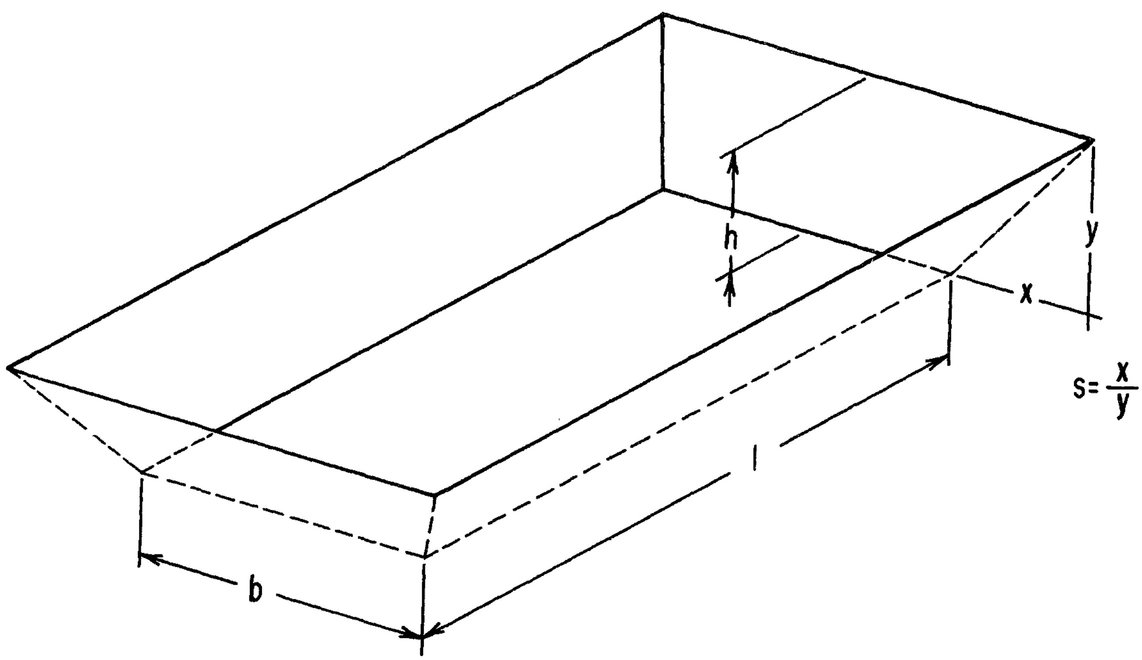


Figure 17. Schematic showing lagoon dimensions

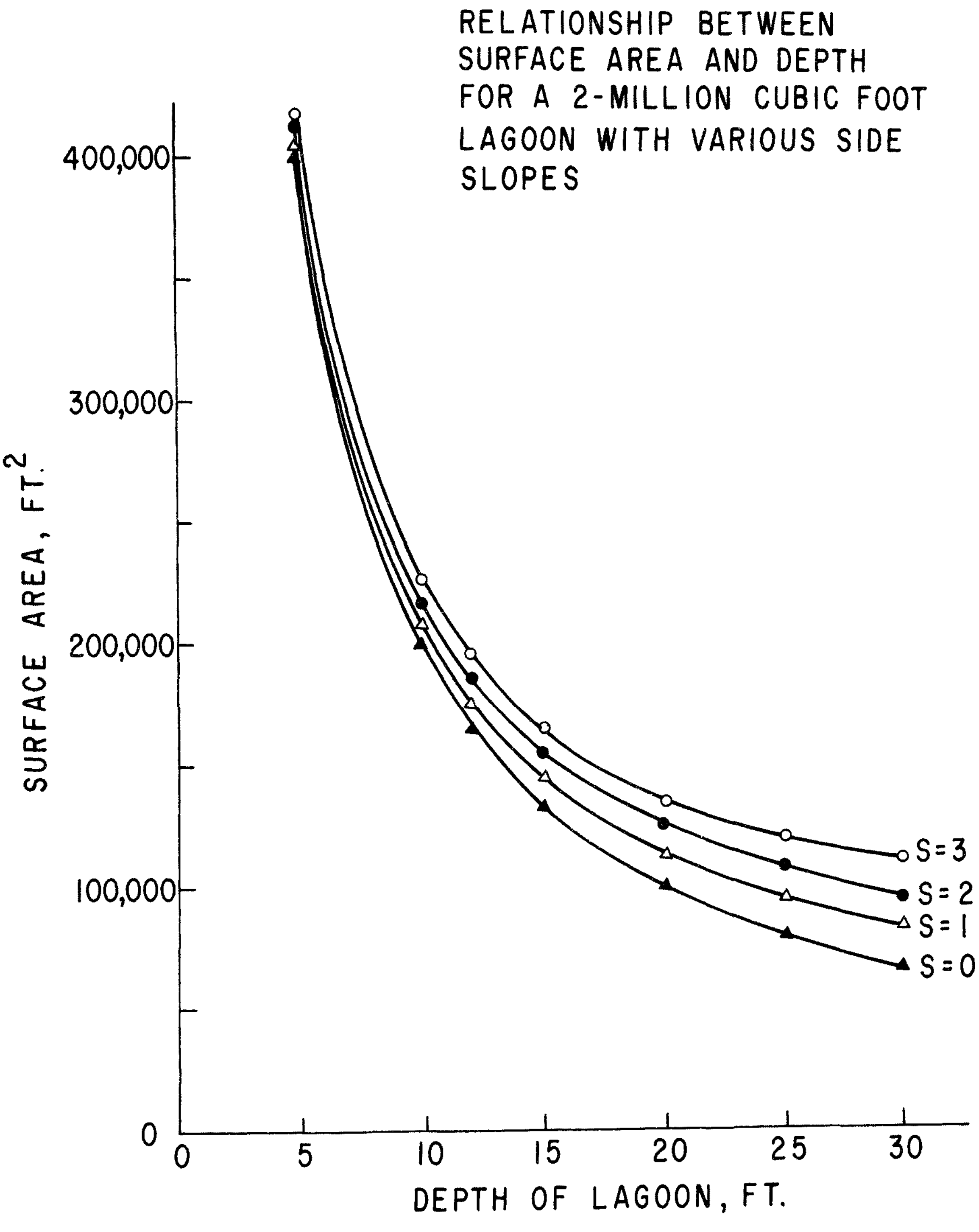


Figure 18. Effect of depth and side slope on the surface area of a 2 million cubic foot lagoon

To avoid pollution of water supplies, the storage tank should be located at least 100 ft downhill from the water supply. Fractured limestone, shale, and other bedrock sites should be avoided because of possible direct ground water pollution. To prevent tank flotation and flooding, tanks should not be constructed below the high water table or in flood plains. The tank should be located for convenient filling, emptying and controlled addition of dilution water.

The tank should be designed for protection against accidents, asphyxiation, and possible over exposure to toxic gases. Openings should have grills or covers to prevent children, animals, equipment, and other objects from accidentally falling into the storage tanks. For emergency escape, ladder or steps should be provided below all openings having least dimensions of 15 inches or larger. Necessary ventilation should be provided where gases may discharge into a building.

Plans for farm waste storage tanks are available from state extension agricultural engineers, generally located at the state's land grant college, at county agents' offices, lumber yards or equipment dealers where manure pumps are sold.

In emptying the storage tank, it is usually necessary to agitate the stored contents just prior to emptying as some solid material settles. Effective agitation is possible with recirculating pumps operating at about 2,000 gallons per minute in storages with ports about 30 feet apart. The compartments should be designed for not more than 40 feet in any width or length. Circular storages also work well for agitating the material and emptying.

There are several types and sizes of pumps available for removing liquid manure. Some systems have a wagon mounted pump which creates a vacuum for loading and a pressure for unloading. Centrifugal pumps without choppers can be used. These range in size from 1 1/2 to 5 horsepower and deliver up to 2,000 gallons per minute, but are subject to clogging. Diaphragm pumps can handle some solids with a three inch size, two-horsepower pump able to pump from 50-70 gallons per minute. Chopper-impeller pumps are designed to pump manure that contains chopped hay, feathers, and other solids. These typically range in size from 5 to 30 horsepower and are capable of delivering from 300 to 2500 gallons per minute. Some are capable of providing a high output pressure suitable for manure irrigation systems.

SOLID TREATMENT SYSTEMS

One of the difficulties of using municipal waste treatment techniques on animal wastes is that animal waste contains a higher percentage of solid material. As noted earlier, solids are encountered in slurry waste, liquid runoff wastes, and of course, the solid wastes from feedlot surfaces. Thus, regardless of the method used for handling and treatment of the beef animal waste, solids are encountered.

Solids Separation--Many researchers and feedlot designers are suggesting that the solids be separated from the liquid wastes for easier handling of the liquid with centrifugal pumps and pipe. Less solid material in the liquid portion requires less oxygen for the biological degradation processes. The solids that are separated can be handled with normal solid handling equipment and treated like other solid waste materials.

Gravity Separation--Whenever the flow velocity of the liquid wastes is low enough, solids will settle to the bottom of the vessel or channel. Two systems have been discussed previously that were developed in Nebraska: 1. continuous flow separation and 2. batch type separation (22). The continuous flow system permits runoff-carried wastes to slow down behind a porous dam long enough for some of the solids to settle out. By having a series of porous dams, an estimated 50% of the solids can be removed by this method.

The batch separation method at Nebraska had two retention structures. In one the material was retained for a period of time to settle out solids and the liquid overflowed into the second retention structure. Most of the liquid was pumped into the second structure, leaving a high percentage of solids in the first structure which could be removed later. Batch systems have more difficulties in terms of the mechanical removal of the settled solids than the continuous flow settling system where conventional front-end loaders can be used.

It may be possible to utilize some of the techniques for solid separation in municipal or industrial waste treatment processes. No solids separation systems of this nature were observed for beef waste treatment systems during the field observational phase of this project. Some settling tanks have been used for dairy and swine installations; however, these tanks have to be cleaned rather frequently.

Mechanical Methods--One of the disadvantages of the gravity separation method is the slowness with which the material can be settled out. A retention time of several hours must be built into the system in order to produce velocities low enough for the solids to settle. By using mechanical screens or other mechanical devices it may be possible to speed up this separation process.

Fairbank and Bramhall (17) describe a manure liquid-solids separation system for dairy wastes in California. Raw liquid manure is pumped from a holding tank to a rotating or vibrating screen separator with screens of stainless steel. Mesh sizes range between 12, 16, and 20 mesh for the dairy installations. Fibers, undigested feed, and coarse sediment are separated from the liquid waste and the solids emerge relatively clean and are not objectionable to handle. In fact, the dried washed solids may be usable for free-stall bedding. The washed manure has approximately 20% total solids or dry matter as compared to approximately 0.4% solids for the liquified waste from the flushing system.

Solids from the separator discharge chute fall directly into a spreader or truck for hauling. The solids can be spread directly on crop land or orchards, or can be stockpiled in high windrows of 10 feet or more for spreading and soil incorporation at the time of plowing. Slow composting will occur in the stockpile. Also, there is insufficient food in the material for fly larvae and the odor is very low.

The total effluent volume will not be noticeably reduced by solids separation and although free of most debris, it retains a high pollution strength and should not be released to public waters.

Other possible separation devices are centrifuges and stationary screens which have been tried experimentally but not under field conditions. Likewise, flocculation and other municipal techniques have not been demonstrated under field conditions although Cassell and Anthonisen (12) used vacuum filtration to reduce the volume of poultry manure.

Drying

Incineration and drying have been suggested as ways in which the total volume of waste can be reduced to minimize the water pollution problems. Most of the research on drying animal wastes has been limited to poultry manure.

Surbrook, Boyd, and Zindel (83) discuss the performance of an experimental dryer used primarily for poultry wastes but also tried a limited amount of dairy, beef, and swine waste. They found an odor given off in the vicinity of the machine during drying, but it was less intense and unlike that of fresh excreta from poultry. Bovine excreta was reduced from an initial moisture content of 82.4% to 12.0% The bulk density of the dried dairy and beef wastes was 12 pounds per cubic foot. The production rate was about 243 pounds per hour for which 2.6 gallons per hour of fuel and 4.2 kilowatt hours of electricity was used in one hour. For one ton of dried dairy or beef excreta, the total cost was estimated to be $63.65 for a forty-hour week and $48.70 for an eighty-hour week.

A dryer was designed to handle the slurry waste from 9,600 dairy-beef steers housed on slotted floors in the Los Angeles area (39). The slurry was pumped into a dehydrator that was capable of producing 25 tons of dry material daily. In the summer of 1970, when this installation was observed, it was no longer in operation due primarily to two reasons:

1. The operation was under attack by local residents because of odor problems.

2. The dryer began to have mechanical problems after a couple of years of operation.

Composting

Gotaas (28) discusses some of the fundamentals of composting. Segregation of the noncombustibles and combustibles or removal of noncompostible materials is desirable. Shredding or grinding the raw materials for composting can render the material more susceptible to bacterial invasion by exposing a greater surface area. Golueke (27) observed that when composting pig manure, anaerobic conditions developed in the large pig droppings when they were not shredded. The most desirable size of particles for composting is less than two inches in the largest dimension.

The course of decomposition of organic matter is affected by the relative availability of carbon and nitrogen as measured by the C/N ratio. A C/N ratio of 20 is suggested as the upper limit for a compost material at which there is no danger of robbing the soil of nitrogen. Since living organisms utilize about 30 parts of carbon for each part of nitrogen, the optimum C/N ratio for composting is around 30.

A moisture content in the range of 40-60% is the most satisfactory range for aerobic composting. If a moisture content is too high, the water displaces air in the interstices between the particles and thereby gives rise to anaerobic conditions. When the moisture content is too low the organisms are deprived of the water needed for their metabolism.

Proper temperature is a very important factor in the aerobic composting process. High temperatures are essential for the destruction of pathogenic organisms and undesirable weed seed. Decomposition also proceeds much more rapidly in the thermophilic temperature range between 50 and 70°C with around 60°C usually being the most satisfactory.

Aeration is necessary for thermophilic aerobic composting in order to obtain rapid nuisance-free decomposition. Aeration is also useful in reducing a high initial moisture content in composting materials. Turning the compost pile at frequent intervals during the first 10 to 15 days of composting is required.

The compost pile can be windrowed and turned frequently to provide aeration; however, this promotes a loss of moisture by evaporation so that moisture may have to be added periodically. For a moisture content of 40 to 60%, turning at at three day intervals appears to be satisfactory. Piles should be from approximately four feet to six feet in height to insure that they do not lose heat too rapidly. Optimum temperatures must be provided for destruction of pathogenic organisms and decomposition by thermophiles. Also, if the piles are too small the loss of moisture may be excessive. Initial width of a windrow should usually be 8 to 12 feet at the bottom for convenience for heat insulation and in turning. The volume of composting refuse may decrease to between 20 and 60% of the original volume and weight to 50 to 80% of the original weight. The actual figures depend upon the character of the materials, moisture loss and amount of compaction.

The time required for composting cow and pig manure and straw was found to be 10 to 16 days under field production conditions. Approximate time required for composting is 9 to 12 days for an initial C/N ratio of 20 and 10 to 16 days for an initial C/N ratio of 30-50.

The Fairfield Engineering Company has designed a digestor for processing of organic waste material (14) and made feasibility studies for 100 to 400 ton per day capacity digestor plants processing cattle manure containing 30% moisture and producing a marketable organic product containing approximately 5% moisture. For a 100 ton per day plant, the total annual operating cost is estimated to be $167,410.00 with capital investment excluding land of $650,000.00. They estimate an income of $195,000.00 based upon a $15.00 per ton market price of the organic product.

Any profits from composting material are contingent upon successful marketing of the material. It is readily apparent that one large feedlot can saturate the compost market in most localities.

CHAPTER IV

ULTIMATE DISPOSAL

Ultimately the animal waste material has to come to a final resting place and the nature of this resting place or ultimate disposal is of vital concern. The ultimate disposal of the waste material should be accomplished in a manner that will not endanger the health and well-being of people, animals, or plants. In this context, ultimate disposal is considered as the receiving media for the material. The material may be subjected to some of nature's own cycles, where it may be chemically or physically altered and possibly transported elsewhere in a different chemical or physical form.

An alternative to disposing of all of the waste material is to recycle the material in whole or in part back to the animal production system. There are attempts being made to recycle the waste as a media for flushing, bedding, or as a feeding material rich in nutrients. Also, the waste may be recycled by application to crops which are grown for animal consumption.

Disregarding the recycling aspects, there are three potential recipients of the waste material: air, land, or water. All three may be involved at one time or another in the disposal of the waste material. For animal waste management systems, the initial discharge or deposition is generally to water or land sources.

In this chapter the methods and effects of disposing of the waste onto the land will be discussed, primarily for the following two reasons:

1. Land disposal techniques are most frequently used for animal waste disposal.

2. By placing the material on the land the probability of pollution of streams and lakes is lessened.

There are other possibilities considered in this chapter for the final treatment and disposal of the material. In most cases operators have decided to use disposal methods that reduce labor costs and dissipate major fractions of the waste material to the atmosphere. In addition to economics, the ultimate disposal may be determined by the physical form of the material and whether it has had prior treatment.

LAND DISPOSAL

The disposal of animal wastes onto the land has been the traditional practice but sometimes presents problems when large quantities of waste are generated in concentrated areas such as large beef feedlots. Animal waste may be treated as an unwanted commodity to be reduced and disposed of by any available means that is publicly acceptable, trouble-free, and economically feasible. Otherwise, it may be treated as a resource, and its use developed for optimum benefit.

Value of Manure

According to Taiganides and Hazen (86), cattle produce approximately 0.4 pounds per day of nitrogen, 0.12 pounds per day of P_2O_5 and 0.3 pounds per day of K_2O per 1,000 pounds of body weight. For fattening cattle, Benne (8) found the following amounts of ingredients in one ton of manure at 80% moisture:

Ingredients	Pounds
N	11.2
P	2.0
K	10.0
S	1.0
Ca	5.6
Fe	0.80
Mg	2.2
Volatile solids	322
Fat	7

Tests conducted by the Beef Cattle Division of Pioner Hi-Bred Corn Company indicate that each ton of slurry contains 6.4 pounds of N, 4.6 pounds of P_2O_5, and 7.2 pounds of K_2O (75). In high roughage rations, there is a higher amount of K in the manure. With an application rate of 20 tons per acre, the material would supply 128 pounds of N, 92 pounds of P_2O_5, and 144 pounds of K_2O per acre. Each ton of slurry manure had a plant nutrient value of $1.43 when figuring N at $.11 per pound, P_2O_5 at $.09 per pound, and K_2O at 4.5¢ per pound.

These prices approximated the delivery and spread prices of the bulk blended dry fertilizers in central Iowa. When spreading costs of $.23 per ton were considered, the net value of the slurry was $1.20 per ton. Application of 20 tons per acre approximates the nitrogen needs for a 130 bushel per acre corn yield.

James Willrett, a feeder located near De Kalb, Illinois, considers the value of the N, P, and K produced from each animal as about $9.00 over the feeding period using the price of $.05, $.08, and $.04 respectively (93). In addition to the N, P, and K, there are other benefits provided by the manure, such as trace elements and the energy material for stimulating the activity of soil microorganisms.

Application Rates

Miner (61) has reviewed research pertaining to the application of animal wastes to crop land and found that most researchers reported farmyard manure increased crop yields over a wide range of soils. Most workers found that high application rates of manure resulted in higher crop yields but lower application rates gave higher returns per ton of applied manure. Recovery values from manure by various crops ranged from about 10 to 30% for N, 10 to 20% for P, and 30 to 100% for K. These values are quite comparable to those reported in the literature for crop recovery from applications of commercial fertilizers.

Hensler (38) found that fresh, fermented (piled) and anaerobic liquid dairy cow and steer manures gave similar increases in corn yield in Wisconsin and were superior to those for aerobic liquid manure for application to Miami silt loam in the greenhouse. The 30 ton per acre rate of application resulted in up to 30% greater yields but 5 to 10% lower percentage recovery of N, and P as compared with the 15 ton per acre rate. The average recovery of N and P by the crop was 52.5% and 29% for anaerobic, liquid dairy cattle manures and was greater for steer manure. Allowing the manure to dry for one week before incorporation into the soil usually gave 10% lower yields and 5 to 40% lower recovery values for N, P, and K. Table 6 presents information on the average yield and recovery of N, P, and K by one crop of corn grown in pots in a Miami silt loam when manure was applied at a rate of 15 tons per acre.

Research plots of corn have been reported as tolerating 100 tons per acre, but increase in corn yields for manure rates higher than 10 tons per acre were quite small (61). Uneven development of corn plants was observed in Kansas, where beef cattle manure was applied to land at about 50 tons per acre a few weeks before planting. Usually, a salt effect is sited as the cause of the inhibition.

Table 6. Effect of Steer Manures Applied at a 15 ton/acre Rate on Average Yield and Recovery of N, P, and K by One Crop of Corn Grown on a Miami Silt Loam in Pots (38) (Hensler, 1970)

Type of Manure	Yield (g/pot)	Recovery by crop N (%)	P (%)	K (%)
Fresh	32.0	53.0	23.5	73.5
Fermented	32.5	54.5	23.5	74.0
Aerobic liquid	20.5	13.0	14.5	34.5
Anaerobic liquid	33.0	65.5	27.5	83.0

Some results in Wisconsin indicated that where excessively high rates of manure are added to quite acid soil for corn, application should be six to eight weeks prior to planting. Fresh manure, incorporated into the soil immediately after application, generally is the most effective in increasing crop yields. Fermented manure usually has a higher percentage content of plant nutrients due to the loss of dry weight by organic matter decomposition, but generally shows no advantage over fresh manure for crops. However, in some Wisconsin studies, corn yields on a Withee silt loam soil were significantly lower for fresh manure than for comparable treatments with fermented or anaerobic liquid manures (38).

The injection of manure slurries below the soil surface appears to have considerable promise according to Miner (60). With this method, the immediate covering of the waste greatly reduces the possibility of pollution caused by storm water runoff and also reduces volatilization losses of nitrogen, reduces odor, and reduces fly breeding problems.

In arid and semi-arid regions, thin spreading by sprinklers may also be a disposal method for fluidized manure. However, in more humid areas there would be the possibility of fly breeding, creation of undesirable odors, and the possibility of pollution of surface waters. Manure slurries mixed into irrigation waters can be used in some cases but attention must be given to recovery of tail water from such irrigation systems if pollution of water courses is a possibility.

Miner concluded that the aerobic treatment of dairy cow and steer manures would likely be the least desirable treatment because of the relatively high cost, reduced value of the manure as a fertilizer for corn, and low recovery of plant nutrients. Also, any method of handling that allows the manure to dry on the surface before soil incorporation favors gaseous losses of N and possible pollution of runoff water.

McCoy (57) found that bacteria from fresh bovine manure was removed within the top 14 inches of silt loam soil with manure applications of 5 to 80 tons per acre. The coliform and enterococcus types of bacteria were efficiently removed by adsorption during percolation through soil and by natural die-off from inability to compete against the established soil or manure water microflora. Thus, there is little concern that bacteria will move any great distance from the point of application of manure to agricultural soil.

In the Panhandle area of Texas, Mathers and Stewart (55) examined the nitrogen transformations and plant growth as affected by applying large amounts of cattle feedlot wastes to soil. Laboratory studies examined the decomposition rates and nitrogen transformations of the animal wastes when applied to soil at varying rates. They also studied the effects on plant growth of varying application rates.

When the feedlot waste, primarily solid waste, was mixed with the soil, evolution of C and transformation of N was rapid. In 90 days, about 50% of the C was evolved as CO_2 and an equivalent amount of N was recovered at NH_3 or NH_4+ and NO_3- in the soil. In a greenhouse study, they found that one unit of N from ammonium nitrate was equivalent to 2.4 units of N supplied in feedlot waste.

High concentrate beef rations easily contain 1% or more sodium chloride to enhance water intake and possibly limit the formation of urinary caluculi. Mathers and Stewart stressed that the high salt content in feedlot manure must be seriously considered before high application be used. They found growth inhibition on plots receiving a 5% rate manure treatment in the first sorghum crop when seeded immediately after application of manure. Most of the growth inhibition was probably due to salinity, but the first crop apparently removed enough salt to allow normal growth in the second crop. Yield results for grain sorghum with fertilizer and manure treatments with and without incubation before planting for two crops are presented in Table 7. The second crop was planted immediately after the first crop was harvested without any further manure applications. Yields were generally higher on the second crop for the manure application rate of 5% whereas the higher application rates took longer to recover. Crops with lower rates and commercial fertilizers utilized most of the available nitrogen during the first crop.

There are still many unknown factors regarding the heavy application of manure to the soil such as the long-term effects salt buildup. Much long-term research is needed to establish these limits and possible effects of various other trace elements on the soil.

IRRIGATION

In the case of hydraulic handling methods, irrigation offers the possibility for the final step of ultimately disposing of the animal waste material on the land. The equipment and techniques for irrigating with manure laden waters are slightly different than for regular irrigation techniques and

Table 7. Yield of Grain Sorghum with Fertilizer and Manure Treatments with and without Incubation Before Planting (55) (Mathers, & Stewart, 1970)

Treatment	Incubated and dried prior to planting		Incubated prior to planting		No incubation prior to planting	
	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2
check	6.3*	1.4	5.5	2.0	8.7	1.6
NPK	12.8	3.7	12.8	2.7	13.3	4.0
Manure-%**						
1	10.4	4.2	10.9	4.1	11.3	4.7
2.5	14.0	11.2	13.8	11.7	13.9	9.5
5	9.7	13.6	9.6	11.9	5.6	12.2
10	0.8	2.9	1.0	3.1	0.1	0.8
20	0.2	1.9	0	2.7	0	1.4

*Yield, g/pot
**g of dry manure/g dry soil; for trials soil watered to 25% moisture content

systems. Liquid animal wastes contain more solids. Slurries, of course, may contain as much as 15% solid material whereas flushing systems and water arising from runoff-carried wastes generally contain lesser but also highly variable amounts of solid material. Solids, if in large quantity, affect the performance and operation of most conventional irrigation pumps and nozzles. Therefore, special equipment, particularly pumps and nozzles, has been developed for manure irrigation systems.

Slurry System

The slurry or flushing systems frequently use a chopper type of pump that has the ability to chop up particles, such as straw or hay. One manufacturer sells a pump that requires a 30 horsepower electric motor and is capable of providing an output pressure of 100 psi and a 200 gallon per minute flow rate. This system has sufficient pressure to pump a 90% moisture content slurry through several hundred feet of irrigation pipe and effectively operate a large diameter nozzle sprinkler. The pump also has a quick closing selector valve to permit the operator to change from hydraulic tank agitation to field discharge. Hauenstein (33) mentions that the friction losses are only slightly higher than conventional irrigation systems and are not an important factor since the pumping time is small and the power cost is quite low. The large sprinkler will wet an area in excess of 2 acres and give a precipitation rate of approximately 1/3 of an inch per hour as long as the proper pressure is maintained. Many farms using this system also pump fresh water following the application of liquid manure so that the manure is washed off the plants and into the soil. The fresh water application also flushes out the system and helps reduce odors.

Runoff Control Systems

Shuyler (79) discusses the design of an irrigation system to utilize the liquid runoff from feedlots. Once the operator and designer of a feedlot has decided to dispose of the liquid waste material from the lot by applying it to agricultural land, there are several items that should be investigated before deciding on a final design system for liquid wastes.

The most important factor is the amount of land needed and type of crops to be grown. A high volume crop, such as a forage or pasture crop, will remove large amounts of nutrients from the soil and be less subject to seasonal limitations from cropping and harvesting practices than some row crops. Fertility needs of various crops, presented in Table 8, must be kept in mind when applying animal wastes to a crop because an excess of any one nutrient may have a toxic effect on plants. A system may be necessary that supplies the fertility needs of the plant with a balanced combination of commercial fertilizer.

Irrigation needs of the various crops must be considered for land disposal of waste water. Irrigation engineers and agronomists working with irrigated crops have maps indicating the amount of irrigation water needed to produce a crop in most years. The most important factor in water use is the daily or monthly use of the crop. Tables 9 and 10 indicate the daily water use and the total consumptive use of crops grown in Kansas. By subtracting rainfall from the total water used each month, it is possible to predict the amount of waste water that can be disposed of in any month. The peak use of most crops is about 0.3 inches per day (Table 11.).

The water holding capacity of the soil is very important in designing an irrigation system or disposal field and Table 12 shows the amount of water per foot that a soil might hold. A plant uses only about 50% of this water without causing damage to the plant, therefore, only enough water should be applied to replace what the plant has used. If more is added, water will be driven below the root zone to a position where it may eventually cause pollution of the ground water. The root zones of the various crops are also indicated in Table 13.

Some tables adapted from the sprinkler irrigation handbook written by Fry and Gray (19), are useful in determining application rates under various climatic and soil conditions (Tables 14, 15, and 16).

The first step in designing an irrigation disposal system is to estimate the amount of liquid runoff expected from the feedlot as discussed in Chapter II. This runoff may be stored for a long or short term, but some local regulations suggest that the storage reservoirs be emptied within 10 to 15 days after a runoff event. The land area needed for irrigation should be based upon the decision for long term or short term storage. Results at Nebraska and west Texas indicate that approximately one-half of the annual rainfall may runoff the feedlot surface (85) (92). Shuyler suggests that, for Kansas conditions, six inches of runoff liquids could be used in an average year on crop land. For long term storage, the total land area needed may be determined by the following expression:

Table 8. Nutrient Needs of Crops in Kansas (79) (Shuyler, 1969), lbs/acre

Crop	N	P_2O_5	K_2O
Corn, 120 bu.	180#	70#	140#
Corn, forage	180	70	180
Sorghum, forage	160	70	180
Sorghum, grain	145	50	110
Wheat	70	20	25
Grass	160	70	120

Table 9. Daily Water Use of Crops for Kansas (79) (Shuyler, 1969)

Crops	June	July	Aug.	Sept.
	Inches per day			
Alfalfa	.30	.32	.30	.24
Corn	.07	.31	.33	.15
Sorghums	.07	.24	.29	.10
Pasture	.26	.29	.27	.21
Wheat	.26	.00	.00	.00

Table 10. Total Consumptive Use of Water for Crops in Kansas (79) (Shuyler, 1969)

Crops	Consumptive Use (inches/year)
Alfalfa	29 - 37
Corn	24 - 27
Sorghums	20 - 23
Pasture	25 - 32
Wheat (winter use)	13 - 17

Table 11. Peak Moisture Use for Common Irrigated Crops and Optimum Yields (19) (Fry & Gray, 1969)

Crop	Cool Climate: Inches per day[1]	Cool Climate: GPM per acre[2]	Moderate Climate: Inches per day	Moderate Climate: GPM per acre
Alfalfa	.20	3.8	.25	4.7
Cotton	.20	3.8	.25	4.7
Pasture	.20	3.8	.25	4.7
Grain	.15	2.8	.20	3.8
Potatoes	.14	2.8	.20	3.8
Beets	.20	3.8	.25	4.7
Orchards and Groves	.20	3.8	.25	4.7
Orchards and Groves w/cover	.25	4.7	.28	5.2

[1] Acre inches per acre per day

[2] Continuous flow required per acre at 100% irrigation efficiency. Divide this value by estimated irrigation efficiency

Table 11. Continued

Crop	Hot Climate		Desert Climate	
	Inches per day[1]	GPM per acre[2]	Inches per day	GPM per acre
Alfalfa	.30	5.7	.35	6.6
Cotton	.30	5.7	.35	6.6
Pasture	.30	5.7	.35	6.6
Grain	.22	4.2	.30	5.7
Potatoes	.25	4.7	.30	5.7
Beets	.30	5.7	.35	6.6
Orchards and Groves	.30	5.7	.35	6.6
Orchards and Groves w/cover	.35	6.6	.38	7.2

[1]Acre inches per acre per day

[2]Continuous flow required per acre at 100% irrigation efficiency. Divide this value by estimated irrigation efficiency

Table 12. Gross Amount of Water to Apply per Irrigation (19) (Fry & Gray, 1969)

Soil Profile	Gross amount of moisture to apply* ac in./ac — For various depths of principal moisture extraction						
	12"	18"	24"	30"	36"	48"	72"
Coarse sandy soils, uniform in texture, 6 ft.	0.60	0.80	1.10	1.70	1.70	2.25	3.50
Coarse sandy soils over more compact sub-soils.	0.60	0.80	2.00	2.25	2.70	2.65	4.00
Fine sandy loams uniform in texture to 6 ft.	1.10	1.70	2.25	2.90	3.50	4.00	5.30
Fine sandy loams over more compact sub-soils.	1.10	2.00	2.65	3.20	3.70	4.30	6.70
Silt loams uniform to 6 ft. .	1.45	2.25	3.00	3.65	4.00	5.30	8.00
Silt loams over more compact sub-soils.	1.45	2.25	3.30	4.00	4.30	5.65	8.30
Heavy clay or clay loam soils	1.20	1.85	2.65	3.20	3.80	5.10	7.30

*Based on 75% water application efficiency

Table 13. Depth of Principal Moisture Extraction of Crops (19) (Fry & Gray, 1969)

Crops	Depths of Principal Moisture Extraction (feet)
Alfalfa	4
Corn	3
Cotton	3
Small grain	2 1/2
Grain sorghum	2 1/2
Forage sorghum	2 1/2
Grass pasture	2

Table 14. Maximum Precipitation Rates to Use on Level Ground (19) (Fry & Gray, 1969)

Light sandy soils.	0.75" - 0.5" per hr
Medium textured soils.	0.5" - 0.25" per hr
Heavy textured soils	0.25" - 0.10" per hr

Allowable rates, increase with adequate cover, and decrease with land slopes and time

Table 15. Slope Precipitation Rate Reduction (19) (Fry & Gray, 1969)

Slope	Precipitation Rate Reduction
0-5 per cent grade[1]	0 per cent
6-8 per cent grade	20 per cent
9-12 per cent grade	40 per cent
13-20 per cent grade	60 per cent
over 20 per cent	75 per cent

[1]Grade = drop in feet per 100 lineal feet

[2]Applied to proper soil type precipitation rate

Table 16. Estimates of Irrigation Efficiencies for Various Climates (19) (Fry & Gray, 1969)

Desert climate.	65 per cent
Hot dry climate	70 per cent
Moderate climate.	75 per cent
Humid or cool climate	80 per cent

Example: Required to apply two inches in hot-dry climate

Thus $\frac{2}{.70}$ = 2.85 acre inches per acre must be applied per irrigation

Land area needed, acres =

$$\frac{1/2 \times \text{annual rainfall, inches} \times \text{feedlot drainage area, acres}}{6 \text{ inches of runoff liquid per year}}$$

Obviously, in dry years, less land area would be required than determined by this expression. It would possibly be better to irrigate small areas in a dry year and to rotate the irrigated areas in a succession of dry years. Runoff wastes should be supplemented by a supply of good quality irrigation water.

If a short term storage reservoir is utilized in the waste management scheme (where the runoff is pumped out within a few days after the rainfall event), then the crop land area can be determined from the following expression:

$$\text{Land area (acres)} = \frac{\text{acre-inches of runoff stored}}{\text{inches of water applied/application}}$$

Minimum application rates comparable to the rate for heavy textured soils of 0.10 and 0.25 inches per hour could be used for this calculation. During cool weather and periods of high rainfall, the soil may be unable to accept the liquid waste as easily as during warmer, dryer periods.

For a system designed for the Pratt, Kansas area, Shuyler (79) suggests about one acre of crop land be available per acre of feedlot. For that area the amount of NPK for corn production can be supplied by about six inches of runoff waste per acre of crop land.

EVAPORATION

Evaporation occurs from the surfaces of the feedlot, ponds, lagoons, and storage pits. This mechanism causes considerable amounts of moisture to be lost from feedlot surfaces as indicated by studies of a flat feedlot located in the Platte River Valley of Nebraska (58). Very little runoff occurs from this feedlot, so most of the moisture is lost by evaporation.

In some areas evaporation may occur very rapidly during hot, dry weather and create a dust problem. In these cases it is desirable to inhibit evaporation or at least create a more moist surface by increasing cattle density or by sprinkling with water.

Evaporation from a feedlot surface is affected by several factors, such as:

- Temperature
- Relative humidity
- Moisture content of the feedlot surface
- Solar radiation intensity
- Wind velocity
- Animal density
- Slope and drainage
- Soil type

The western portion of the country has more potential for using evaporation as a means of animal waste disposal than the eastern portions of the United States. A map showing the annual evaporation for the adjacent 48 states of the United States is presented in Figure 19 (45). Annual precipitation for these states is presented in Figure 20 (13). Areas where annual evaporation exceeds the annual rainfall rate are generally favorable areas for evaporating excess liquid wastes. In the higher rainfall areas, evaporation may be used during certain dry periods of the year.

Evaporation is one of the alternatives to disposing of liquid runoff wastes by irrigation. Using this concept, the major concern is getting rid of the liquids as economically as possible. Thus, an evaporation pond should be designed with a fairly large area and a shallow depth so that no runoff will go beyond the pond and enter public streams or waterways. Precautions should also be taken to prevent the pollution of underground water sources by infiltration through the soil beneath the pond. The fundamentals of evaporation pond design are similar to the design of a lagoon as discussed in Chapters II and III.

INCINERATION

Incineration of the solid waste material is a potential alternative to land disposal. Feedlot manures are a low grade energy source material. Pratt (72) found the heat of combustion of dried beef animal waste was approximately 6,300 BTU's per pound of dry matter and Ludington (52) found the heat of combustion of poultry manure to be about 5,400 to 5,800 BTU's per pound of dry matter. This compares with the values for anthracite coal, 13,000; lignite coal, 6,900; and wood products, 8,500 BTU/lb.

There are indications that manure with a moisture content higher than 30% cannot be fed directly into the combustion chamber of an incinerator. In this case, predrying, possibly using waste heat from the incinerator, is necessary. Obviously, dry waste collection systems are necessary if incineration is to be used. An inherent liability of the

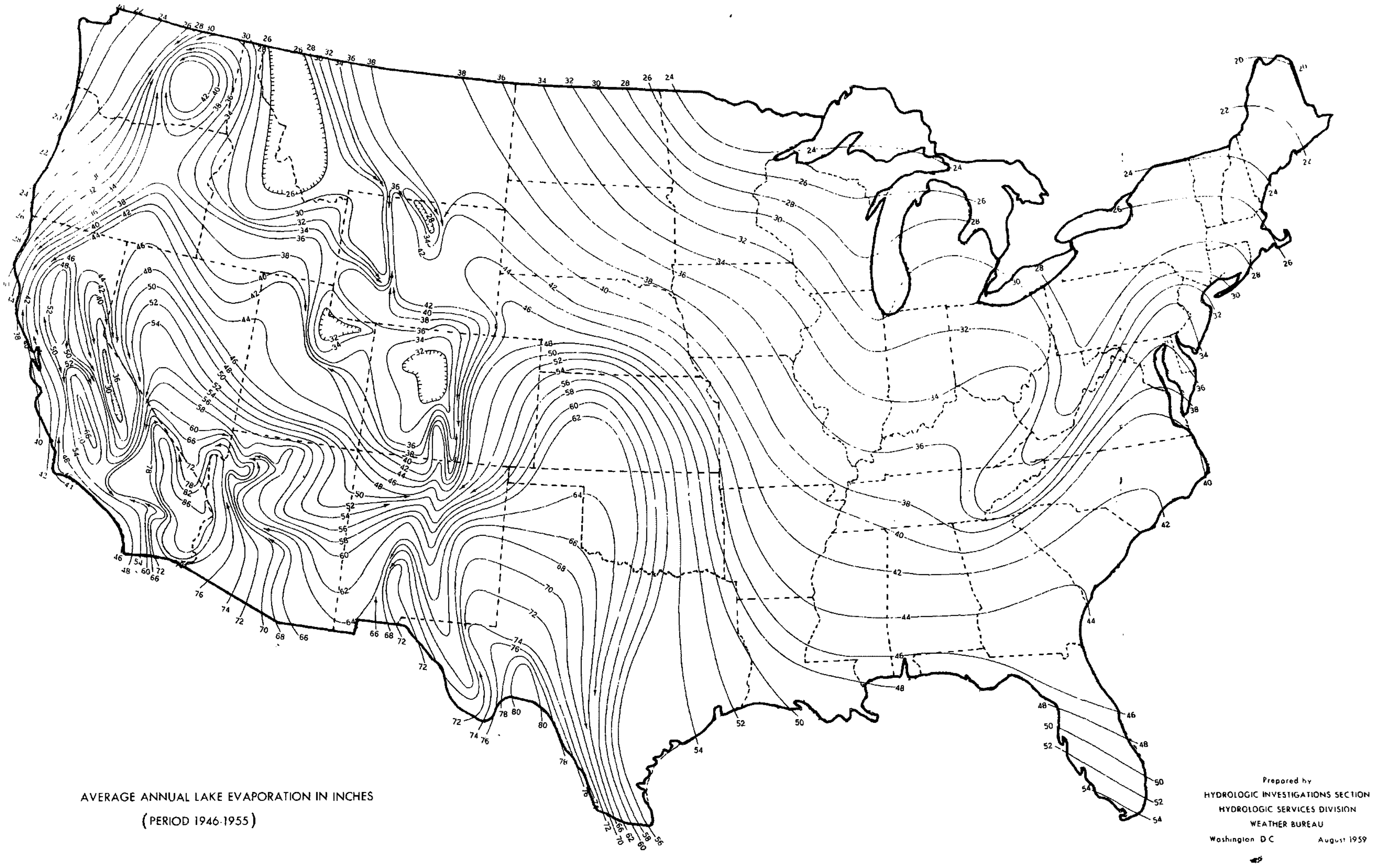


Figure 19. Average annual lake evaporation for 48 adjacent states

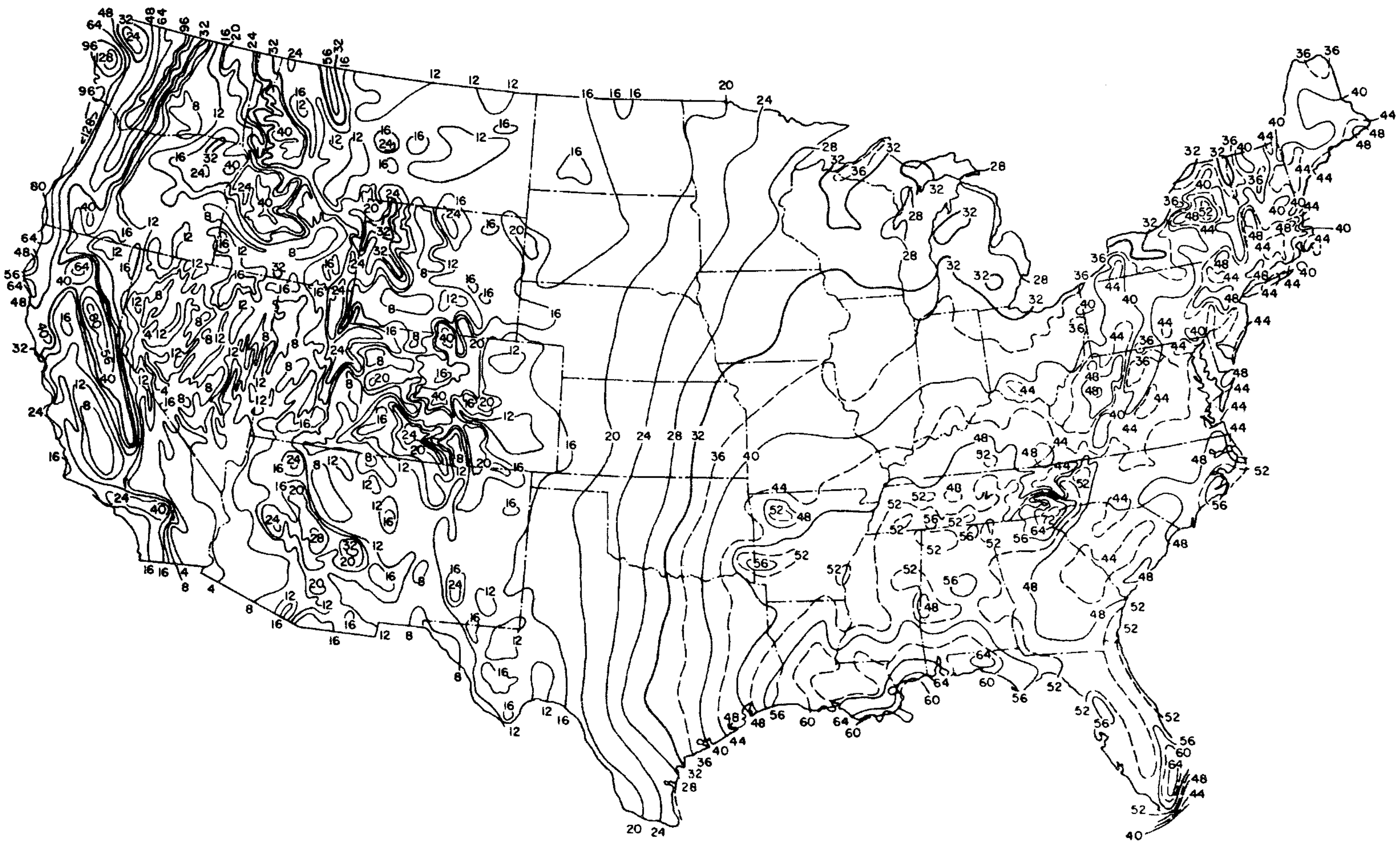


Figure 20. Mean annual total precipitation in the United States (Chow, 1964)

process is air pollution. Experiences in California, as related by Fairbank (18), indicate that several operations have been closed because of complaints by area residents about odors arising from incineration or drying animal wastes.

Another promising method for disposing of feedlot wastes is the use of the manure as a fuel to generate the power to run the feedlot (2).

SECTION II

OPEN FEEDLOTS

CHAPTER V

OPEN FEEDLOT DESIGN

Open feedlots for feeding beef cattle are prevalent in the southern High Plains and Desert Southwest. These feedlots range in size from a few hundred to 100,000 animal capacity. Smaller open feedlots, ranging in size from 200 to 2,000 animal capacity, are found in the colder climates, such as the upper Midwest and Pacific Northwest. The larger open feedlots, with a typical size of 20,000 to 30,000 head capacity, increased in numbers rapidly in the southern High Plains during the late 1960's primarily because of a dry, warm climate. The area is also close to an abundant supply of feed grains and feeder cattle. Many of the southwestern feedlots are located in close proximity to irrigation areas.

The design of open feedlots in this chapter will refer mainly to large commercial feedlots with over 1,000 head capacities. These feedlots typically are dirt-surfaced and afford little protection from the environment. There are no major buildings for housing although in some instances sunshades and windbreaks may be provided. There are few paved feedlots for capacities above 1,000 head.

Classification of these open feedlots is difficult because of the many alternatives that are possible for feedlot construction. The major classification would be between dirt and paved feedlots. Other areas of differences may be in pen construction, drainage, type of feed processing facilities, and type of waste handling facilities. These design options are illustrated in Figures 21 through 24.

FUNCTIONAL PLANNING

In designing an open feedlot for beef feeding, there are several areas that must be planned. These areas serve a particular function in the overall operation of a beef feeding facility. The basic functional areas are:

- Pens
- Feeding and watering
- Feed processing and storage
- Receiving and shipping area for cattle
- Cattle handling
- Sick pens
- Office
- Drainage and runoff control
- Solid waste handling, stockpiling and disposal
- Horse stables and feeding area
- Equipment maintenance and storage area

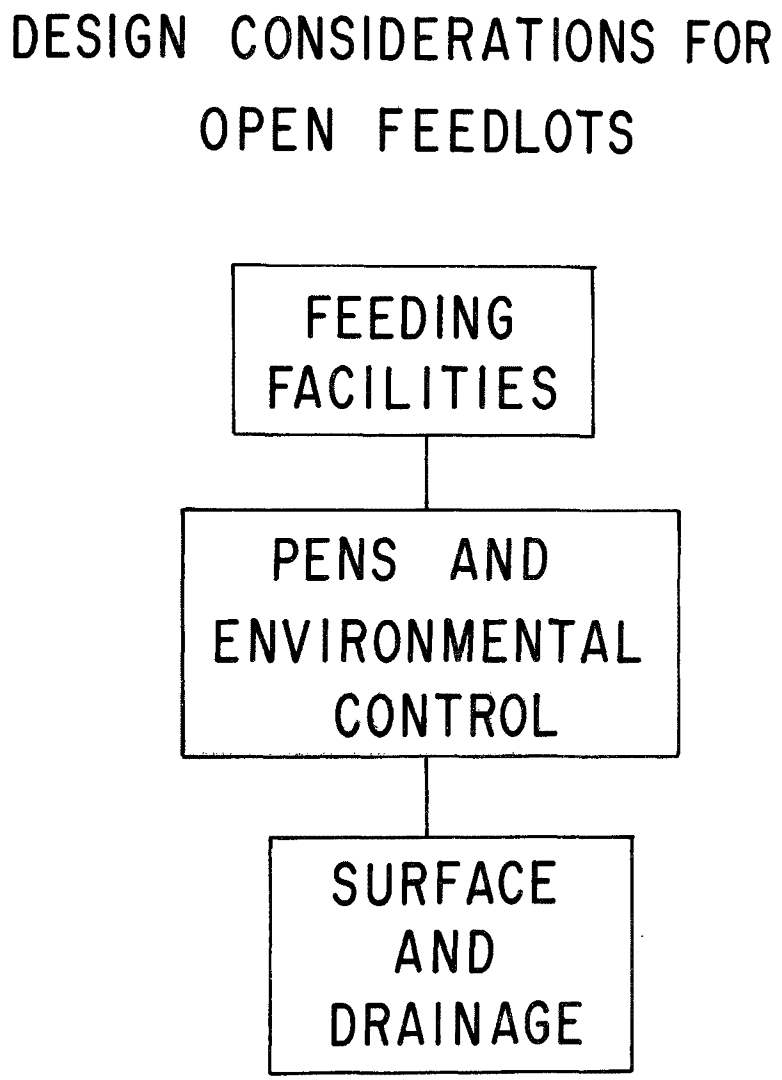


Figure 21. Design considerations for open feedlots

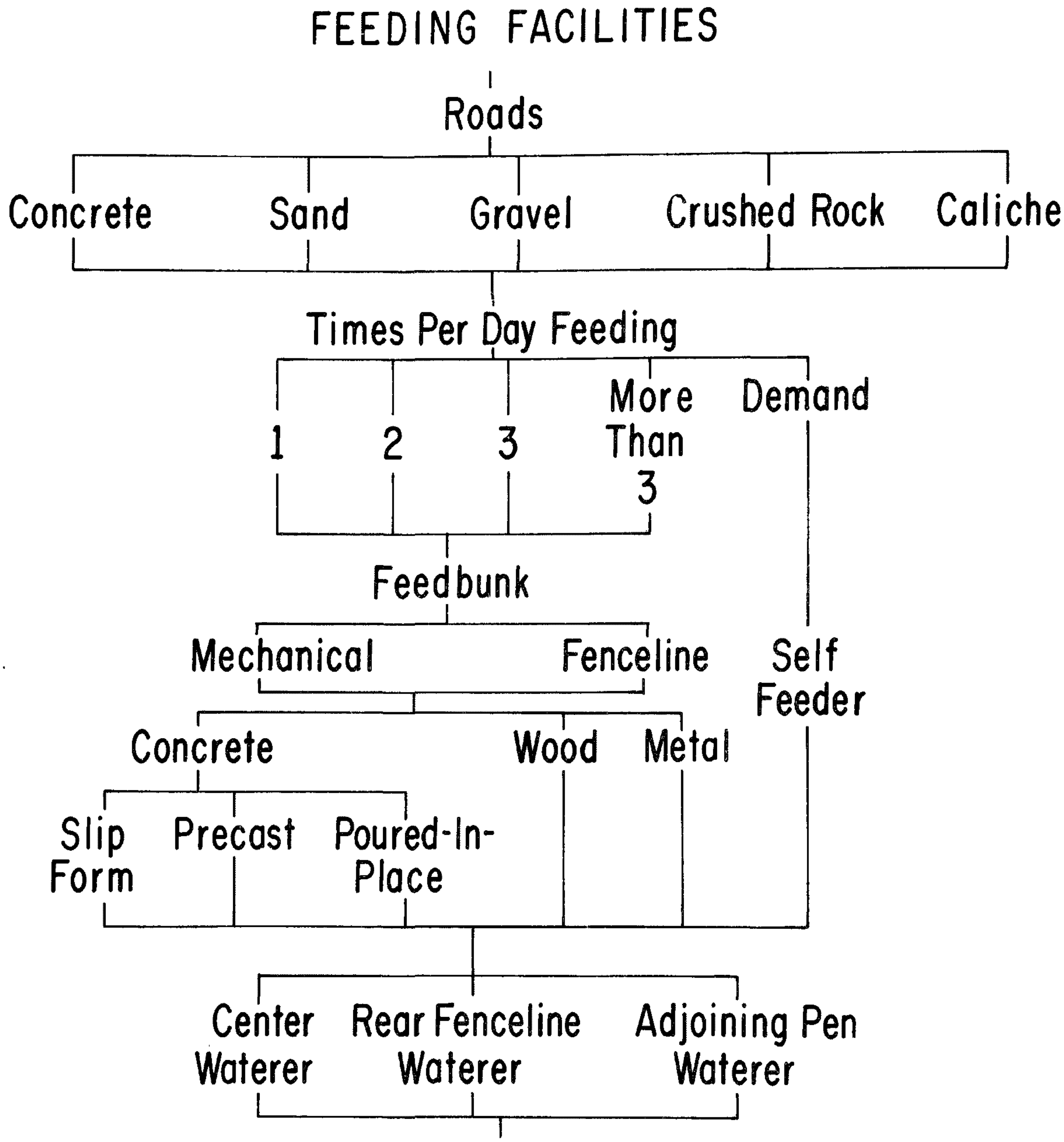


Figure 22. Feeding design

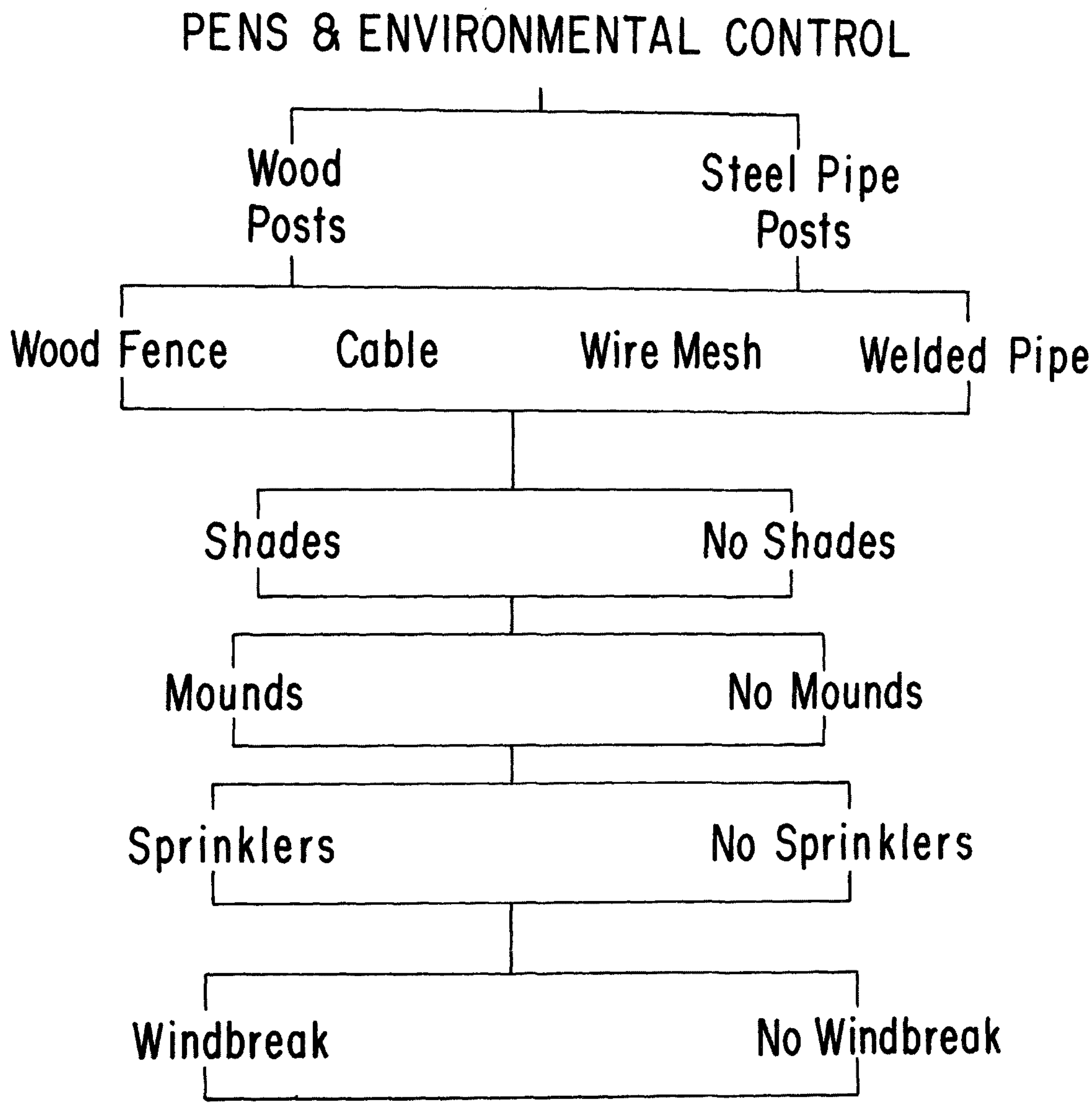


Figure 23. Pen and environment control design

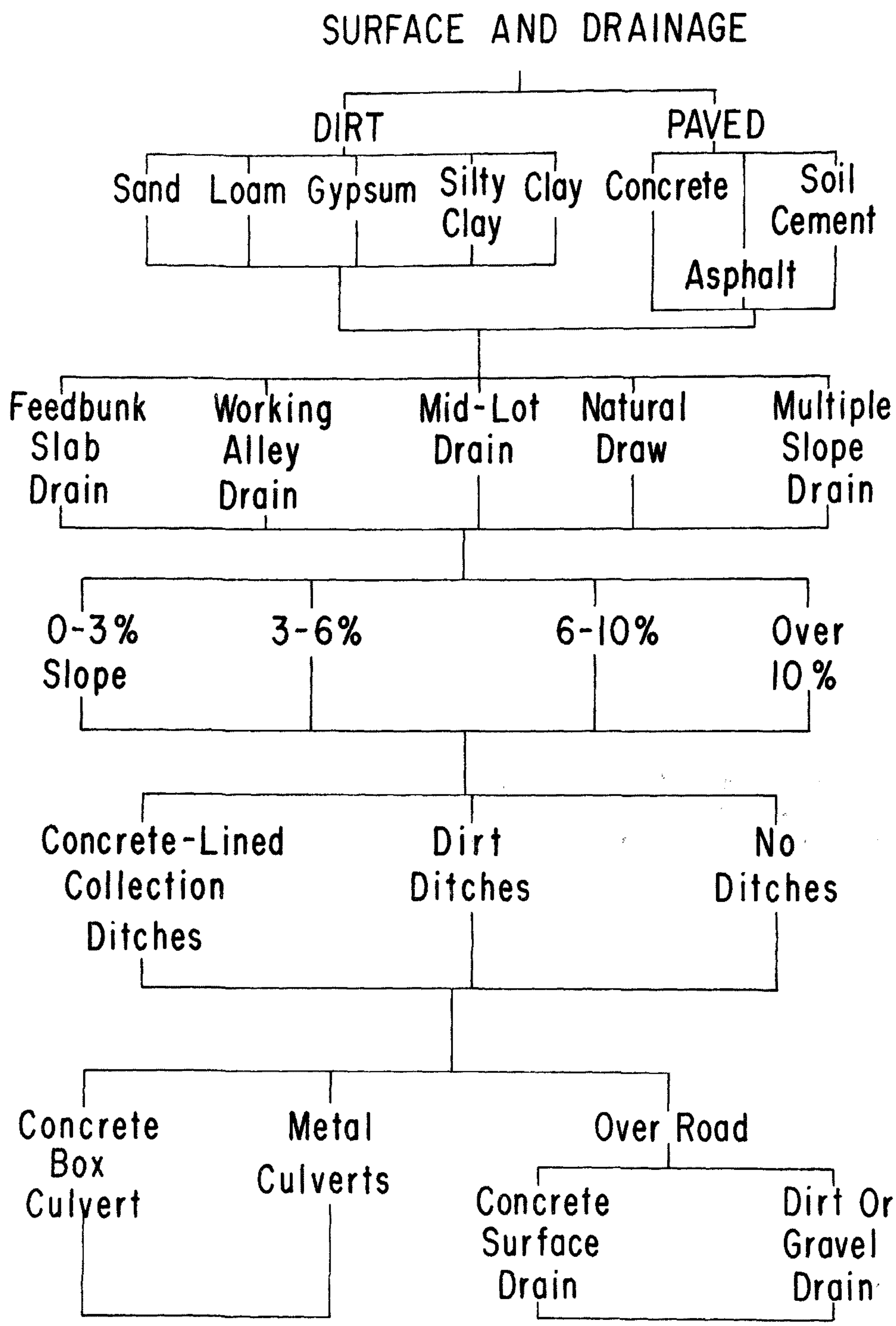


Figure 24. Drainage design

A summary of some of the design requirements for planning are presented in Tables 17 and 18. These design requirements are essentially those formulated by the Midwest Plan Service (7) and Van Fossen and Myer (94) and may have to be adjusted to meet local conditions.

SITE SELECTION

Many factors must be considered in selecting a site for a beef feedlot. Some of the factors relate to socio-economic and some to engineering design decisions. Marketing and transportation considerations have to be analyzed prior to the selection of an area for a feedlot. Feeder cattle supply, feed grain supply, and marketing of the finished cattle affect the site selection. Land prices and agricultural practices in the area may also influence the choice of a feedlot location.

Feedlots should be located in socially acceptable areas, away from major residential areas and highways if possible, to avoid complaints from odors or dust. In essence, the community or area should want the feedlot. State and local laws and regulations may affect the general, as well as the specific, location of a feedlot.

Much can be done to reduce the water and air pollution potential from a feedlot by properly planning its location and design. In most cases, this can be done more economically through planning prior to construction than by having to later install pollution abatement structures. Miner states that site selection is the decision of greatest importance in determining the acceptability of feedlot operations (60).

Basically, selecting a feedlot site consists of examining features of the local terrain and micro-climate which provide some environmental protection and an opportunity to minimize air and water pollution while providing good features for carrying out the operations of the feedlot. Many of the factors affecting feedlot site selection are related to the control of surface water flowing across the feedlot, while others are related to the control of odors and the handling of the runoff and solid wastes. The following points should be considered in feedlot site selection:

1. Location with respect to water sources.
2. Diversion of precipitation falling outside lot.
3. Lot topography and drainage.
4. Soil type and structure.

Table 17. Summary of Design Requirements for Open Feedlots

Design Factor	Recommendation
Space	
Lot Area	
unsurfaced	400 ft^2/animal
partially surfaced	150 "
surfaced, no shelter	55 "
surfaced, open housing	30 "
concrete	3 ft^2/100 lb animal
Resting Area in Sheds or under Shade	2 to 3 ft^2/100 lb animal
mature cows	25-30 ft^2/animal
600 lb. to market	20-25 "
calves to 600 lb.	15-20 "
bedded barn	2 ft^2/100 lb animal
Corrals	
holding pens	20 ft^2/animal
crowding pen	150 ft^2 or one truck load
working chute	18 to 30 ft^2
sorting alleys	10 to 12 ft wide
loading chute	30 to 42" wide
working alleys	14 ft
Feeding Space	
once per day feeding	
calves to 600 lb.	18 to 22 in/animal
600 lb. to market	22 to 26 "
mature cows	26 to 30 "
feed always available	
hay or silage	4 to 6 in/animal
grain or supplement	3 to 4 "
grain and silage	6 "
feeding 3 or more times/day	
600 lb. to market	6 to 12 in/animal
600 lb.	12 "
Watering	40 head per waterer
	15 gal/head/day
drylot	5500 gal/year

Table 17. Continued

Design Factor	Recommendation
Bunk Dimensions	
Throat Height	
calves	18 inches
yearlings and cows	22 inches
Width	
fed both sides	48 inches
fed one side	18 inches
mechanical feeder	54 to 60 inches
Height of Bunk Floor Above Apron or Step	
where apron scraped	4 to 6 inches
where snow, mud can accumulate	8 to 12 inches
Step Along Bunk (Needed when apron is sloped less than one inch/ft or bunk is higher than needed)	4 to 6 inches high 12 to 16 inches high
Concrete Apron Along Bunk	
Slope	
self-cleaning	1 inch/ft
minimum	1/2 inch/ft
Length	
for tractor scraping	6 to 8 ft
(If area below will be muddy and lot slopes away from bunk)	8 to 12 ft

Table 18. Basic Requirements for Beef Cattle Housing (78)

<u>Feedlot Area</u>	
dirt, medium textured soil	200-300 ft^2/animal
dirt, poor drainage on heavy soil	300-400 ft^2/animal
paved, 1/4 to 1/2 inch/ft slope	50-70 ft^2/animal
	100-125 cattle/pen normally 200 cattle/pen large operation
<u>Shed Space</u>	15-25 ft^2/animal below 600 lbs 20-35 ft^2/animal above 600 lbs 30-50 ft^2/animal mature cows
<u>Shade</u>	30-40 ft^2/animal covered area 10-12 ft high
<u>Daily Feed Consumption</u>	2.5-3.0% of body weight for fattening cattle (air dry basis)
<u>Daily Water Consumption</u>	0.5 gal/lb dry matter consumed at 60°F 0.9 gal/lb dry matter consumed at 90°F

5. Land area.
6. Wind direction.
7. Location with respect to residential areas.

Location with Respect to Water Sources

Feedlots should be located so that water pollution is prevented. Thus, untreated runoff water from feedlots should be prevented from entering streams, rivers, lakes, irrigation supply canals, and underground water supplies. In the Pacific Northwest, it has been suggested that feedlots be located outside of a 10 year flood plain of all river or stream systems or at least 100 yards outside of the streams apparent high water marks (89). It is also suggested that feedlots be located at least 100 yards away from any intermittent dry storm drainage gulley or irrigation canals. The Iowa Pollution Control Commission requires that beef feedlots be registered if a feedlot is less than two feet per animal from a watercourse that drains five sections or more of land (40).

To avoid ground water pollution, attempts should be made to prevent seepage or percolation of contaminated surface waters through the soil to the water table. Unpaved feedlots should have at least a 30 foot soil mantle between the surface and the water table and 10 feet for paved feedlots (89). Avoid locations where polluted water may enter the underground aquifer directly through fractured rock, abandoned wells, well casings, or tile drains.

Diversion of Runoff

A feedlot site must be carefully chosen in order to control runoff from the feedlot and prevent runoff from adjacent land from entering the feedlot. A feedlot should be located away from a stream or watercourse (60). Terraces or road ditches can be used to intercept uphill water and divert it around the feedlot, thereby minimizing the amount of waste water to be handled or treated by runoff control structures.

Lot Topography and Drainage

Drainage within the feedlot area should be controlled from the feedlot pen surfaces until it later discharges the runoff into a collection basin for treatment or ultimate disposal. Sufficient land area should be allowed for the drainage system and collection facilities. The aim should be to keep the runoff on the feedlot property and not permit it to run on the neighbor's. A topographic map is invaluable in planning the drainage system for the feedlot.

Sites for open, unpaved feedlots should be uniformly sloped from 3 to 6 per cent to provide adequate surface drainage. Unpaved lots having slopes over 10 per cent may erode. In the upper Midwest, the Midwest Plan Service's Beef Housing and Equipment Handbook (7) recommends that the outdoor lots should slope away from the prevailing winter wind which is usually a south or east slope. Mounds may also be constructed to provide dry locations for cattle resting areas in the pens. Avoid drainage from one lot to another, if possible.

Feeding lines should be oriented to provide the best drainage either at the high side of the lot or up and down the slope. In northern climates, a north-south or north-west-southeast orientation is generally preferred because the sun can melt the ice and dry the pavement along both sides of the bank. Roads should be slightly crowned and lots should be sloped away from buildings and feeding lines.

Soil Type and Structure

The soil type and structure beneath a feedlot site should be considered to avoid ground water pollution. For example, fractured limestone can allow polluted water to rapidly enter a ground water aquifer. Guidelines developed for Pacific Northwest cattle feedlot waste management (89) suggest that unpaved feedlots not be located on gravelly soils. In Kansas, it has been recommended that the soil type underneath the feedlots and waste retention facilities should have a tight subsoil rather than a porous one (15).

There is some indication that manure may serve as a sealant on feedlot surfaces and at lagoon bottoms. McCalla, et al., (56) found no movement of nitrates and other possible pollutants through the soil to the water table for a flat feedlot in eastern Nebraska. Apparently, there is an essentially impermeable barrier formed at the soil-manure interface. Lehman, et al., (48) also found that nitrates did not penetrate the bottom of a playa lake which served as a storage and evaporation facility for runoff-carried wastes from a feedlot near Amarillo, Texas. In view of the above information, some feedlot operators do not completely remove the solid waste material on the feedlot surface. Instead, they leave approximately an inch of manure so as not to disturb the soil-manure interface. Again, local conditions may dictate whether this practice can be used at a particular site.

Land Area

Adequate land area, not only for the feeding facilities but also to accomodate runoff control facilities and manure disposal, is a necessary consideration. Productive agricultural land, or land that can be developed into productive land, should be provided adjacent to the feedlot operations. It is advantageous for a feedlot to be surrounded by a buffer zone of feedlot controlled land to provide an area for manure disposal as well as some space separation for odor dilution.

Wind Direction

Wind directions fluctuate considerably so it is difficult to establish firm guidelines as to location of a feedlot with respect to wind direction. Also, local terrain and micrometeorological conditions affect wind directions.

Generally, feedlots should be located downwind from a residential area for the prevailing wind conditions. For the summer, most areas in the Midwest or Great Plains have southerly or southwesterly prevailing winds. Therefore, feedlots should be located east or northeast of a residential area.

Residential Areas

Feedlots should be located so that they will not interfere with residential areas or enterprises where concentrations of people may be found who are not able to appreciate the odors arising from a feedlot. Miner (60) states that "although no maximum distances have been established beyond which complaints are not valid, it would seem logical to stay three miles away from an urban area; at least one mile from a housing development and one-half mile from the nearest residence."

Most court cases between neighbors and a feedlot have arisen because of odors coming from a feedlot during certain periods. One way of reducing the chance for such litigation against the feedlot is to locate in agricultural and desolate places away from residential areas.

ENVIRONMENTAL CONSIDERATIONS

Several environmental factors may affect the performance of beef animals during the finishing period. Esmay (16) divides the environmental factors into physical, social, and thermal. The physical factors are space, light, sound, pressure, and equipment. The social factors are the numbers of animals per pen and behavior. The thermal factors are air temperature, relative humidity, air movement, and radiation.

Nelson (65), reviewed the literature published on the effects of climate and environment of beef cattle with emphasis on hot weather effects. Several investigators found significant differences in physiological response and performance of beef cattle due to ambient temperature effects. With increasing outside air temperature from 50 to 100°F, body temperature tends to increase, although there are differences between breeds. The Brahman cattle maintain body temperature at a more uniform level than the European breeds. Also, calves do not withstand as high air temperatures as cows. For nearly all breeds the energy cost per pound of gain was less at 50°F than at 80°F.

Solar radiation also affects the performance of beef cattle. Increased thermal radiation increases the radiation heat load on the animals and is quite critical when air temperatures are above 100°. Brahman cattle withstand more solar radiation than European cattle. Relative humidity also influences the production of cattle particularly when combined with high ambient temperatures.

Kelly (44) discusses the effects of thermal environment on beef cattle. The European breed of calves held at 50°F grew much more rapidly than those held at 80°. Indian cattle withstand about 20° higher temperature with a comfort zone from 50° to 80°F compared with 20° to 60°F comfort zone for most European breeds.

Schulz (78) presents some basic requirements for beef cattle housing, feeding, and handling and published data on recommended feedlot areas per animal, dairy feed and water requirements, daily water intake, amount of manure produced, manure obtained from cattle fed on paved floors in open sheds and man-hours per ton for handling manure for beef cattle.

Hinkle (36) reviewed environmental research with beef cattle for both low and high temperature effects and found that feeder calves with shelter had a higher average daily gain than calves with no shelter and also had a lower cost of feed per pound of gain. Results from research conducted in Saskatchewan indicated that board fences had a significant advantage over no shelter with higher rates of gain and a better feed efficiency during the winter months. There were no significant differences between the performances of sheltered animals and those protected by windbreaks.

Morrison, et al., (64) found that slopes up to 7° did not depress weight gains or feed efficiencies. A slope of about 5° was sufficient for removal of most of the manure, whereas floors with only 1.25° slope were covered with sloppy manure. They found the 4.75° sloped floor to have the least manure accumulation and the highest daily gains.

Givens, et al., (24) found that satisfactory winter gains at Davis, California were obtained with beef cattle in either concrete or dirt corrals when allowed 212 to 255 square feet of space per animal. Animals housed in shelters and on slotted floors gained as well in only 58 square feet of space per animal as did unsheltered animals in a dirt corral with 255 square feet per animal.

Bond, et al., (10), found that mud depressed cattle production more than either wind or rain during the winter months at Davis, California where winter temperatures range between 40 and 60°F. Mud reduced daily gains by approximately 30% per pound of gain in comparison with the concrete pens. When the cattle in the muddy pen had a dry place to rest, their production loss was considerably less. Exposure to artificial rain equivalent to 0.19 inches during a 10 minute period each hour decreased daily gain 15% and reduced feed conversion efficiency 20%.

Considerable research has been conducted in the Imperial Valley of California on determining the shade requirements for beef feedlots and methods for increasing beef production in a hot climate. Ittner, Bond, and Kelly have summarized some of the research that has been conducted at the El Centro Field Station (41). They suggest five factors that affect animal comfort and production in hot weather: shade, water, air movement, radiation, and feed.

Shades should be from 15-20 feet wide, 10 to 12 feet high and could be several hundred feet long and be oriented north and south so that the sun covers the entire parts of the feedlot which improves sanitary conditions. Shade space of 60 square feet per animal is adequate. Hay is the coolest of all materials tested although it provides problems of replacement and protection from wind and rain damage. Also, tests indicate that painting the top side of the metal white and the bottom side of the metal roof black reduces the radiant heat load under the shade received by the animals. Reducing the solar radiation is a complex problem but improvements can be made by constructing corrals from wire or cable rather than wood. The fences in a wooden corral absorb a great amount of heat and radiate.

it directly back onto the penned cattle. Also, other buildings, machinery, and obstacles radiate heat back to the cattle. Cattle located in pens near growing crops gain much better than when subjected to radiation from the bare earth. Cooling of drinking water to about 65° resulted in noticeable weight gains from the animals.

Increased air movement is beneficial to the cattle when provided by mechanical or natural means. Wire or cable corrals offer little resistance to natural air movement. Also, large fans operating part of the time increase the air movement over penned cattle. The increased air movement speeds up the evaporation of moisture from the skin and brings about more rapid cooling.

In feeding beef animals during the summer months, care should be taken to not supply a high fiber diet. Such feeds produce a high heat increment which must be dissipated by the body, a difficult task during hot weather. Cooling the drinking water to about 65°F produces noticeable weight gains in beef animals.

Givens (23) found that the radiant heat load on the animals in southeast United States is greater under high shades than low ones as shades over six feet high had no advantages in reducing the heat load. Apparently, the increase in cloud cover in southeastern United States causes a different radiation effect than under clear sky conditions.

A feeding trial in Tulara County, California conducted by Miller (59), indicated that dust from feedlots in the summer can be controlled by reducing allotted space to as low as 50 square feet per head without adversely affecting performance of cattle. The corral surfaces in the 100 and 150 square feet per head pens were dry enough to cause a dust problem whereas the surface of the 50 square feet per head pens were wetter than desirable. Spacing for 5.5 square feet per hundred-weight produced a surface which was wetter than desirable whereas a spacing of 8.5 square feet per hundred-weight failed to settle the dust. Spacing somewhere between these figures would be optimum.

Mahoney, Nelson, and Ewing conducted research in Oklahoma to determine the performance of experimental close-confinement cattle feeding systems (53). They ran tests with animals housed at 15 square feet per animal on a slotted floor and shelter, 25 square feet per animal on a slotted floor and shelter, and 100 square feet per animal in a dirt lot with no shelter. Cattle limited to 15 square feet of slotted floor space required 20% more feed per pound of gain than cattle allowed 25 square feet of slotted floor space or cattle on dirt lots with 100 square feet of space per animal. There were essentially no differences between the 25 square feet per animal spacing on a slotted floor and the 100 square foot per animal on the dirt lot.

ENVIRONMENTAL MODIFICATION

Modification of the environment of open feedlots is more difficult than for confinement shelters. However, there are at least three major modifications that can be undertaken in open feedlots:

1. Shades can be constructed to reduce the amount of solar radiation on the animals. Also, shades can be installed over feedbunks to intercept rainfall.

2. Windbreaks can be used to reduce the wind velocities particularly for wintertime conditions. Some recommendations for windbreaks are given in the Midwest Plan Service Booklet on Beef Housing (7).

3. Mounds can also be provided in the feedlots. This permits the cattle to find a higher and dryer spot during wet weather and also provides a certain amount of shelter from the wind during the winter. During the summer, animals can get on top of the mound and will come into contact with an increased amount of air movement.

PEN DESIGN

Andrews (1), developed a nomograph to determine the pen size, Figure 25. For feedlots in the Desert Southwest, he suggests the following steps in laying out the plan for a pen:

1. Orientate the shades north-south and, if possible, the pens also.

2. Decide how many square feet to allow per head.

3. Decide how much bunk space to allow per head.

4. Determine how many animals the pen is to hold.

5. Find the pen length by multiplying the number of head by the length of bunk space per head.

6. Find pen depth by dividing the square feet allowed per head by the bunk length per head.

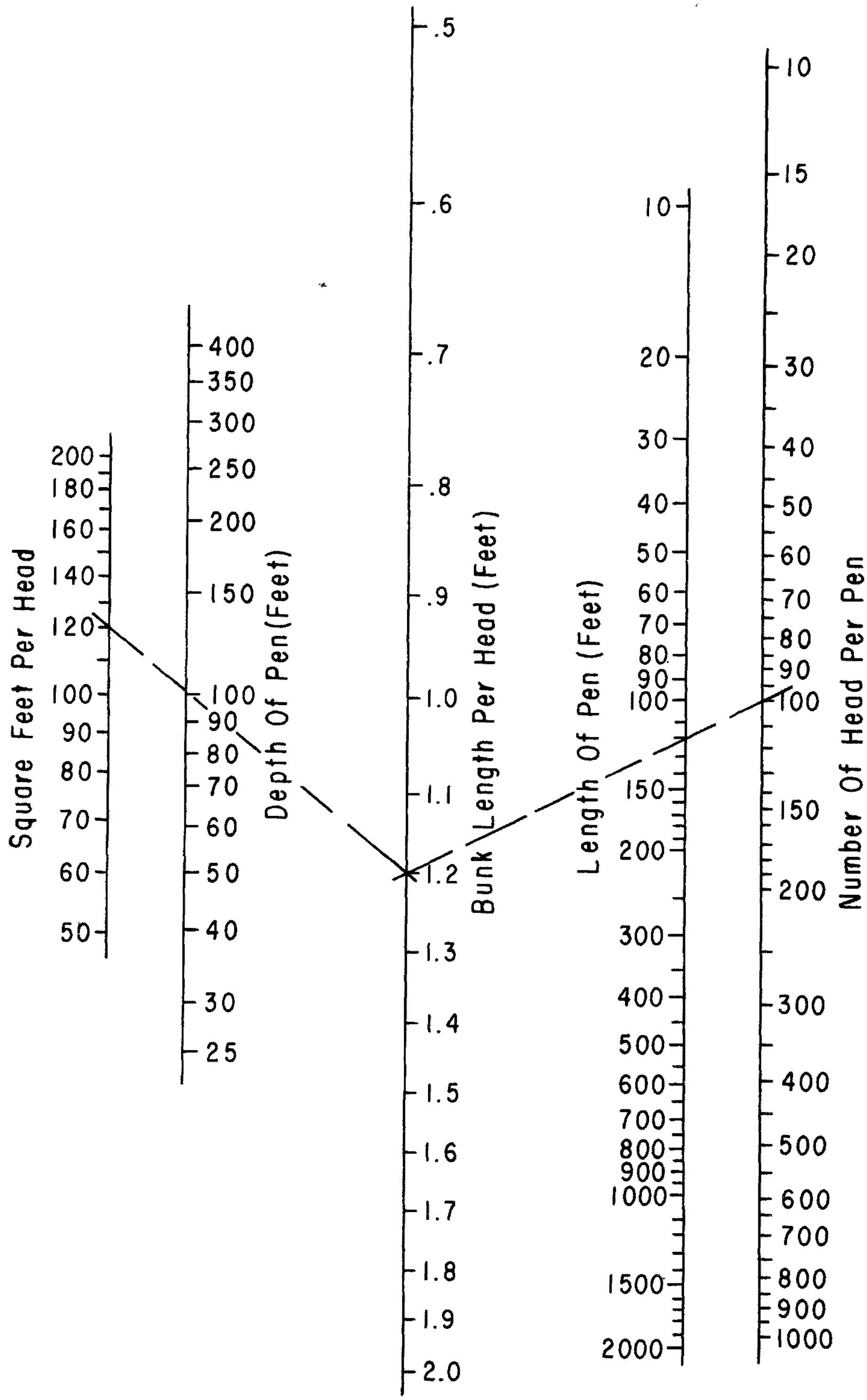


Figure 25. Nomograph for determining pen size (Andrews, 1970)

The two major considerations in determining pen dimensions are the bunk capacity and the space per animal. The bunk capacity is determined primarily by the method and frequency of feedings. The area per head affects the moisture conditions of the pens, and is further complicated by the weather and drainage. The area per head will be determined primarily by local rainfall and land costs.

CHAPTER VI

ANALYSIS OF ALTERNATIVES FOR OPEN FEEDLOT WASTE MANAGEMENT

In analyzing open feedlot waste management systems, the system was separated into facility and handling segments. The facility segment of the system was either an unpaved feedlot or a paved feedlot. The waste handling segment was separated into a solid waste handling system and a runoff control system.

The analysis used in this investigation was based upon procedures developed by Paine (71) for determining the economic analysis of livestock systems as a function of the magnitude of the operation. This procedure provided for an estimation of facility, machinery, labor and capital costs for a livestock operation. Seven different expense categories contributed to the expense of the total system:

1. land
2. animal
3. storage
4. cattle facilities
5. field machines
6. farmstead machines
7. power or tractors

The operating expenses for machinery and tractors were based upon computer programs written by Bowers (11). This included depreciation, interest, maintenance and fuel costs.

In this investigation the procedures developed by Paine were re-written and adapted for use on a conversational programming system (CPS) to enable quick interaction with the IBM/360/65 digital computer located at the Oklahoma State University Computer Center. Paine's procedures did not include waste management systems, therefore, new procedures and programming had to be made to include the waste handling aspects. Prior to programming, much information had to be obtained on the costs and design of the facilities and waste management systems. After this information was obtained, the procedures were written and cost factors included in the calculations. Input to the programs consisted essentially of physical factors needed for design, e.g., number of animals in the feedlot. Output consisted of sizes of facilities or number of pieces of equipment and their associated operating and investment costs. Some of the design procedures discussed in Chapters II, III and IV were included in the calculations. The investment cost, capacities and estimated life of the various machines used in this analysis are presented in Table 19. Some of the capacities were estimated from a field observation whereas others were estimated using information provided by manufacturers. The investment costs are those listed as the sales cost by selected manufacturers. The CPS programs are available from the authors of this report.

FACILITIES COST

The cost of construction and materials for open feedlots were obtained primarily from field observations and personal communications with commercial firms constructing feedlots. These costs are summarized in Table 20.

A computer program was written to calculate the feedlot costs for the entire facility using the various construction costs from Table 20. It also included the procedures for designing a feedlot utilizing various alternatives of construction. The program was designed to calculate the number of pens and placed a limit of ten pens per row (or twenty pens in a group) with a road in front of each set of ten pens and a work alley between each set of ten pens. Roads and cattle alleys were included in the pen design and their sizes were based upon the design criteria found from the field observations and in the literature. As the feedlot capacity increased and a second group of pens was necessary it was assumed that the road would be constructed around the entire feedlot area as if there were two full groups of pens (or 40 pens in total). This permitted space for future expansion of pens but momentarily increased the surface area for runoff.

Unpaved Feedlots

Unpaved feedlots are used almost exclusively in the Great Plains, Desert Southwest and Western states. Investment costs per animal and operating costs per animal day for various combinations of feedbunk types and fence types for 20,000 head unpaved open feedlot are presented in Table 21. The following assumptions were made: 200 sq ft per animal, 1 linear foot per head of feedbunk space, and 200 animals per pen. These values were typically encountered in the Southern High Plains region. For the operating costs it was assumed that the facilities would be depreciated in 10 years and that feedlots would operate at full capacity.

Of the feedbunk and fence types analyzed, the wood bunk with a wire fence had the least initial cost and had the lowest operating cost. The systems using the slip form concrete bunk had the highest investment and operating costs.

Table 19. List of Machines and Their Cost, Wearout Life, Capacity, and Fuel and Lubrication Requirements

No.	Machine	Cost ($)	Wearout Life (hrs)	Capacity (yd/hr)	Fuel & Lub Cost ($/hr)
1	Caterpillar 950 loader	31,100	12,000	168	1.87
2	Int. 656 tractor w/ft end loader	8,900	12,000	37.2	0.66
3	Chev. 80 dump truck	9,700	2,000	39.6	1.91
4	Spreader truck, Int. F1800, Oswalt MB 17.5	12,800	2,000	67.5	2.08
5	Pull-type spreader, AC 299	1,434	2,500	38	----
6	Liquid manure spreader, Badger BN 212[a]	1,740	2,000	42	----
7	Vacuum spreader, Badger BN 215	1,899	2,000	28	----
8	Liquid spreader truck, Int F1800	9,300	2,000	55.7	2.08
9	Liquid manure pump, Sahlstrom[b]	1,433	2,000	250	----
10	Liquid spreader w/injector, Sahlstrom[c]	2,894	2,000	37	----
11	Blade on tractor, AC6'	245	2,500	350	----
12	Grader, cat. 112F	22,325	12,000	1,210	1.35

Table 19. Continued

No.	Machine	Cost ($)	Wearout Life (hrs)	Capacity (yd/hr)	Fuel & Lub Cost ($/hr)
13	Elevating scraper, Cat. 613	37,226	12,000	105	2.14
14	Rotary scraper, BeBe RS-8565-4	5,895	5,000	56	----
15	Cable scraper, Big Dutchman	2,280	2,500	--	----
16	Oxidation rotor, Honeybee #75	2,228	8,000	--	----
17	Fans, Acme Engr., DC 4BH	339	12,000	17,000 CFM	----
18	Electric motor, 40 HP Reliance 324T	882	12,000	--	----
19	Tractor, Int. 656	7,770	12,000	65 HP	----
20	Dragline a. 1500 gal. capacity b. 1400 gal. per min. c. 1400 gal. capacity	67,500	------	156	----

Table 20. Costs for Feedlot Construction

	Cost, Dollars
Feedbunk Costs per Linear Foot	
Wood	2.00
Precast concrete	4.50
Slipform concrete	6.25
Mechanical	7.50
Feedbunk Apron Cost per Square Foot	0.45
Fence Costs per Linear Foot (Including Labor)	
Wire	1.04
Cable	1.95
Pipe	1.65
Wood	1.25
Windbreak	3.13
Road Costs per Square Foot	
Hard surface	0.45
Gravel	0.10
Waterers with Slab Cost per Pen	300.00
Paved Lots Cost per Square Foot	0.45
Land Forming for Lot Drainage	
Cost per Head	1.00
Shade Costs per Square Foot	0.32
(for 27 sq ft per animal)	

Table 21. Investment Cost per Head and Operating Cost per Animal Day for Various Combinations of Feed Bunk Types and Fence Types for a 20,000 Head Unpaved Open Feedlot with 200 square feet per Animal, One foot per Head Feed Bunk Space, and 200 Animals per Pen

Fence Type	Feed Bunk Type: Wood	Feed Bunk Type: Precast Concrete	Feed Bunk Type: Slipform Concrete
Wire	11.36[1] (.0062)[2]	13.86 (.0076)	15.61 (.0085)
Cable	13.27 (.0073)	15.77 (.0086)	17.52 (.0096)
Wood	11.80 (.0065)	14.30 (.0078)	16.05 (.0088)
Pipe	12.64 (.0069)	15.14 (.0083)	16.89 (.0092)

[1]Investment cost per head capacity, dollars

[2]Operating cost per animal day, dollars

Many feedlots that were visited had precast concrete feedbunks with a cable and steel post frame. This type had an investment cost of $15.77 per head and an operating cost of $0.0086 per animal day. This included all of the facilities needed for the pens and roads, including waterers, feedbunk aprons, landforming costs and the necessary fencing and feedbunks. This assumes a gravel road but does not include windbreaks or shades. This cost compares quite closely with the rule-of-thumb cost of $15 per head for feedlots that have been constructed in western Oklahoma and the panhandle area of Texas.

Various combinations of animal densities, feedbunk space and number of animals in a pen were analyzed to determine the effect of these parameters on the total lot area, investment cost per animal, and cost per animal day (Table 22). A 20,000 head unpaved open feedlot with precast concrete feedbunk and a cable fence was assumed. The minimum facility costs were for 250 animals in a pen. As the animal density increased and the feedbunk space increased, the investment and operating costs increased linearly. An optimum combination appeared to be for 150 sq ft per animal, 0.75 linear feet per animal per feedbunk space, and 250 head of animals per pen, giving a total lot area of 372,700 sq ft an investment cost of $13.17 per animal, and an operating cost of $0.0072 per animal day. This reduced the investment cost per animal by about $2.50 per head over the cost for space allowance of 200 sq ft per animal, 1 linear foot of bunk space per animal and 200 animals per pen.

Paved Feedlots

With paved feedlots the space allowance per animal can be reduced. The cost for a paved feedlot using precast concrete bunks and a cable and steel post fence was made for 50 sq ft per animal and 75 sq ft per animal space allowance. For 50 sq ft per animal the paved feedlot area was reduced by 1/3 to 1,623,600 sq ft from over 4,700,000 sq ft for an unpaved feedlot with 200 sq ft per animal. However, the investment cost and operating cost for the paved feedlot were about double the unpaved feedlot. The investment cost per head was $32.11 and the cost per animal day was $0.0176, not including the value of the land.

Increasing the space allowance for a paved feedlot to 75 sq ft per animal increased the feedlot area to 2,140,000 sq ft and increased the investment cost about $11 from $32.11 to $43.64. The operating cost increased from $0.176 per animal day to $.0239 per animal day.

Table 22. Operating Costs per Animal Day and Investment Cost per Head for 20,000 Head Open Feedlot with Precast Concrete Feed Bunks and Cable Fence for Various Animal Densities, Feed Bunk Space per Animal, and Number of Animals in Pen

Animal Density* (sq ft/head)	Total Lot Area (sq ft)	Investment Cost per Head ($)	Cost per Animal Day ($)
100	2,653,600	14.67	.0080
150	3,683,600	15.22	.0083
200	4,713,600	15.77	.0086
250	5,743,600	16.32	.0089
300	6,773,600	16.87	.0092
350	7,803,600	17.42	.0095
400	8,833,600	17.97	.0098
Feed Bunk Space (ft/head)**			
0.5	4,553,600	12.45	.0068
0.75	4,613,600	13.74	.0075
1.0	4,713,600	15.77	.0086
1.25	4,829,600	18.09	.0099
1.5	4,953,600	20.56	.0113
Number in pen* (head)**			
100	4,867,200	19.41	.0106
150	5,003,040	17.08	.0094
200	4,713,600	15.77	.0086
250	4,682,880	13.72	.0075
300	5,594,880	14.65	.0080

* Feed bunk space is 1.0 ft/head and number of animals per pen is 200

** Animal density is 200 sq ft per animal and number of animals per pen is 200

*** Animal density is 200 sq ft per animal and feed bunk space is 1.0 ft per head

As feedlot size or capacity increases the investment cost per head decreases slightly but less than $1 per head between 5,000 animals and 20,000 animals. Likewise, the operating cost decreases only slightly from $.0180 for 1,000 head to $.0179 per animal day for 20,000 head at 50 sq ft per animal capacity for the paved feedlots.

SOLID WASTE HANDLING

For handling wastes in large commercial feedlots, three major systems are used:

1. A commercial loader and spreader truck.
2. A rotary scraper attached to a tractor.
3. An elevating scraper.

The last two systems remove the waste from the feedlot and carry it in the same vehicle to the stockpile or point of distribution. The first system is the most prevalent system. It permits the material to be hauled considerable distance to fields. Other systems using smaller tractors with front-end loaders and either spreader truck or a pull-type spreader are not used extensively in the large commercial feedlots. Discussion of their use is presented in Chapter VIII on waste handling methods for confinement buildings.

Days of Use per Year

The total operating costs per animal day and the total investment cost for six solid waste handling systems are presented in Figures 26 and 27 respectively. For 20,000 head, 1/4 mile hauling distance, and over 50 days of use per year, the elevating scraper had the lowest operating cost. A commercial loader plus spreader truck had the highest cost, because of the low capacities in the dump truck compared with other systems.

The system with the least total investment cost for 20,000 head was the rotary scraper with tractor. The other systems had approximately the same investment cost until 100 days of use per year was reached. Then the elevating scraper had a low cost which remained steady with higher days of use per year, primarily because of the one machine doing several jobs. The tractor loader plus dump truck and tractor loader plus pull spreader continued to decline in investment cost as the days of use increased. This was due primarily to fewer pieces of equipment needed as the days of use increased. A more detailed breakdown of the operating and investment costs for these systems are included in the

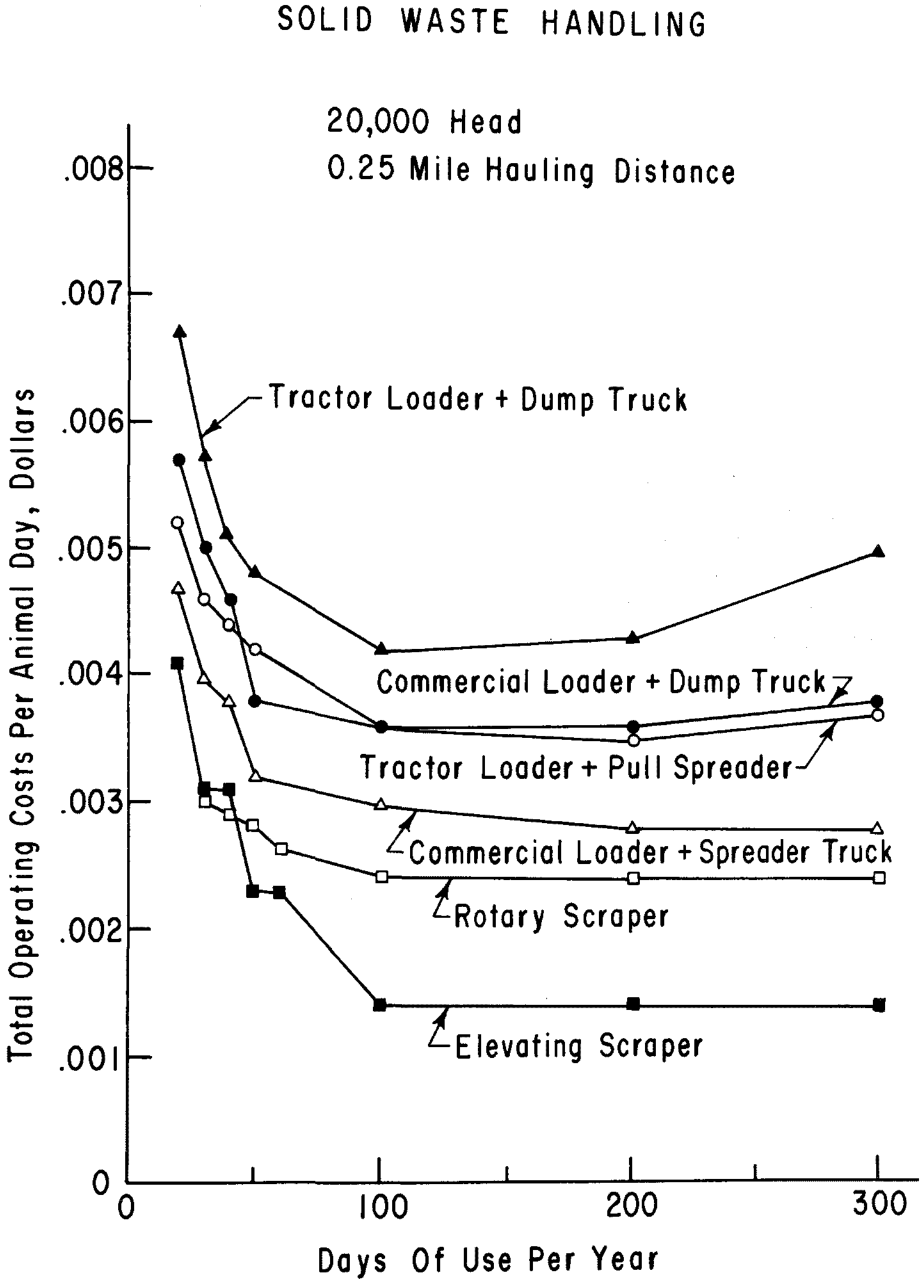


Figure 26. Solid waste handling: total operating cost vs. days of use per year

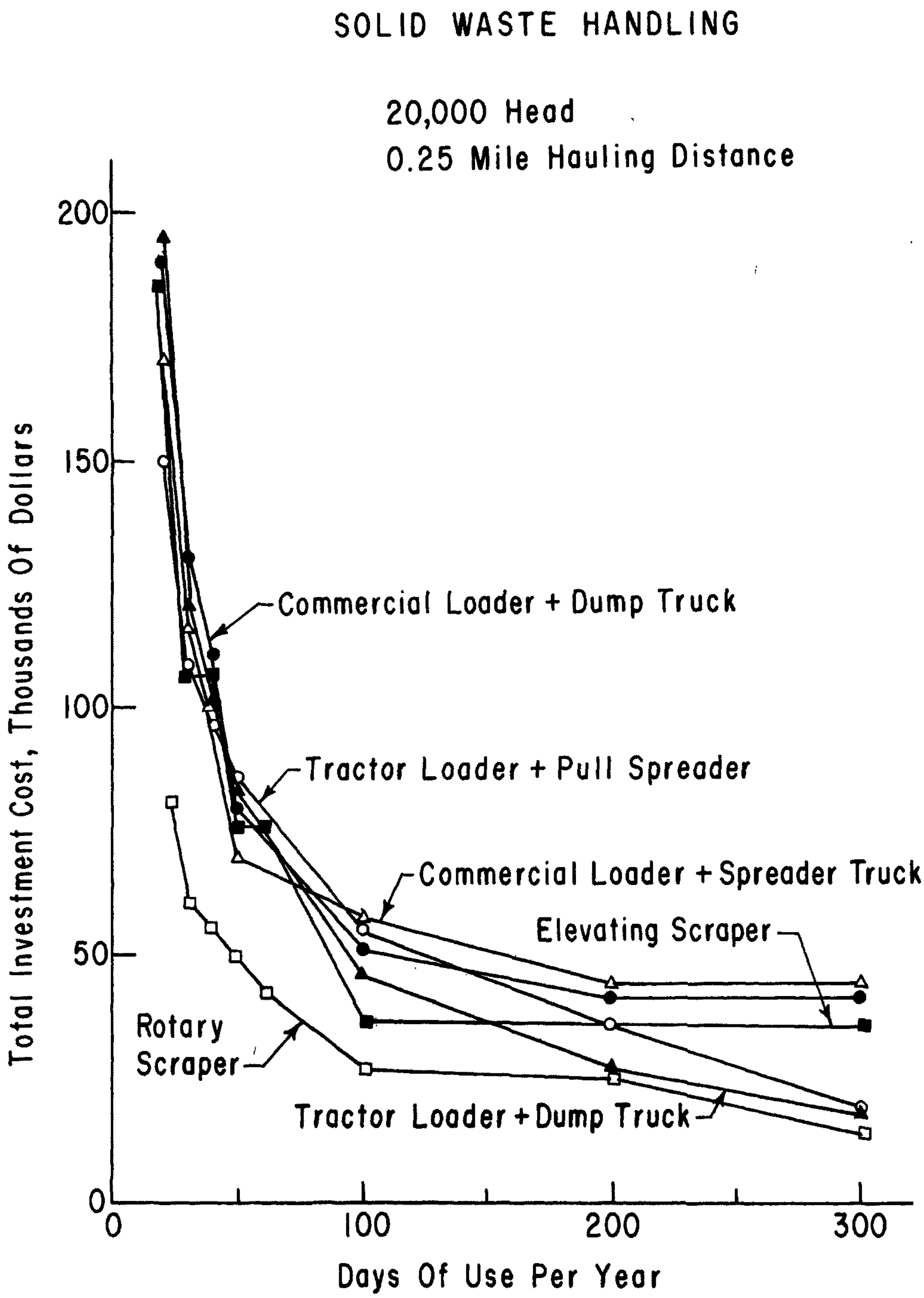


Figure 27. Solid waste handling: total investment cost vs. days of use per year

tables in the Appendix, which present the number of pieces of equipment and the hours of use per day. For this analysis it was assumed that the machines would operate to a maximum of 10 hours per day before another piece of equipment was added to that particular system.

Feedlot Capacity

The effect of size of feedlot on the operating costs was compared for the three major handling systems in use in commercial sized feedlots (Figure 28). In this analysis a 1/4 mile hauling distance and 100 days of use per year for the machinery was assumed. Above 10,000 head capacity lots the elevating scraper had the lowest operating cost per animal day. Below 10,000 head capacity lots the rotary scraper with tractor had the lowest operating cost per animal day.

The rotary scraper with tractor had the lowest investment cost for all capacities because the tractor could be used for other operations on the feedlot. The elevating scraper had a constant investment cost of approximately $37,000 up to 20,000 head capacity lots because only one machine is required. At 30,000 to 40,000 head capacity lots two elevating scrapers are required to remove the waste in 100 days. For 20,000 head lots the investment costs are approximately $27,000 for a rotary scraper with tractor, $37,000 for an elevating scraper, and $57,000 for commercial loaders plus spreader trucks.

Hauling Distance

The effect of hauling distance on the operating costs for the three different solid waste handling systems are presented in Figure 29. Below a two mile hauling distance the elevating scraper had the lowest operating cost. The commercial loader plus spreader truck had the next lowest operating cost over approximately one-half mile hauling distance. The operating cost for a rotary scraper with tractor increased very rapidly as hauling distance increased. In this analysis, 100 days per year of machinery use and a 20,000 head feedlot was assumed. At a two mile hauling distance, five rotary scrapers and tractors were required having a total investment cost of $68,000; two elevating scrapers were required having a total investment cost of approximately $74,000 and one commercial loader with two spreader trucks were required having a total investment cost of approximately $57,000. Thus, the commercial loader plus spreader truck had the lowest investment cost as distance increased. Although the calculations were not made, it was

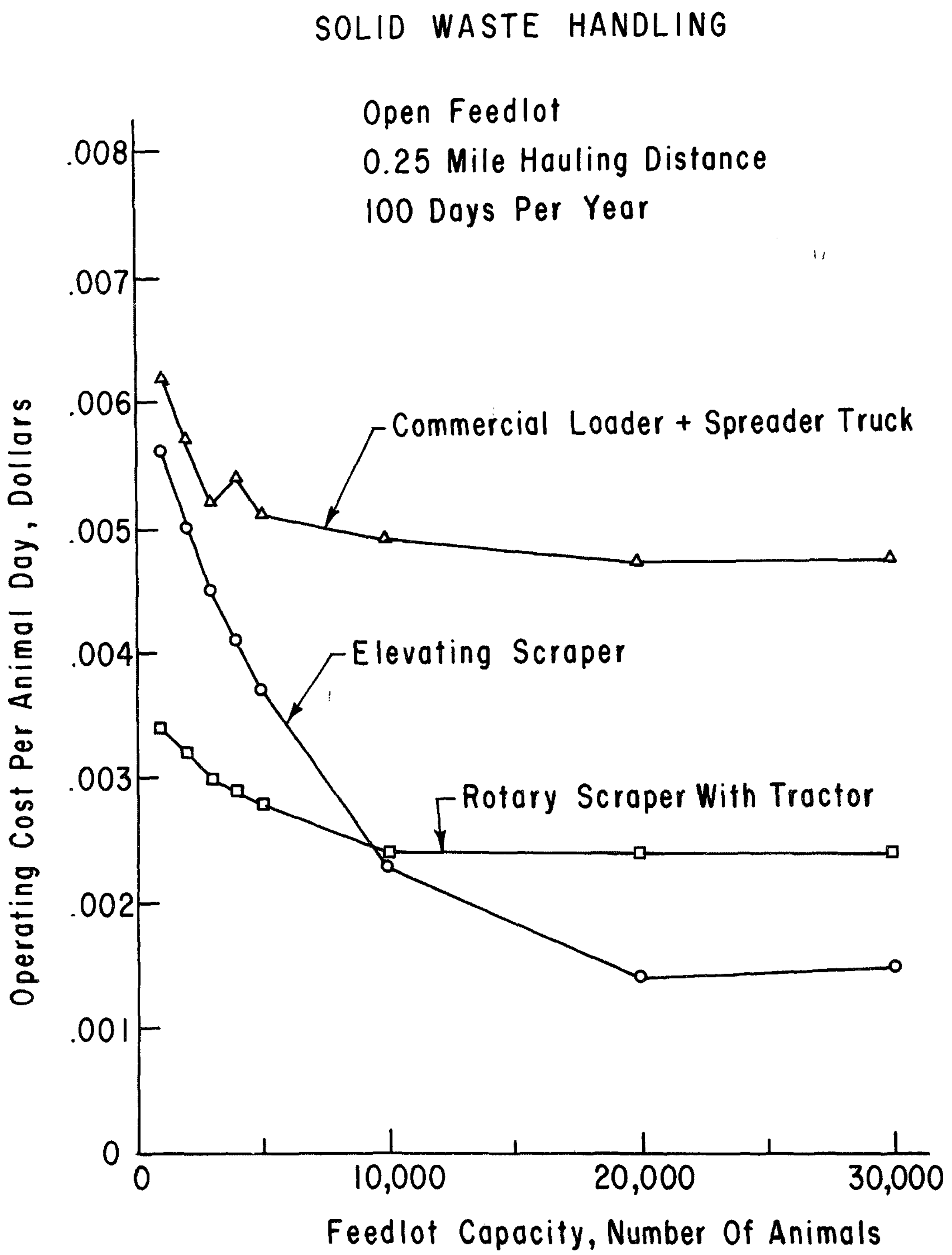


Figure 28. Solid waste handling: operating cost vs. feedlot capacity

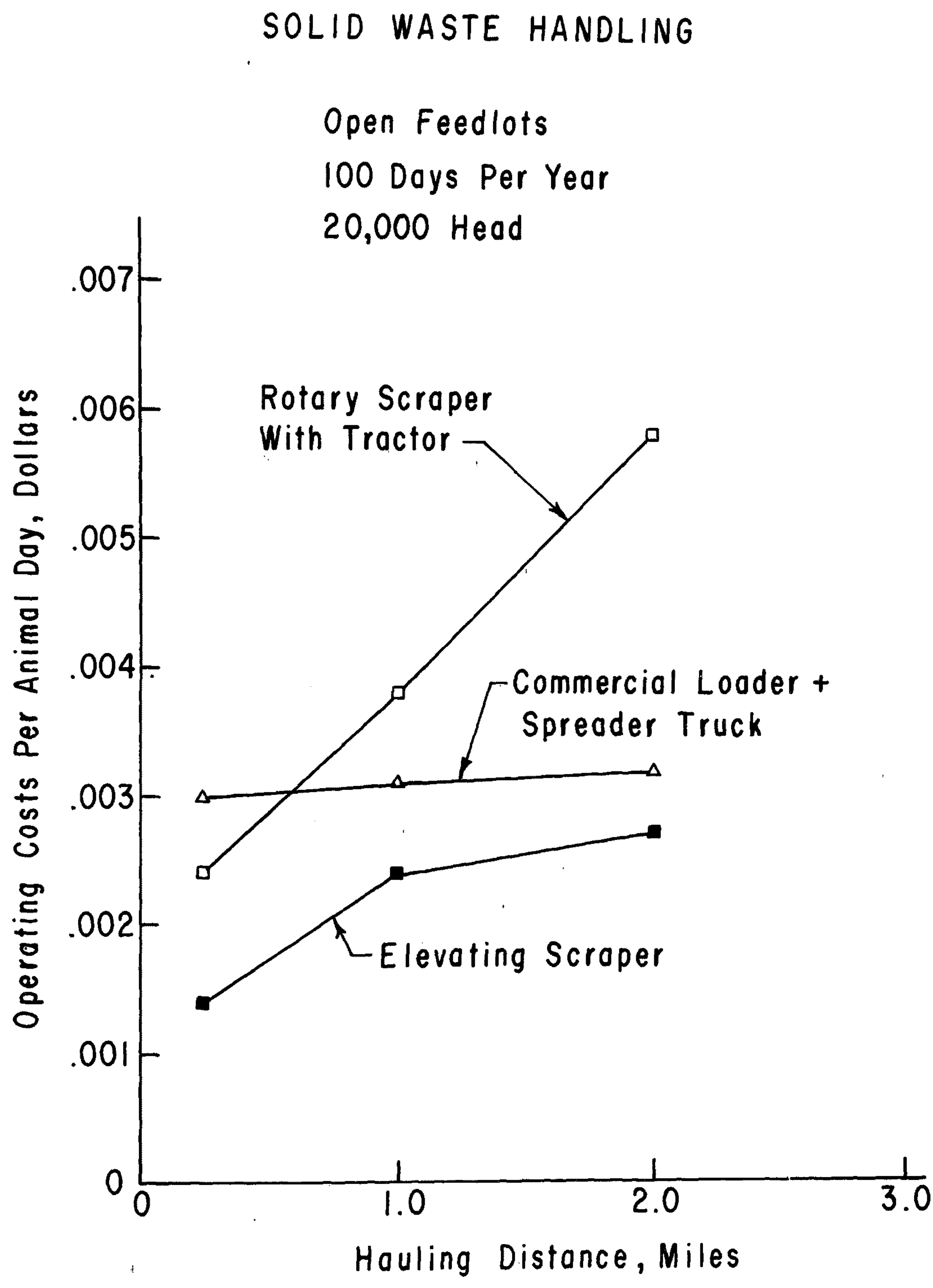


Figure 29. Solid waste handling: operating cost vs. hauling distance

apparent that the commercial loader plus spreader truck was the optimum system when hauling distances were three miles or greater.

Paved Feedlots

For paved feedlots, the mechanical removal costs are similar to the unpaved feedlots. The exception is that a scraper mounted on a tractor is prevalently used. The cost for operating a tractor scraper for a 20,000 head lot is $0.00018 per animal day. For 20 days of use per year it requires two tractors and scrapers having an investment cost of $3,866.

Paved feedlots could be cleaned by an alternative system: a flushing system. Flushing systems are more conventionally used for confinement or partial confinement structures but their system costs were not analyzed.

RUNOFF CONTROL SYSTEMS

As discussed in Chapter II the runoff control system begins on the feedlot with the drainage and collection system. In this analysis the costs of the pen and feedlot drainage collection system is included in the open feedlot construction cost as presented in the previous section in this chapter. The internal drainage system costs are about $0.50 and $1.00 per animal of capacity.

System Design

Several factors affect the runoff from the feedlot as discussed in Chapter II. In this analysis, the design storm rainfall was assumed to be a five year, two day storm which is comparable to the ten year, one day storm used in many states. The runoff-precipitation relationship developed by the SCS and presented in Chapter II was used in this analysis. Essentially, the first one-half inch of precipitation is stored on the feedlot surface which closely approximates results found in Kansas and Nebraska. Also, a drainage area for the feedlot 20% larger than the pen and alley surface area was assumed. The feedlot surface area was one of the items of input information used in this subprogram to calculate the cost of the runoff control system.

In the computer sub-program, choices for alternatives in the system were presented. The first choice was a settling basin based upon the Nebraska continuous flow concept (porous dams).

Choices of detention structure types were a large detention reservoir only, a batch detention reservoir with a long, narrow reservoir constructed so that it could be easily cleaned with the aid of a drag line. The third choice in detention structures was the broad basin terrace based upon research conducted in Nebraska. This broad basin terrace could be constructed either in the feedlot or adjacent to the feedlot to collect the runoff and permit settling of the solids. For all of the detention reservoirs, the runoff wastes were assumed to be pumped out rather frequently, such as within a 14 day period from the time of runoff. The fourth choice in this sub-program was a lagoon based upon a design value of 1500 cubic feet per animal according to design recommendations by Miner (61). Of course, combinations of these systems could be utilized in the total runoff control system.

System Analysis

The costs and sizes for various runoff control systems for 20,000 open feedlots, with dirt surfaces and with paved surfaces are presented in Tables 23 and 24. For this analysis, a three-inch design rainfall was assumed.

Runoff control systems costs for paved feedlots averaged about one-third as much as the unpaved feedlots for the detention reservoirs. Whenever lagoons were used the operating costs were approximately the same as for both paved and unpaved surfaced lots.

Rainfall Effects

The influence of a five year, two day design storm rainfall on various runoff control systems is presented in Tables 25 and 26 for 20,000 head paved and unpaved open feedlots. The total design volume for the system, investment cost, feedlot plus runoff control area, and runoff control costs per animal day are presented in the table for all of the systems except for lagoon only. The lagoon costs remain constant on a per animal day basis because the total volume was based upon 1500 cubic feet per animal.

Feedlot Capacity

Costs, as affected by capacity of feedlot, for runoff control systems using a solid settling area plus a detention reservoir for a dirt lot are presented in Table 27. A three inch design rainfall for a five year, two day storm, and 200 sq ft per animal was assumed. The total feedlot plus runoff control systems cost per animal day declined from \$.0135 per animal day at 500 head to \$.0092 per animal

Table 23. Costs and Sizes for Various Runoff Control Systems for a 20,000 Head Open Feedlot with Dirt Surface, 200 Animals per Pen, 200 sq ft per Animal and One Foot of Bunk Space per Animal and Three Inch Rainfall

Runoff Control System	Total Volume of Runoff Control Structures (mill ft^3)	Investment Cost for Runoff Control Structures ($)	Total Area* of Feedlot and Runoff Control Structures (mill ft^2)	Cost per Animal Day for Runoff Control
Settling Basin + detention reservoir + lagoon	23.537	266,798	7.623	.00676
Settling Basin + detention reservoir	1.037	16,798	6.292	.00043
Settling Basin + lagoon	22.976	260,557	7.578	.00660
Detention Reservoir + lagoon	23.249	258,321	7.045	.00654
Detention Reservoir only	0.749	8,321	5.714	.00021
Lagoon only	30.000	333,333	7.414	.00844
Broad Basin Terrace Only	0.799	8,880	6.023	.00022
Batch Detention Reservoir only	0.749	8,321	9.628	.00021

*Feedlot pen area is 4,713,600 sq ft. Total feedlot area is assumed to be 20 percent higher than pen area

Table 24. Costs and Sizes for Various Runoff Control Systems for a 20,000 Head Open Feedlot with Paved Surface, 200 Animals per Pen, 50 sq ft per Animal, and One Foot of Bunk Space per Animal and Three Inch Rainfall

Runoff Control System	Total Volume of Runoff Control Structures (mill ft^3)	Investment Cost for Runoff Control Structures ($)	Total Area* of Feedlot and Runoff Control Structures (mill ft^2)	Cost per Animal Day for Runoff Control
Settling Basin + detention reservoir + lagoon	22.861	255,870	3.506	.00648
Settling Basin + detention reservoir	0.361	5,871	2.175	.00015
Settling Basin + lagoon	22.668	253,721	3.487	.00643
Detention Reservoir + lagoon	22.758	252,866	3.303	.00640
Detention Reservoir only	0.258	2,866	1.972	.00007
Lagoon only	30.000	333,333	3.706	.00844
Broad Basin Terrace only	0.259	2,880	2.067	.00007
Batch Detention Reservoir only	0.258	2,866	3.316	.00007

*Feedlot pen area is 1,623,600 sq ft. Total feedlot area is assumed to be 20 percent higher than pen area

Table 25. Costs for Various Runoff Control Systems for Unpaved Open Feedlots as Affected by a Five Year, Two Day Design Rainfall, 20,000 Head

2 inch rainfall	Solids Settling + detention	Solids Settling + lagoon	Detention + lagoon
Total Volume ($ft^3 \times 10^6$)	0.757	22.976	22.875
Investment Cost (dollars)	13,680	260,560	254,170
Feedlot + Runoff control area ($ft^2 \times 10^6$)	6.272	7.578	7.019
Runoff Control cost/an. day (dollars)	0.00035	0.0066	0.0064
4 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	1.349	22.980	23.659
Investment Cost (dollars)	20,300	260,640	262,870
Feedlot + Runoff control area ($ft^2 \times 10^6$)	6.317	7.582	7.072
Runoff Control cost/an. day (dollars)	0.00051	0.0066	0.0066
6 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	2.005	22.984	24.528
Investment Cost (dollars)	27,630	260,700	272,540
Feedlot + Runoff control area ($ft^2 \times 10^6$)	6.364	7.587	7.126
Runoff Control cost/an. day (dollars)	0.00070	0.0066	.0069

Table 25. Continued

2 inch rainfall	Detention Pond Only	Broad-basin Detention	Batch Detention
Total Volume ($ft^3 \times 10^6$)	0.375	0.533	0.375
Investment Cost (dollars)	4,170	5,920	4,170
Feedlot + Runoff control area ($ft^2 \times 10^6$)	5.688	5.901	7.645
Runoff Control cost/an. day (dollars)	0.00011	0.00015	0.00011
4 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	1.159	1.332	1.159
Investment Cost (dollars)	12,880	14,800	12,880
Feedlot + Runoff control area ($ft^2 \times 10^6$)	5.741	6.267	11.802
Runoff Control cost/an. day (dollars)	0.00033	0.00037	0.00032
6 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	2.028	2.131	2.028
Investment Cost (dollars)	22,540	23,680	22,540
Feedlot + Runoff control area ($ft^2 \times 10^6$)	5.796	6.633	16.414
Runoff Control cost/an. day (dollars)	.00057	.00060	.00057

Table 26. Costs for Various Runoff Control Systems for Paved Open Feedlots as Affected by Design Rainfall of Five Year, Two Day Storm, 20,000 Head

2 inch rainfall	Solids Settling + detention	Solids Settling + lagoon	Detention + lagoon
Total Volume ($ft^3 \times 10^6$)	0.261	22.660	22.629
Investment Cost (dollars)	4,700	253,600	251,400
Feedlot + Runoff control area ($ft^2 \times 10^6$)	2.162	3.292	3.292
Runoff Control cost/an. day (dollars)	.0001	.0064	.0064
4 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	0.467	22.668	22.899
Investment Cost (dollars)	7,050	253,700	254,400
Feedlot + Runoff control area ($ft^2 \times 10^6$)	2.183	3.487	3.313
Runoff Control cost/an. day (dollars)	.00018	.0064	.0064
6 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	0.692	22.668	23.199
Investment Cost (dollars)	9,540	253,700	257,800
Feedlot + Runoff control area ($ft^3 \times 10^6$)	2.199	3.487	3.334
Runoff Control cost/an. day (dollars)	.00024	.0064	.0065

Table 26. Continued

2 inch rainfall	Detention Pond Only	Broad-basin Detention	Batch Detention
Total Volume ($ft^3 \times 10^6$)	0.129	0.173	0.129
Investment Cost (dollars)	1,435	1,920	1,435
Feedlot + Runoff control area ($ft^2 \times 10^6$)	1.962	2.028	2.633
Runoff Control cost/an. day (dollars)	.00004	.00005	.00004
4 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	0.399	0.432	0.399
Investment Cost (dollars)	4,435	4,800	4,435
Feedlot + Runoff control area ($ft^2 \times 10^6$)	1.982	2.146	4.065
Runoff Control cost/an. day (dollars)	.00011	.00012	.00011
6 inch rainfall			
Total Volume ($ft^3 \times 10^6$)	0.699	0.778	0.699
Investment Cost (dollars)	7,760	8,640	7,760
Feedlot + Runoff control area ($ft^2 \times 10^6$)	2.003	2.305	5.654
Runoff Control cost/an. day (dollars)	.0002	.0002	.0002

Table 27. Costs for Runoff Control System Using Solids Settling Area + Detention Reservoir, Dirt Lot, 500 to 50,000 Head, Three Inch Rainfall, 200 sq ft per Animal

No. Head	Feedlot Area (ft^2)	No. of 3900 ft^3 Settling Basins	Total Feedlot + Runoff Control Area (ft^2)
500	213,120	6	289,184
1000	304,320	8	409,839
2000	486,720	13	655,745
3000	760,320	20	1,018,930
4000	942,720	25	1,264,019
5000	1,885,440	49	2,520,682
10,000	2,828,160	74	3,781,354
20,000	4,713,600	122	6,292,012
30,000	7,541,760	196	10,066,497
40,000	9,427,200	244	12,575,940
50,000	12,255,360	318	16,349,388

Table 27. Continued

No. Head	Volume (ft^3)	Investment Cost	Cost per An. Day	Total Lot & Runoff Cost per Animal Day
500	48,795	801	.0008	.0135
1000	67,463	1095	.0005	.0103
2000	108,698	1769	.0004	.0095
3000	168,600	2737	.0005	.0093
4000	209,835	3411	.0004	.0092
5000	415,769	6736	.0007	.0095
10,000	625,604	10,148	.0005	.0092
20,000	1,037,472	16,798	.0004	.0091
30,000	1,663,076	26,946	.0004	.0091
40,000	2,074,945	33,596	.0004	.0090
50,000	2,700,549	43,744	.0004	.0091

day at 4,000 head. The anomaly that occurs at 5,000 head is due to additional pen area being added by the computer for that particular increment in size of feedlot. The extra pen rows are not filled with cattle but the surface area does contribute to the drainage that has to be controlled by the runoff control system. Otherwise the runoff control cost remains essentially constant after 4,000 head capacity feedlot is reached.

Drag Line

Settleable solids, in runoff-carried wastes, settle out of the liquid wastes under low velocity conditions collecting in ditches, settling basins, and detention reservoirs. One method of removing the wastes is to use a drag line. The drag line throw distance limits the width of reservoir to about 50 feet. Thus some existing detention reservoirs with wider dimensions can not be cleaned with this method.

The annual operating costs for a drag line as affected by runoff is presented in Figure 30. The initial investment for a drag line used in this analysis was $67,500. In this analysis the amount of solids settled was assumed to be 0.65 tons per acre-inch of runoff. This value was determined for eastern Nebraska, but may vary under other geographic and feedlot terrain conditions. These operating costs may be lower than actual costs because of difficulty in determining the amount of inactive operation due to moving of the drag line machinery and time delays between hauling vehicles.

The total hauling operating costs for cleaning of settling basins would have to include dump truck or spreader truck costs plus drag line costs. Settled wastes in 5,000 acre-inches of annual runoff represent approximately the same amount of solid waste that has to be removed from a 1,000 head feedlot by mechanical means. It would cost about $2300 annually to remove this amount of waste.

Field Irrigation Systems

Whenever a detention structure was used, it was assumed that the runoff carried wastes would be pumped onto fields within 14 days after a runoff event. In this analysis, it was assumed that the liquid waste would be pumped within the last seven days of the period as the soil may not be in a condition to adequately receive the wastes during the first seven days following a rainfall event. Also, the irrigation system was designed for a 10,000 head feedlot. Feedlots larger than 10,000 head would use two or more irri-

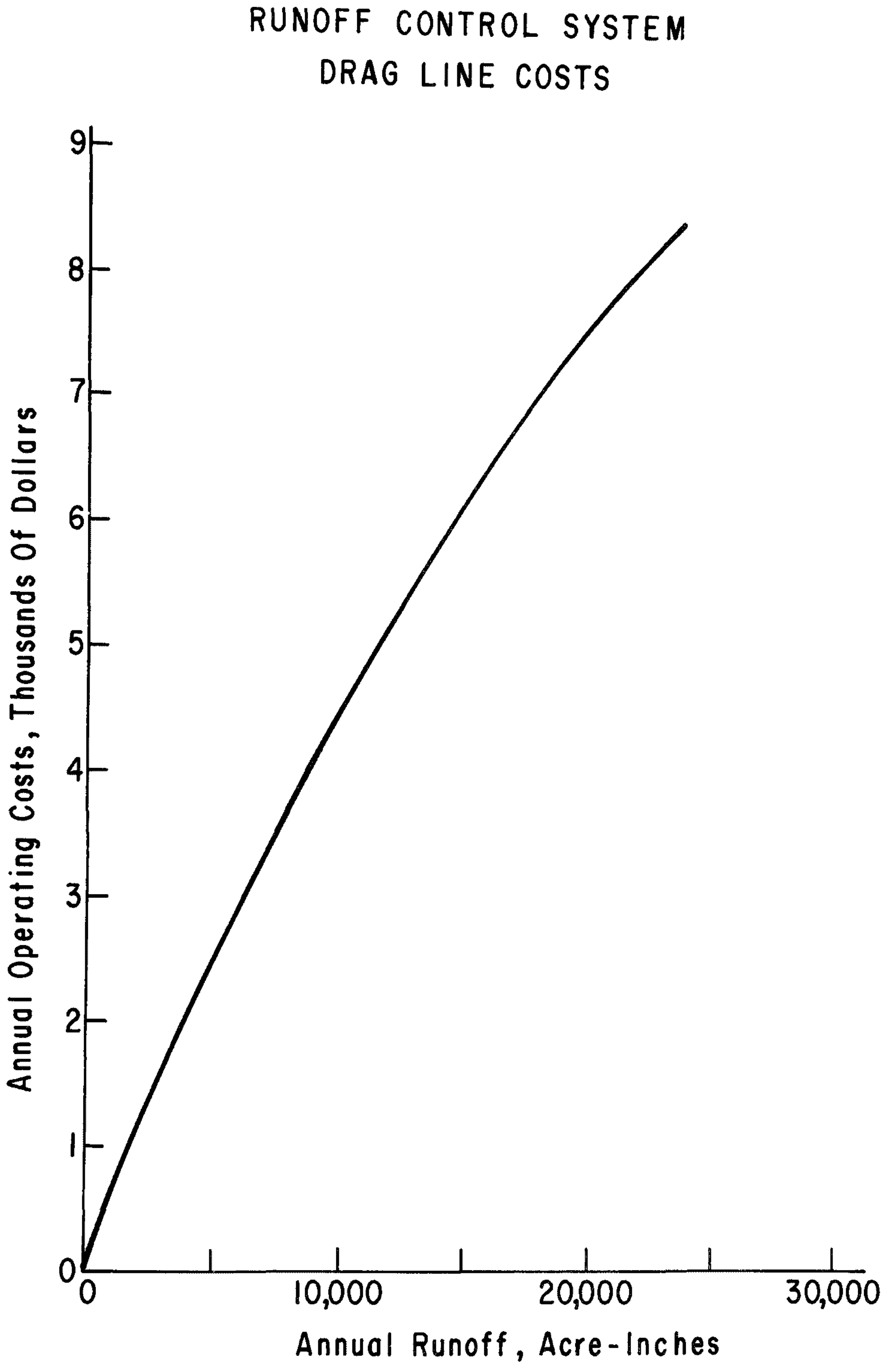


Figure 30. Runoff control system-drag line costs

gation systems based upon the 10,000 head size; for instance, a 20,000 head feedlot would use two irrigation systems. Other irrigation design considerations were discussed in Chapter IV on ultimate waste disposal. No more than six inches of runoff waste was applied on a particular area in one year. It was also assumed that the runoff carried waste would be one-half of the total annual rainfall.

System Costs

The total acres needed for the field irrigation system, number of days required for pumping and the cost per animal day of the systems are presented in Tables 28 and 29 for 10,000 head and 20,000 open feedlot respectively. The investment cost for a 10,000 head capacity lot was $11,630. This included the cost of the pump, mains, and gated pipe for distances to one-half mile from the feedlot.

Rainfall Effects

The annual average precipitation affects the cost per animal day and the land area required for irrigation as illustrated in Figures 31 and 32. The cost per animal day increases rapidly as annual average precipitation increases. The differences between the 10,000 head and 20,000 head lots are due to proportionately less total feedlot surface area per animal needed for the 20,000 head lot (proportionally less feedlot area taken by roads and cattle handling areas).

The storm design rainfall affects the number of days required for pumping which varies between less than one-half day for a one inch rainfall to about five or six days for a five inch rainfall. This assumes 200 animals per pen, 200 sq ft per animal and one foot of bunk space per animal with a three inch design rainfall for a five year, two day storm.

The costs in this analysis were based upon a charge of $0.30 per cubic yard of material that had to be removed. This value was one that was commonly used by the SCS for estimating costs in Oklahoma. On this basis, the lagoons or systems using a lagoon had the highest volume to be removed and therefore had the highest investment and operating cost. Systems using a detention structure only had the least investment cost and cost per animal day.

Whenever a settling basin or detention reservoir was used with one of these systems, it was assumed that 25% of the total solids were settled out for each settling basin or detention reservoir. The settling basin plus detention reservoir may offer the greatest protection in regard to

Table 28. Costs for Field Irrigation for Using Runoff from a 10,000 Head Open Feed-lot* as Affected by Annual Rainfall and Storm Design Rainfall

	Storm Design Rainfall, Inches				
10 inch annual rainfall	1	2	3	4	5
Total acres needed	72.3	72.3	72.3	72.3	72.3
Number days required for pump	.31	1.44	2.87	4.45	6.09
Cost per animal day	.00047	.00047	.00047	.00047	.00047
20 inch annual rainfall					
Total acres needed	144.7	144.7	144.7	144.77	144.77
Number days required for pump	.31	1.44	2.87	4.45	6.09
Cost per animal day	.00051	.00051	.00051	.00051	.00051
30 inch annual rainfall					
Total acres needed	217.0	217.0	217.0	217.0	217.0
Number dats required for pump	.31	1.44	2.87	4.45	6.09
Cost per animal day	.00060	.00060	.00060	.00060	.00060

Table 28. Continued

40 inch annual rainfall	1	2	3	4	5
Total acres needed	289.4	289.4	289.4	289.4	289.4
Number days required for pump	.31	1.44	2.87	4.45	6.09
Cost per animal day	.00075	.00075	.00075	.00075	.00075

*Feedlot area is 3,781,000 sq ft

Table 29. Costs for Field Irrigation for Using Runoff from a 20,000 Head Open Feedlot* as Affected by Annual Rainfall and Storm Design Rainfall

	Storm Design Rainfall Inches				
10 inch annual rainfall	1	2	3	4	5
Total acres needed	120.4	120.4	120.4	120.4	120.4
Number days required for pump	.26	1.20	2.39	3.70	5.06
Cost per animal day	.00044	.00044	.00044	.00044	.00044
20 inch annual rainfall					
Total acres needed	240.7	240.7	240.7	240.7	240.7
Number days required for pump	.26	1.20	2.39	3.70	5.06
Cost per animal day	.00050	.00050	.00050	.00050	.00050
30 inch annual rainfall					
Total acres needed	361.1	361.1	361.1	361.1	361.1
Number days required for pump	.26	1.20	2.39	3.70	5.06
Cost per animal day	.00054	.00054	.00054	.00054	.00054

Table 29. Continued

	Storm Design Rainfall Inches				
40 inch annual rainfall	1	2	3	4	5
Total acres needed	481.5	481.5	481.5	481.5	481.5
Number days required for pump	.26	1.20	2.39	3.70	5.06
Cost per animal day	.00064	.00064	.00054	.00064	.00054

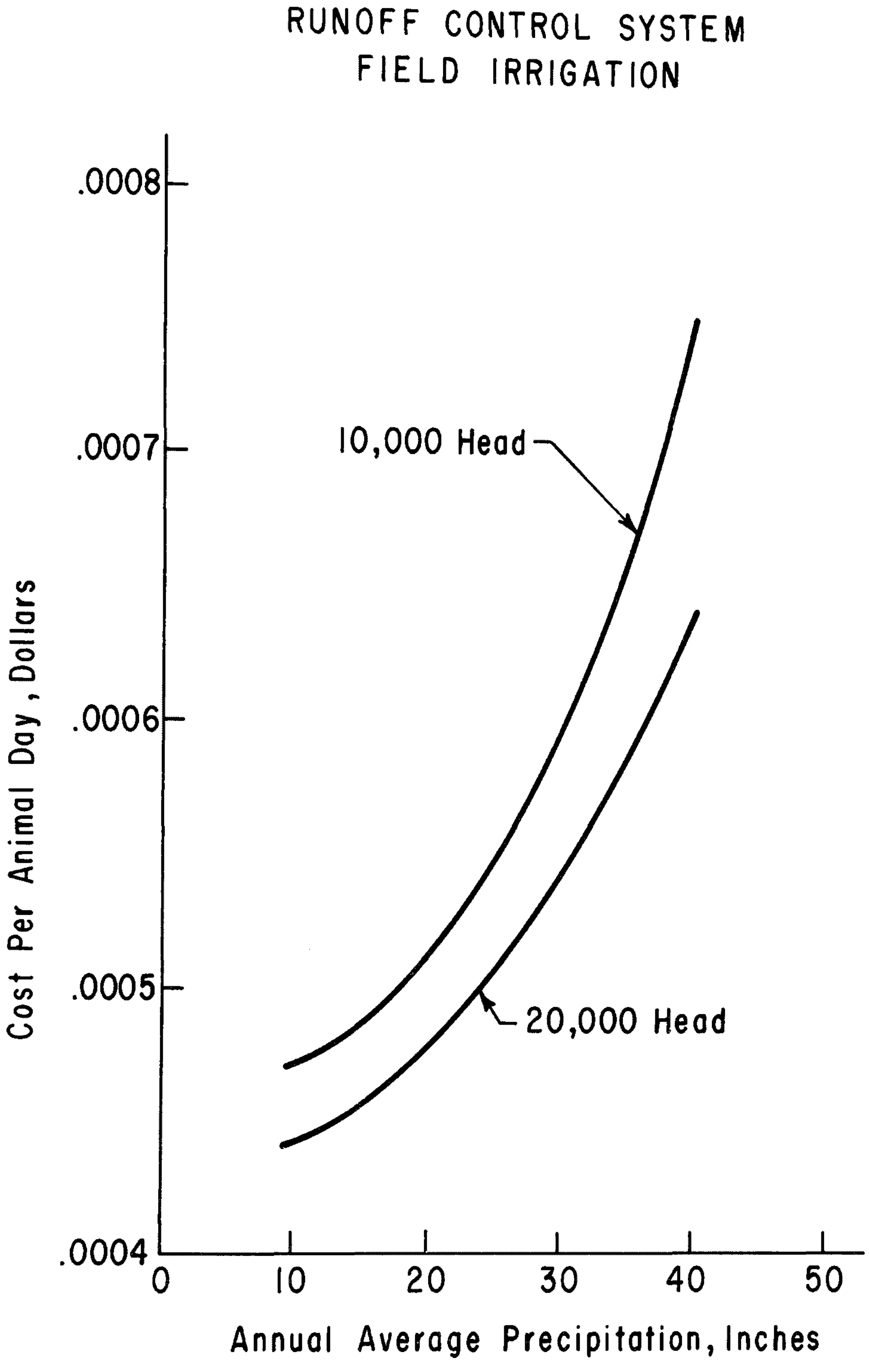


Figure 31. Irrigation operating costs vs. annual average precipitation

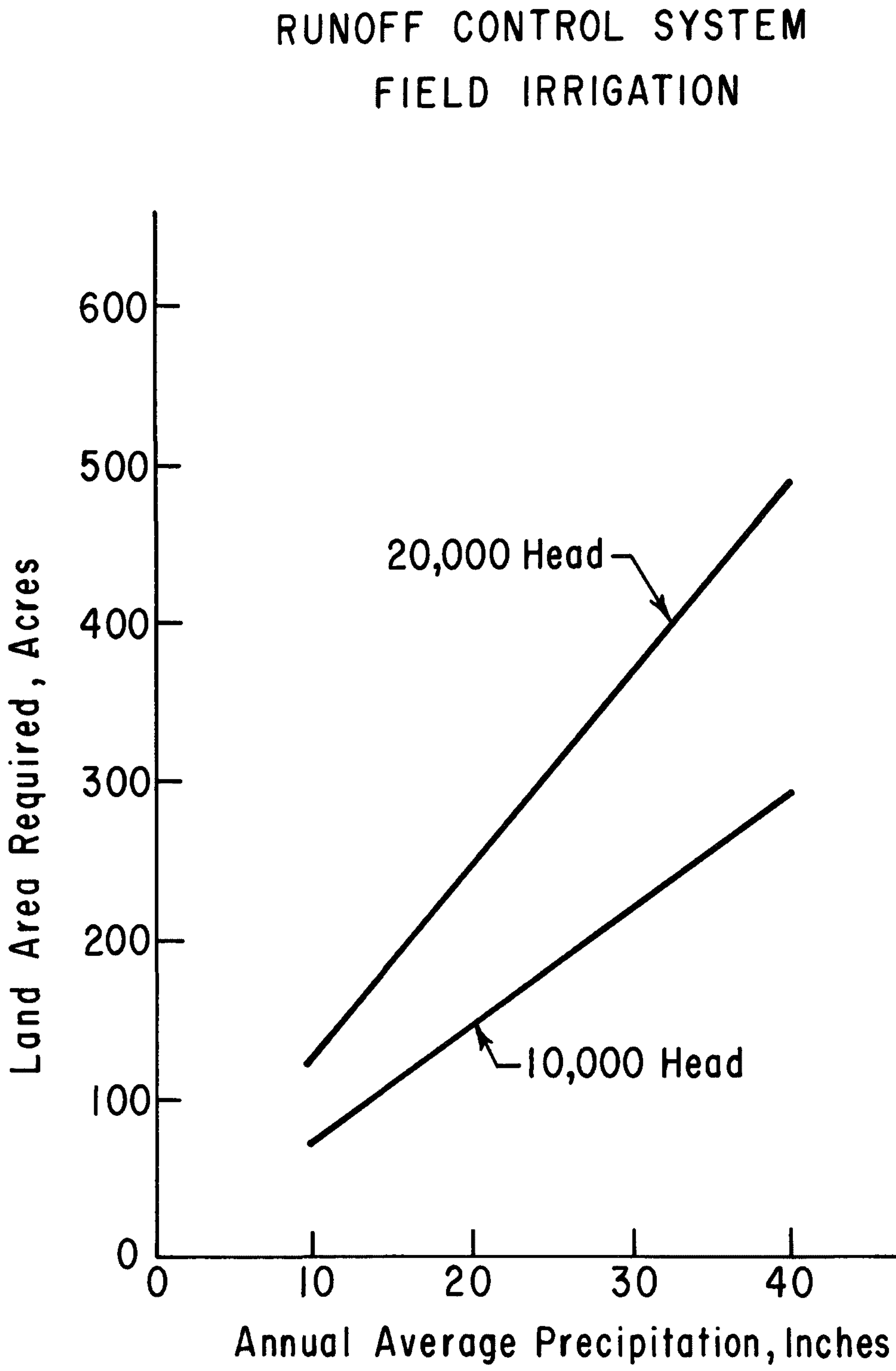


Figure 32. Irrigation land area vs. annual average precipitation

control of pollution, however, it costs about twice as much as the broad basin terrace or the two types of detention reservoirs, primarily because of the cost of construction of porous dams from planking, posts and crushed rock. Each of these porous dams was assumed to contain 3900 cubic feet of runoff wastes. It is possible that porous dams could be constructed cheaper and also to contain higher volume of runoff. This is an area of current research and other methods may be developed which will reduce the solid loading in detention structures.

Evaporation Pond

In areas where the annual lake evaporation exceeds the annual average precipitation, the runoff-carried wastes may have the liquids evaporated as a means of ultimate disposal. The costs for an evaporation lagoon, for a 20,000 head dirt surfaced open feedlot with 6,292,000 sq ft area, as influenced by annual precipitation and moisture deficit are presented in Table 30. For this analysis, the evaporation lagoon was assumed to be three feet deep.

For many feedlot areas in Texas, Oklahoma and Kansas the annual precipitation is approximately 20 inches and the annual lake evaporation is approximately 60 inches. Thus, a moisture deficit of approximately 40 inches per year is prevalent in many of the major feedlot areas in the Southwest. From this analysis, areas with low annual precipitation and a high moisture deficit have a good potential for using evaporation lagoons for disposing of the liquid wastes. The investment costs are relatively low for a 10 inch annual precipitation, and even the 20 inch annual precipitation, when the moisture deficit is high. However, by using evaporation ponds there is no possibility of gaining further benefits from the water and nutrients by recycling the water and nutrients through crops.

Feedlot Capacity

The effect of number of animals in the feedlot on the feedlot and lagoon area, investment cost and cost per animal day are presented in tables in the Appendices. For this analysis, a 20 inch average annual precipitation and a 60 inch average annual evaporation was assumed. The cost per animal day was reduced about one-half by increasing the number of animals from 500 head to 2,000 head. The inconsistencies in the cost per animal day was due primarily to fluctuations in the feedlot area because of changes in the design of the pens and number of rows in the feedlot. In the computer programming, these changes occurred at intervals and thus included excess area which is included in the

Table 30. Costs for an Evaporation Lagoon for 20,000 Head Dirt Surfaced Open Feedlot as Influenced by Average Annual Lake Evaporation Minus Annual Precipitation and Depth of Lagoon, 20 Inches of Annual Precipitation, 6,292,012 sq ft Feedlot Area

	Evaporation - precipitation, inches					
3 ft depth	10	20	30	40	50	60
Lagoon area, ft^2	7,550,414	3,775,207	2,516,805	1,887,604	1,510,083	1,258,402
Investment cost, dollars	211,244	105,936	70,786	53,191	42,625	35,575
Cost per animal day, dollars	.00535	.00268	.00179	.00135	.00108	.00090
5 ft depth						
Lagoon area, ft^2	7,550,414	3,775,207	2,516,805	1,887,604	1,510,083	1,258,402
Investment cost, dollars	353,762	177,759	118,957	89,504	71,806	59,991
Cost per animal day, dollars	.00896	.00450	.00301	.00226	.00182	.00152

drainage. The evaporation lagoon area is approximately 1/3 of the total feedlot area for a 40 inch moisture deficit.

TOTAL WASTE HANDLING COSTS

For a 20,000 head open feedlot, the total system costs (feedlot construction + waste management systems) are approximately $0.01319 per animal day and with an investment cost of approximately $416,000. This assumes that the feedlot is located in a vicinity where a three inch design storm rainfall, 20 inch annual average precipitation, and 60 inches of annual lake evaporation exist. It also assumes that the system consists of a commercial loader and spreader truck for hauling the solid waste 50 days per year. A detention reservoir only is assumed for this system and designed for a three inch rainfall with an irrigation system for handling the runoff-carried wastes. The wastes that settle in the detention structure are cleaned with the drag line. The investment cost of the drag line is not included in the total investment cost as the $67,500 for a drag line was considered an unreasonable investment for 20 days of use per year and most feedlot operators would contract for the use of the drag line.

The waste management cost for the above system is $.0046 per animal day with an investment cost of $101,000. The waste handling costs are approximately one-third of the daily operating cost and one-fourth of the total investment cost (minus drag line investment cost).

SECTION III

CONFINEMENT

BUILDINGS

CHAPTER VII

CONFINEMENT BUILDING DESIGN

The feeding of beef in totally confined buildings has become increasingly popular in some areas of the United States, particularly in the upper Midwest where the animals can be housed to protect them from severe winter weather and muddy spring weather conditions that exist in open feedlots. They are also popular in areas where land prices are high. Confinement buildings show promise of providing the initial collection step for a pollution free waste management system.

Confinement housing is subject to a variety of definitions. Pratt (72) considers it to be a building in which beef animals are confined under a roof. Moore, et al., (63) have defined a beef confinement system which provides animals with an area of 50 sq ft or less per animal. A beef confinement system has to provide an adequate feeding system, a shelter which controls or modifies the air temperature, humidity and external effects of the weather, and a waste handling system.

Most beef confinement buildings are located in areas where family farms predominate. Thus, the capacity of the facilities are generally less than 1,000 head, with most beef confinement barns between 200 and 500 head of animals. Most of these are located in the upper Midwest states ranging from Michigan and Ohio across to North and South Dakota and Nebraska. There are a few facilities that contain between 10,000 and 20,000 head capacity. However, these larger facilities generally have more than one housing unit.

The weather conditions in the areas where confinement beef buildings are popular are such that there is an abundance of rainy weather during certain periods of the year or extremely cold weather with considerable snow depth possible during the winter. Thus, feeding in outside lots during the winter and early spring months seriously affects the animals' performance and health. With adequate ventilation in the confinement buildings, animals do quite well during the summer months also.

Some economic considerations are involved in the selection of beef confinement building facilities. Most of the facilities are adaptable to labor saving equipment for both feeding and waste handling. Thus, a farm operator has been able to feed and care for the beef animals and still have time for the necessary field work. In some areas, land prices are high, and therefore, the farmers desire to have as much land into crop production as possible. By housing the animals in a confinement building, the space requirement is reduced to 1/10 to 1/20 of the open feedlot space requirement per animal.

The main advantages suggested for confinement cattle feeding buildings are:

1. Less labor in feeding and manure disposal.

2. No bedding if slotted floor systems are used.

3. Better feeding performance as indicated by generally higher rates of gain and better feed efficiencies.

4. Animals are more comfortable as evidenced by the cattle being quieter and more docile in confinement buildings and the animals are not subjected to severe weather conditions.

5. Cattle stay cleaner and healthier as evidenced by fewer parasites and insect problems and freedom from hoof rot and other diseases caused by muddy feedlots, if housed on a slotted floor.

6. Eliminates need for pasture and a large outside lot requiring perhaps expensive land.

ANIMAL PERFORMANCE

Most confinement beef feedlot operators consider that the animals gain from 0.3 pounds to 0.6 pounds per day per animal better than animals in outside feedlots.

Grussing (30) reported on some research conducted by Mieske in Minnesota on beef feeding trials with animals housed under an open shed with dirt floor, an insulated confinement building with slotted concrete floor, and an insulated confinement building with a solid concrete floor with gutter (Table 31). Cattle confined in the insulated buildings had a better feed efficiency than those housed in the other two systems. The cattle housed in the insulated buildings with slotted floors had a slightly higher average daily gain (2.88 compared to 2.67 for the open shed with dirt floor and the concrete floor insulated building).

Bates, et al., (6) and Smith, et al., (80) reported on the influence of housing on the performance of beef cattle housed in five different structures and found that warm housing produced the highest daily gains with the lowest amount of

Table 31. Shelter Effects on the Performance of Steers Fed in Different Housing Systems in Minnesota (30)

	Open Shed with Dirt Floor	Insulated Confinement with Slotted Concrete Floor	Insulated Confinement with Solid Concrete Floor with Gutter
Average daily gain, lb	2.67	2.88	2.67
Average daily feed consumption, lb	23.60	22.80	21.60
Feed efficiency, lb feed per lb gain	8.84	7.92	8.09

feed per pound of gain (Table 32). The greatest relative advantage of shelter occurred during the period from February 17 to May 11 in southwestern Minnesota. The performance and carcass characteristics were not greatly affected by different animal densities in any of the units. Their housing units consisted of a slotted floor cold confinement building, a manure scrape barn (solid dirt floor with the manure pack with an outside lot for feeding), outside lot with mound, and a slotted floor warm confinement building. In their warm building, the fresh air was drawn through a plenum chamber in the attic and hence through a ceiling duct. Exhaust fans were located in the walls and in the manure pit. In addition, a heating unit was installed at the north end of the duct for permitting the outside air to be warmed to combat any fogging effect during extremely cold weather. The pit fans operated continuously and the wall fans operated in response to thermostats.

Hellickson, et al., (34) compared selected environmental conditions and beef cattle performance for a pole-type building and a totally enclosed environment and found higher average daily gains and better feed conversion for cattle housed in a cold confinement pole barn than in a totally enclosed building during the summer period. They, however, admit to having some ventilation distribution problems during the summer months in the totally enclosed environment.

Johnson (42) reported on a survey of beef cattle feeding facilities in North Dakota. Some of the facilities were open covered buildings but with access to outside yards. In that area, feeders preferred an enclosed feeding facility to keep the cattle and feed out of the severe weather. A 12 foot wide concrete slab along the bunk for the cattle to stand on plus a 5 inch by 14 inch step to prevent cattle from backing up to the bunk was preferred. Scraping of the manure accumulation along the feeding slab depended upon the animal density and weather conditions, but a frequency of at least once per week appeared to be preferred.

Hoffman and Self (37) found that shelter significantly increased rate of gain in both summer and winter. Feed efficiency was not significantly different between the summer and winter trials. Floor surface did not significantly affect rate of gain, feed intake or feed efficiency, although paving did greatly expedite the removal of manure and feedlot maintenance. A summary of the six years results of the performance of yearling steers as influenced by shelter is presented in Table 33.

Henderson and Geasler (35) conducted an extensive

Table 32. A Comparison of Five Housing Systems for Feedlot Cattle in West Central Minnesota (6, 80)

	Conventional		Manure Scrape		Cold Slat	
Sq ft/head	30	20	30	20	25	17
Av lb bedding per day/head	2.16	1.98	2.70	2.49		
Av daily gain, lb	2.15	2.05	2.16	2.26	2.21	2.14
Av daily dry feed intake, lb	13.22	13.54	13.76	13.78	14.16	13.90
Av dry matter required/100 lb gain, lb	616	660	638	610	641	650
No. head	200	300	200	300	204	300
Cost of housing unit, $	21,000	21,000	24,000	24,000	34,500	34,500
No. days feeding to put on 560 lb gain[a]	260	273	259	248	253	262
Housing cost per head, $[b]	6.75	4.70	7.66	4.90	10.56	7.45

Table 32. Continued

	Warm Slat		Open Lot
Sq ft/head	25	17	250
Av lb bedding per day/head			
Av daily gain, lb	2.23	2.33	2.04
Av daily dry feed intake, lb	14.78	14.16	13.35
Av dry matter required/100 lb gain, lb	634	608	654
No. head	204	300	300
Cost of housing unit, $	51,000	51,000	7500
No. days feeding to put on 560 lb gain[a]	240	240	275
Housing cost per head, $[b]	14.81	10.07	2.01

Table 32. Continued

	Conventional		Manure Scrape		Cold Slat	
Non-feed cost per head, $[c]	22.60	23.80	22.54	22.18	22.18	22.72
Heat & vent. cost/head $						
Bedding cost per head, $[d]	4.21	4.05	5.24	4.63		
Manure handling cost, $/head	2.28	2.28	1.82	1.82	1.39	1.39
Manure credit, $/head	3.78	3.78	3.41	3.41	5.01	5.01
Feed cost per 100 lb gain, $	13.43	14.36	13.84	13.23	13.88	14.09
Profit, head, $[e]	18.57	14.16	13.23	19.48	17.99	19.70

Table 32. Continued

	Warm Slat		Open Lot
Non-feed cost per head, \$[c]	21.40	21.40	23.50
Heat & vent. cost/head \$	4.46	4.46	
Bedding cost per head, \$[d]			2.25
Manure handling cost, \$/head	1.39	1.39	0.80
Manure credit, \$/head	5.01	5.01	1.70
Feed cost per 100 lb gain, \$	13.73	13.19	14.17
Profit, head, \$[e]	10.39	16.34	18.37

Table 32. Continued

[a] Days of feeding to produce 560 lb of gain from an initial weight of 436 lb to a final weight of 996 lb

[b] Housing cost/head/year is the depreciation/year plus interest/year divided by the number of cattle fed per year

[c] Fixed cost considered to be $7/head and time related costs (interest on cattle and feed, labor, power and depreciation on equipment)

[d] Straw and corn cobs charged at $15/ton

[e] Market value/head plus manure credit/head minus initial cost, feed cost for 560 lb gain, non-feed costs, bedding costs, manure handling cost and housing cost. (Initial cost was $39/100 lb and carcass value between $46.51 and 47.04/100 lb for average carcass weight of 629 lb)

Table 33. Shelter Effects on Performance of Yearling Steers in Northwestern Iowa (37)

	Winter		Summer	
	Shelter	No Shelter	Shelter	No Shelter
Average daily gain, Kg	1.32	1.15	1.36	1.29*
Daily feed consumption, Kg	12.08	12.12	11.69	11.51
Feed efficiency, Kg feed per Kg of gain	4.15	4.77**	3.97	4.13

* p. .05
** p. .01

review of the effect of the environment and housing on the performance of feedlot cattle under upper Midwest conditions. They found from a total of 68 feeding trials reviewed that average daily gain for the no housing group during the winter was consistently depressed from 2 to 22% (12% average), feed cost was consistently increased from 4% to 28% (14% average), and carcass grade was slightly depressed but not consistently. For summer feeding trials the average daily gain for the no housing group was consistently depressed from 2 to 7% (5% average), feed cost was increased and average carcass grade was not affected. Feed costs favored the enclosed and insulated group. No difference was found attributable to floor surface.

The major disadvantage of confinement buildings is the high initial investment. The facility costs may, however, pay for themselves in terms of reduced labor requirements and increased performance of the animals. Also, the pollution potential is less for confinement buildings because the waste is entirely contained and the possibility exists for controlled treatment, handling, and disposal of the waste.

CLASSIFICATION OF CONFINEMENT BUILDINGS

A confinement building can either provide for total confinement or partial confinement of the animals. In a total confinement building, the animals are totally enclosed in the space of the building. The feedbunk location for a totally confined building may be down the center of the building or along the outside walls or outside of the pens with a drive for feed trucks. For the smaller totally confined buildings, mechanical bunk feeders are usually used.

In a partial confinement facility, the animals are free to roam in an outside lot and seek shelter when they desire it. Feeding is generally done with an outside feedbunk located either in the center of the lot, where mechanical feeders are used, or along the outside of the pens where feed trucks or wagons are used. The lots and building floors may be paved or unpaved.

A classification of the various types of confinement buildings is presented in Figure 33. In addition to the total versus partial confinement building classification, there are some other subclassifications which are related chiefly to the totally confined facilities.

A total confinement facility may be either a cold or a warm facility. Cold confinement barns usually have open fronts towards the south or east. The barns are usually enclosed on the north and west sides during the winter, but have a

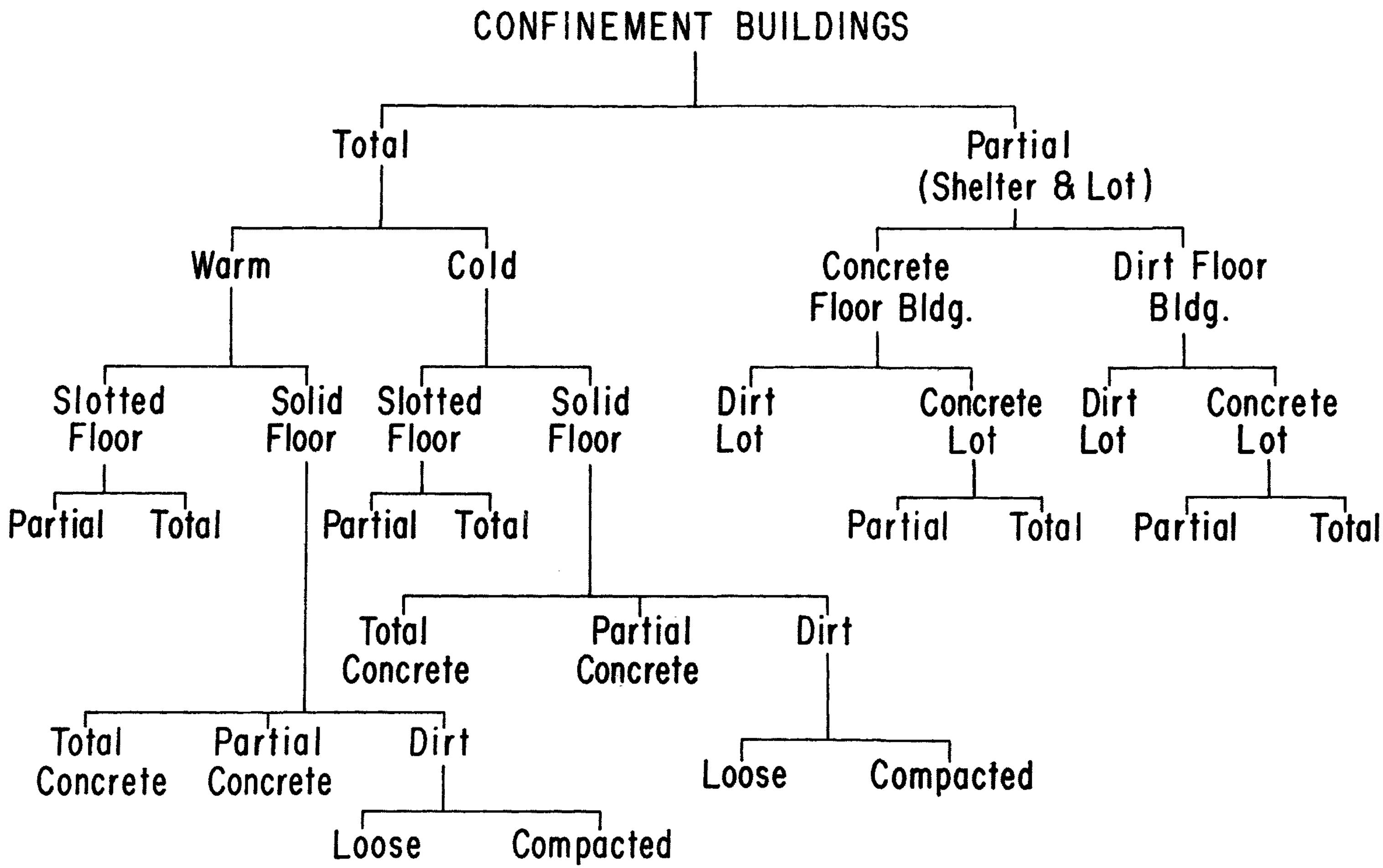


Figure 33. Confinement building classification

provision for removing panels for free air flow during the summer months. For winter operation, the panels are put in place to reduce the effects of cold winds flowing through the building. The temperatures within the building are generally 10 to 20 degrees above outside temperatures during the winter months. Cold confinement buildings provide protection from intense solar radiation during the summer months and provide a dry relatively draft free environment during the winter months.

Warm confinement buildings are well insulated and have a mechanical ventilation system. The amount of insulation varies with the climatic areas, however, two to three inches of standard insulation (k = .27 to .30) are used in the side walls and four to six inches of insulation in the ceiling. Exhaust fans are used to exhaust the warm moist air out of the building during the winter months. Some buildings have the fans located on the sidewalls, however, many buildings have fans installed so that the air is sucked through the slats in order to remove any noxious gases that may evolve from the manure in the storage pit underneath the slotted floor. Inlet areas are provided at strategic locations to insure a uniform distribution of the air. In extremely cold climates where subzero temperatures may be reached, cold air may cause fogging and condensation near the inlets. Some barns have heat exchangers for the outgoing air to partially warm the incoming air. Also, some buildings have heaters to provide for additional control of the temperature and moisture.

During the summer months most of the warm confinement barns use extremely high air flow rates to move air through the building. This causes evaporation of moisture within the building which takes some of the sensible heat from the air for the latent heat of evaporation. Thus, most of the totally insulated buildings have an inside temperature lower than the outside temperature during the warm part of the day. Also, the effects of solar radiation on the animals are reduced by the shade and by the time lag between the maximum solar radiation and the transmission of the thermal energy to the interior of the building. Buildings observed during the summer of 1970 had inside temperatures of around 85°F when outside temperatures were approximately 95°F under clear sky conditions. Evaporative coolers or mechanical refrigeration systems could also be used for cooling the incoming air during the summer months.

Flooring Type

Another variation in confinement facilities is the type of flooring with basically a choice between a solid floor or a slotted floor (Figure 34). A solid floor may be partially or totally dirt or may be a totally paved floor. Partially dirt floors may permit some of the moisture to percolate through the soil. One confinement barn located in Ohio had the dirt floor compacted so that very little moisture would penetrate into the soil in order to reduce the potential for the flow pollutants into the water table. Some facilities have a concrete slab located beside the feed bunk with the remainder of the floor being dirt, while other facilities have the entire building floor paved. With either concrete or dirt floors, the method for removing the animal waste is primarily by a solids handling system with the exception that a totally paved floor could potentially have a flushing system.

Besides a solid floor, the other possibility is to have a slotted floor. A slotted floor may be either totally slotted or partially slotted. A partially slotted floor has the slots located in the center of the pens with concrete slabs along the outside walls and the feed bunks. The concrete slabs slope towards the slotted floor section at about one inch per foot. The waste material then falls into a deep pit underneath the slotted floor section. Some facilities have the entire floor slotted with a pit located under the entire building pen area. Liquid handling methods are used to remove the waste from the pit.

Slat materials may be either concrete, steel or aluminum. Generally, concrete slats are used with the most common being 5 1/2 inch width at the top and 8 feet long with reinforcing steel. The slot width for beef cattle is generally 1 3/4 inches. Slats may be designed individually or in a grid design as discussed by Pratt and Nelson (73). The grid design has the possibility of distributing the load over the entire grid. Mahoney, Nelson, and Ewing (53) found that a 5 inch slat with a 1 3/4 inch slot was the most economical grid to construct.

A unique housing system was observed at Olivia, Minnesota, where a "solar confinement building" was constructed (29). This southwestern Minnesota building was constructed with a glass front to the south which permitted the winter solar radiation to heat the cold incoming air. At the same time the outgoing warm air heated the incoming air in a heat exchanger. In addition, some heating units were installed in the building to heat the air. The intent was to have warm, dry air move through the building and remove the moisture coming from the animals and from the manure. No cleaning of the dirt floor building had been accomplished over a two-year period. No bedding was used in the build-

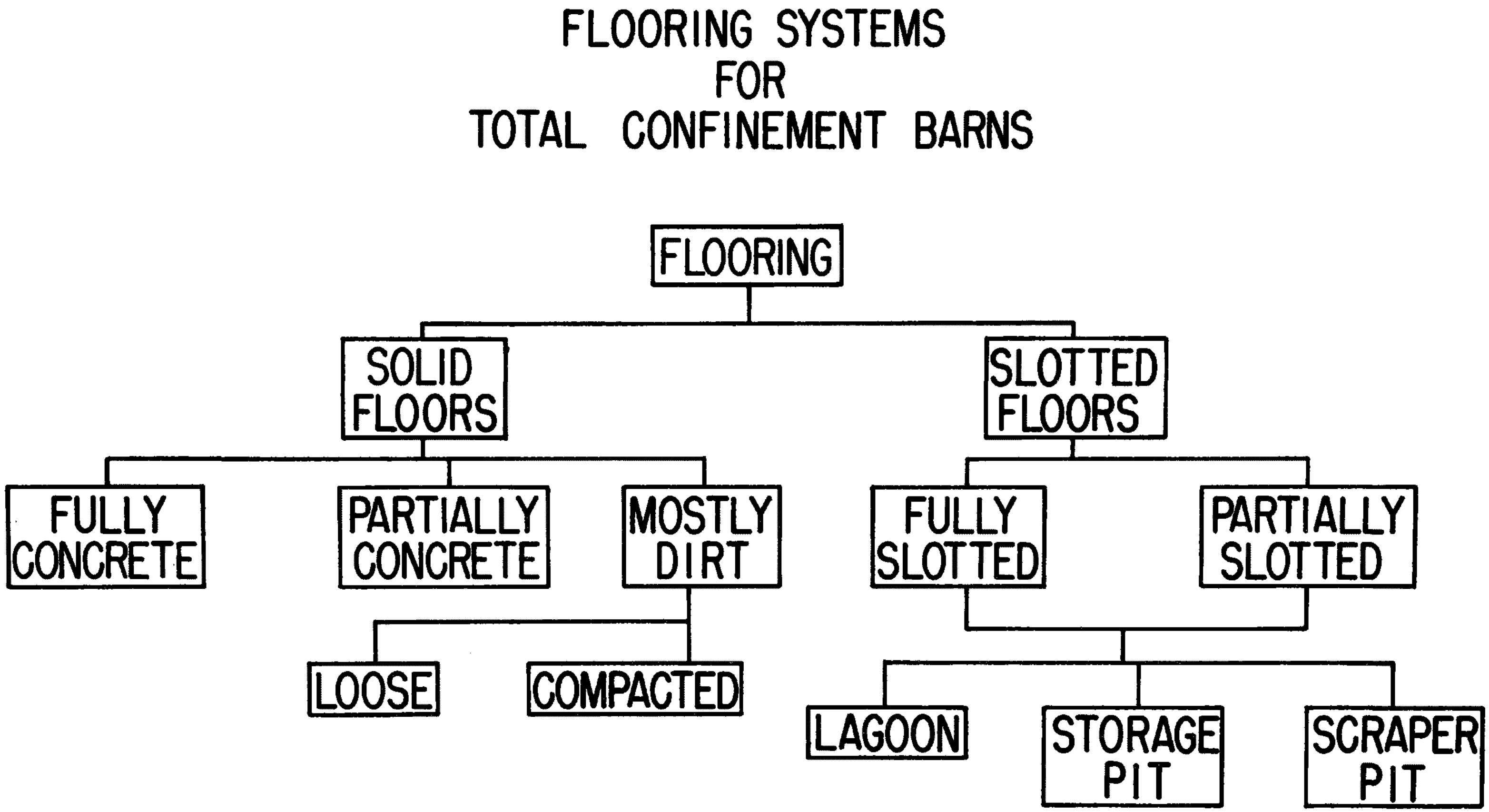


Figure 34. Flooring systems for total confinement barns

ing, so the animals used their own waste as a bedding material. The animals were quite clean and the manure pack was approximately 6 to 10 inches in depth during the summer period when this barn was observed in July, 1970.

FUNCTIONAL DESIGN

Some of the functional design requirements discussed in Chapter V for open feedlot design also apply to confinement building design. The basic functional requirements for a confinement building system are:

1. feeding and watering facilities
2. feed processing and storage
3. cattle handling
4. space requirements
5. environmental control
6. waste handling

The first three functional requirements for confinement buildings are approximately the same as for the open feedlots with the exception that cattle handling and feed handling facilities may be slightly different for confinement buildings.

The space requirement is the major difference between confinement building design and open feedlot design. Space requirements for confinement buildings are approximately two square feet of floor space per 100 pounds of body weight for winter time conditions and three square feet per 100 pounds of body weight for hot weather conditions. Thus, floor space for confinement feeding facilities, particularly on slotted floors, are approximately 18 to 25 sq ft per head of capacity. Feed bunk space depends upon the frequency of feeding, with feeding of three or more times per day requiring six inches of capacity per head.

Environmental control to modify the extremes in the outside environment is a major consideration for confinement feeding facilities. One of the major considerations is to keep the animals dry by having a roof. Other factors needing control are: air temperature, humidity, wind or draft, and solar radiation.

Another environmental consideration is to provide for adequate ventilation of the manure storage pit, particularly during times when the slurry is removed from the deep pit. Many noxious gases are prevalent during this time and extreme care should be exercised to prevent loss of human life or of animals. Thus, with deep storage pits, a pit ventilation system should be installed. Also, animals should be removed from the facility during times when the waste is removed.

The National Safety Council (4) recommends the following precautions for work around manure pits:

1. Never work alone.
2. Use a lifeline and make sure there is power enough to lift a victim clear of the tank.
3. If you must go inside a tank, ventilate the tank before entering it and during the work.
4. Test for combustible gases and oxygen level with a miner's lamp or testing device.
5. Use self-contained air breathing apparatus (such as a scuba diving outfit) if in doubt.

Taiganides (87) mentions that several noxious gases may be harmful to the occupants of an enclosed building with a manure pit with the primary gases being: ammonia, carbon dioxide, methane, and hydrogen sulfide. There are also other gases in the air, including carbon monoxide.

The waste handling method will be dictated primarily by the type of facility and flooring selected. Where a solid floor system has been selected the waste handling choice is primarily limited to mechanical means for scraping, loading, and hauling the waste. In some cases, liquid flushing systems may be used. Where storage pits are located underneath slotted floors, a liquid slurry system is needed for handling of the waste by using pumps, piping, tank wagons, etc.

BUILDING DESIGN

In examining the confinement building design, the total structure has to be considered. This includes the building components from the foundation and flooring to the superstructure and roofing. Most of the flooring systems have already been discussed.

There are many possible main frame and building styles. Pole-type buildings with interior poles may be used, particularly for solid floor type of systems. However, clear span buildings are most prevalent, which permits easier access for cleaning with mechanical equipment. Most of the slotted floor buildings have clear spans over the slotted floor areas. These spans may be from 24 feet up to 50 or 60 feet. Roof shapes may vary from gable to quonset type to half-monitor type of roofing styles. Some typical styles are illustrated in the various figures in this chapter. Typical building designs are illustrated for some of the confinement beef feeding buildings observed during 1970 in Figures 35 through 40.

SITE SELECTION

The type of confinement feeding facility and associated waste handling system may be dictated by the nature of the site that is selected. Obviously, drainage around the site should be adequate to carry rainfall and snow melt runoff away from the facilities.

Another major factor to consider is the depth to the water table. In areas of rather shallow water tables a deep pit underneath the slotted floor system may not be feasible. Likewise, lagoons or other similar treatment facilities may not be appropriate.

Other considerations regarding site selection are those essentially related to farmstead planning. This includes locating the feed processing and handling center for best labor efficiency and movement of materials. Also, shelter belts and protection from the wind and weather elements should be considered. Location in relation to housing developments and highways are other factors to be considered. Some of the principles for site selection discussed in Chapter V for open feedlots are applicable to beef confinement buildings.

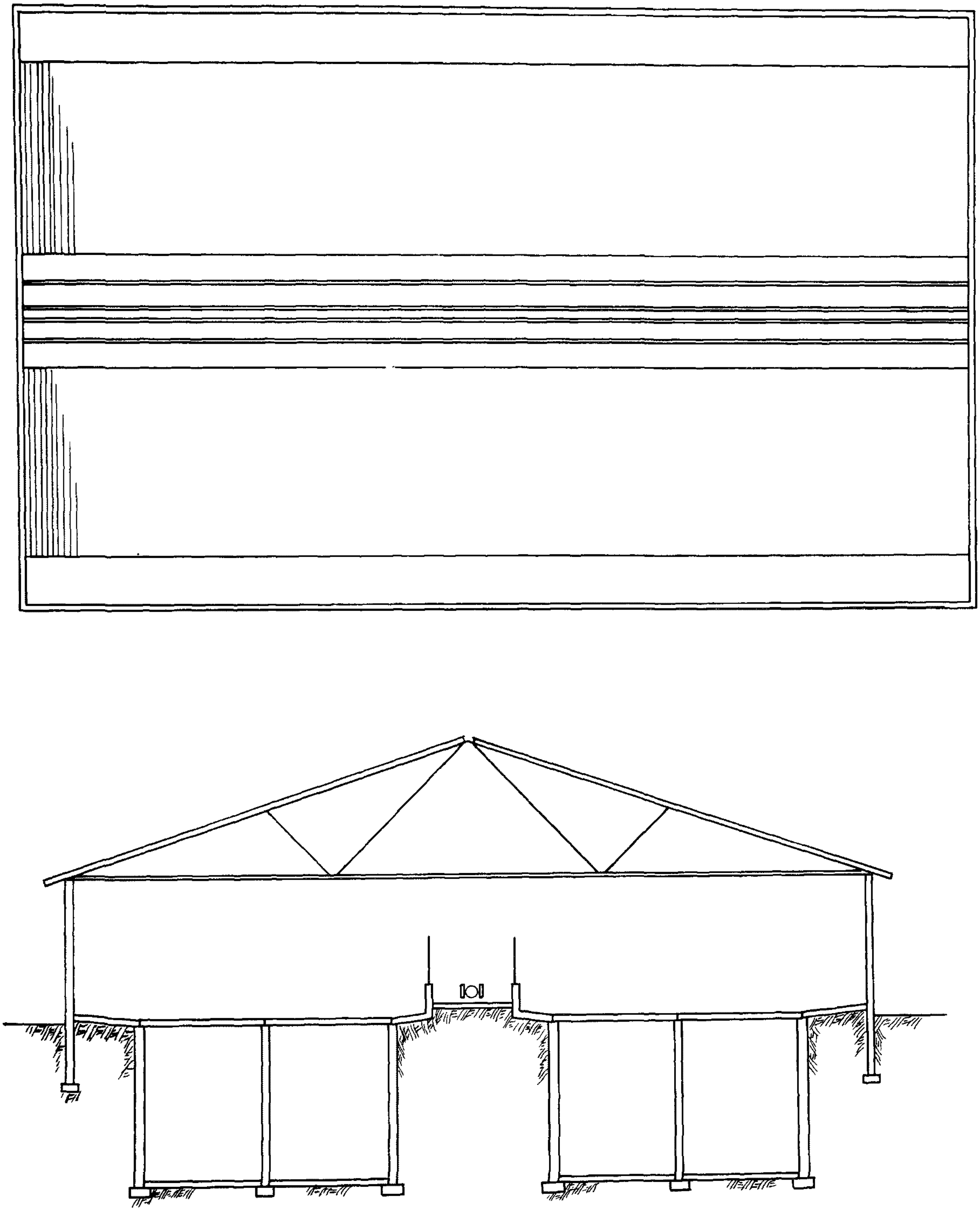


Figure 35. Warm confinement building with deep pit

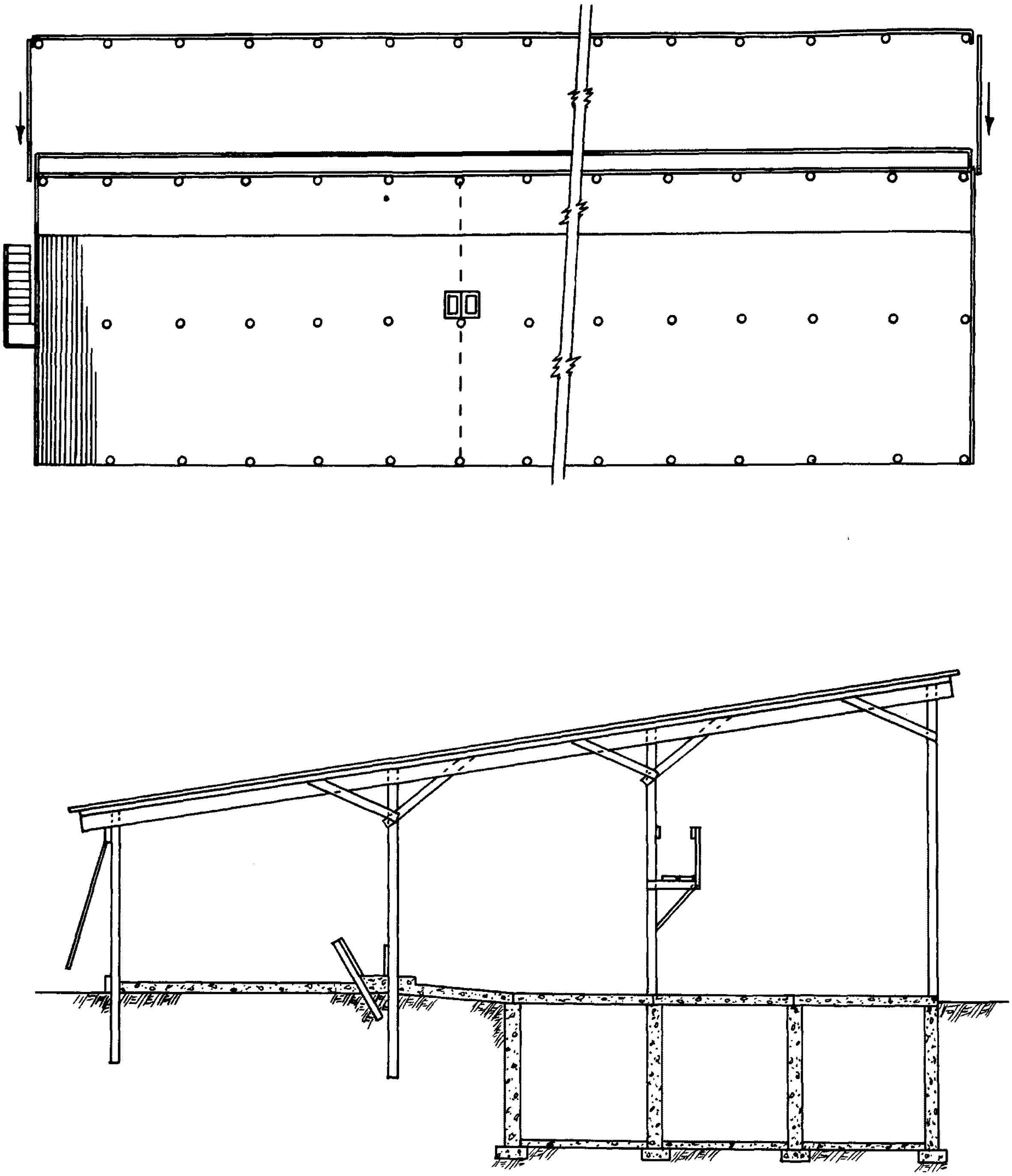


Figure 36. Cold confinement building with deep pit

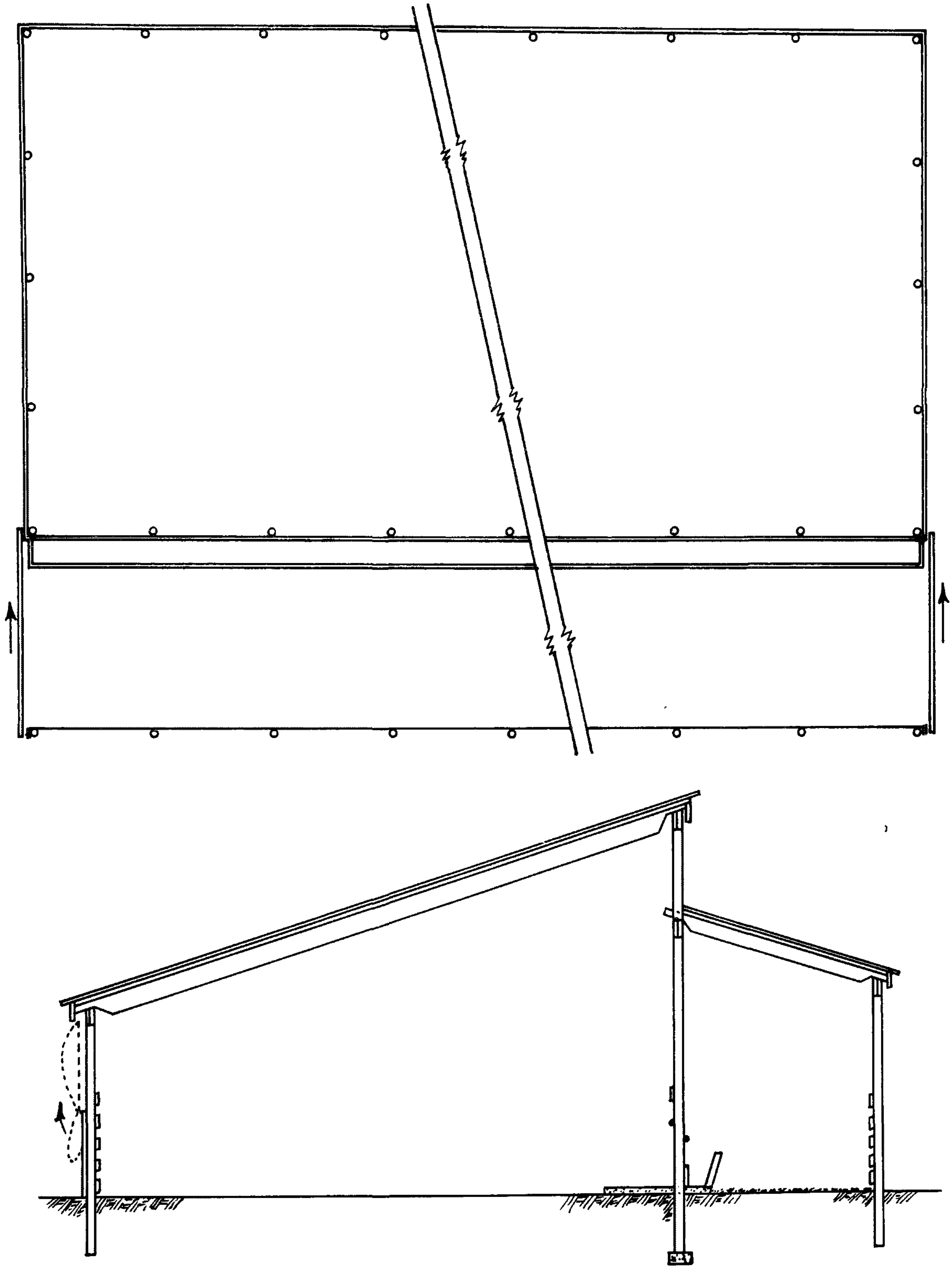


Figure 37. Cold confinement building with dirt floor and canvas side curtains

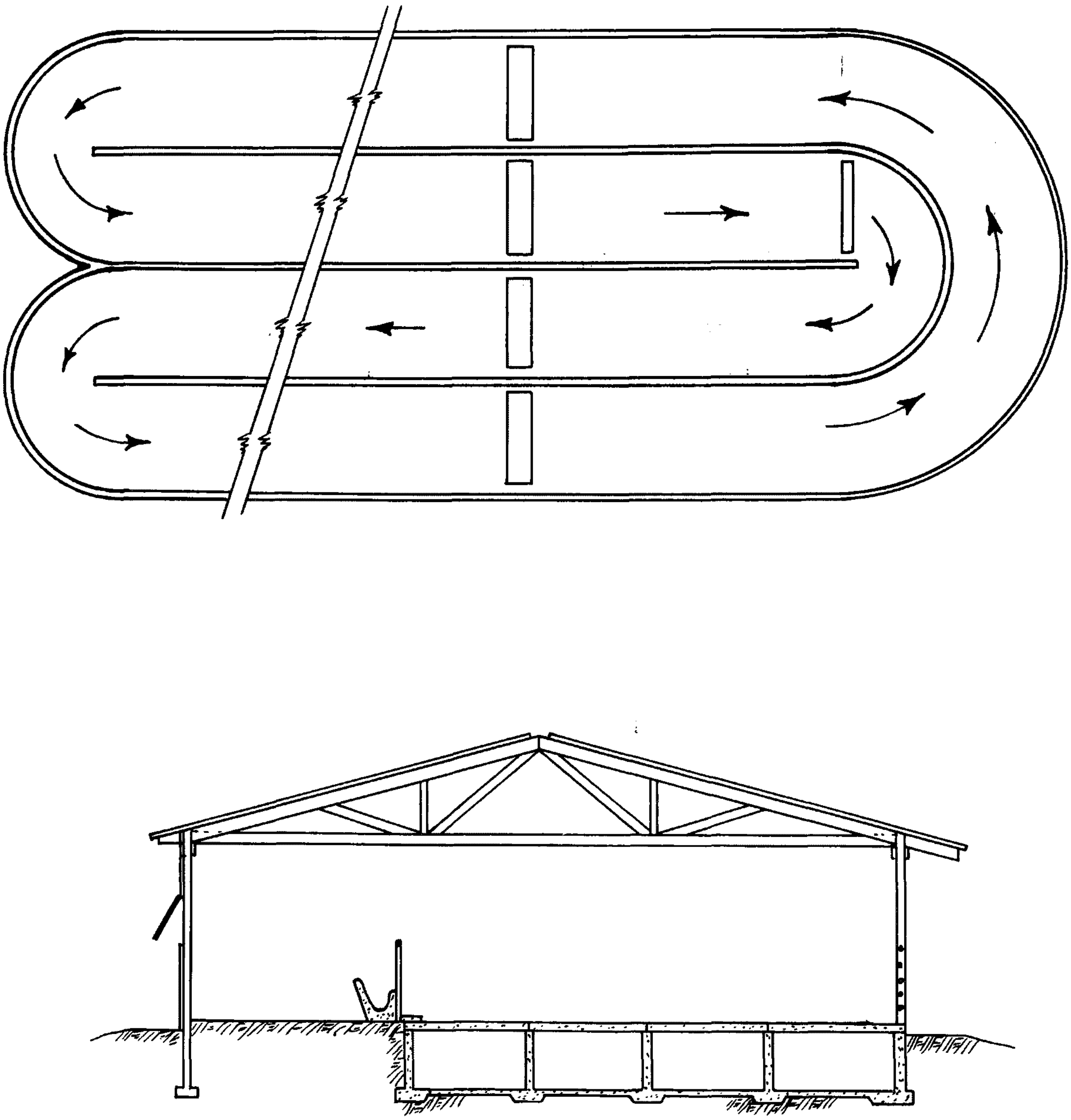


Figure 38. Cold confinement building with shallow pit for oxidation ditch

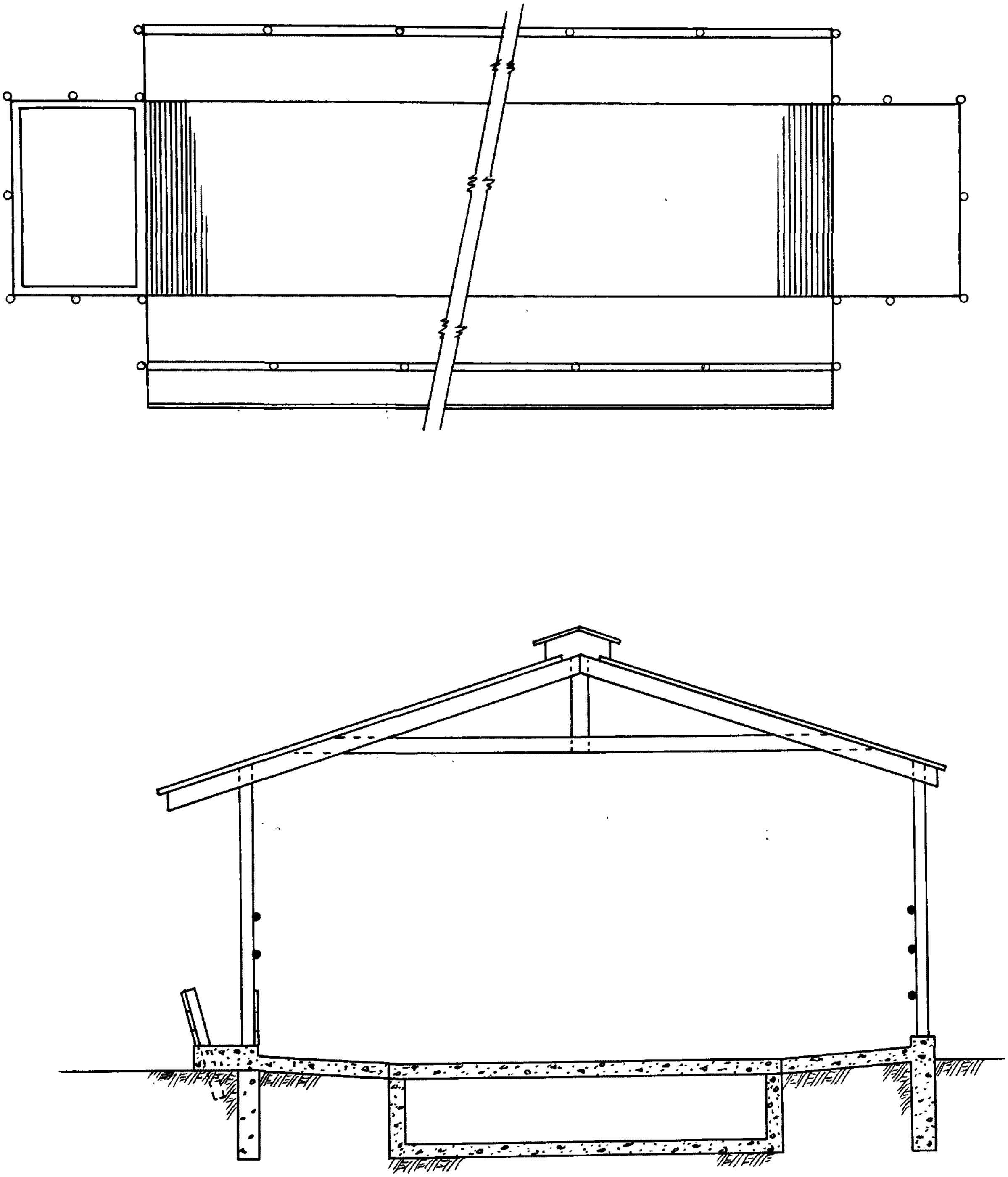


Figure 39. Cold confinement building with shallow pit for cable scraper

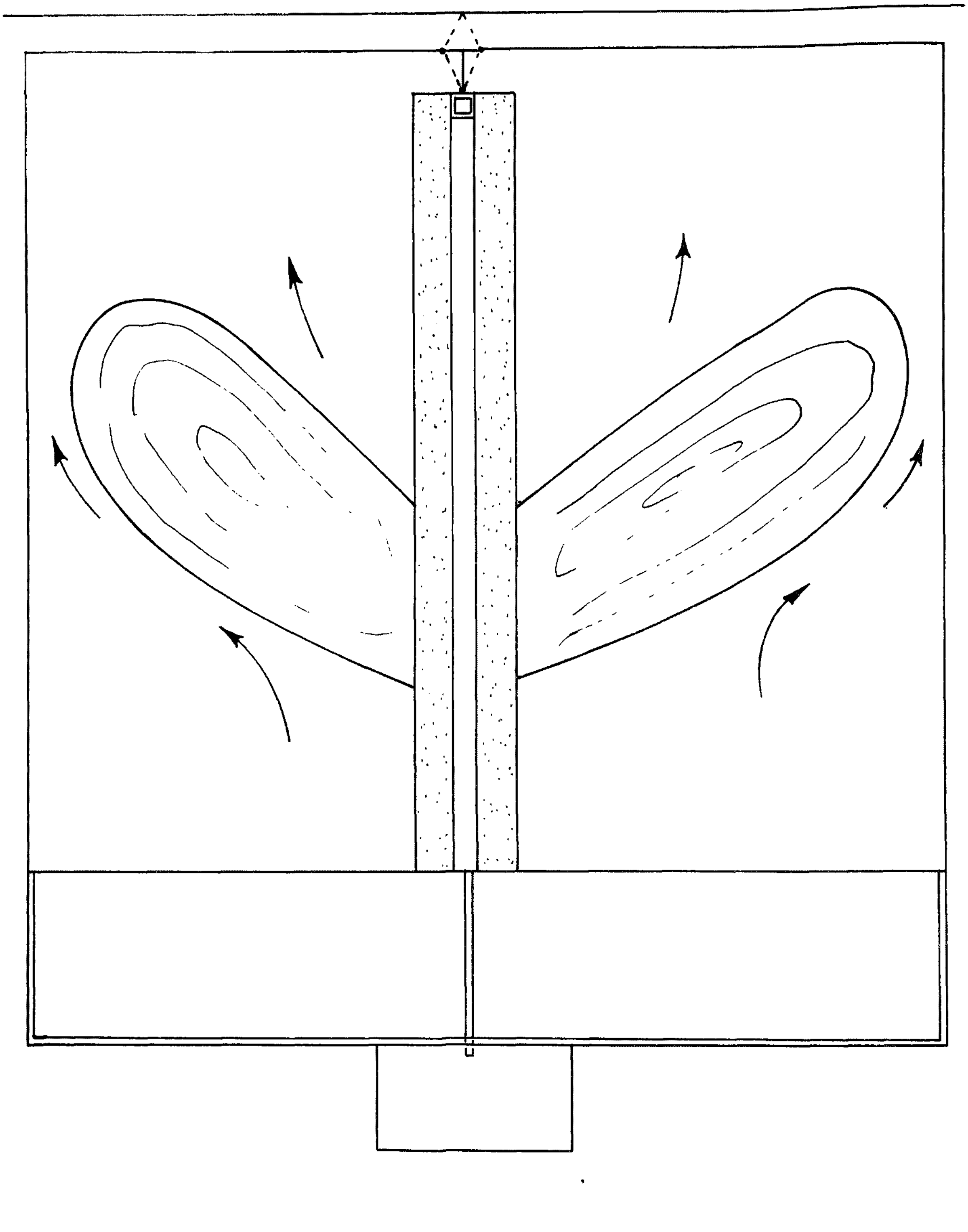


Figure 40. Partial confinement, shelter plus open lot with mounds

CHAPTER VIII

AN ANALYSIS OF ALTERNATIVES FOR CONFINEMENT BUILDING WASTE MANAGEMENT SYSTEMS

The analysis of the alternative waste management systems for confinement beef buildings was based in part upon a computer program developed by Paine (71). The program was expanded to include a section on the design and cost of confinement beef buildings, the costs of handling the waste material by various methods, and the design and costs of treatment and ultimate disposal systems. In this chapter, the initial investment costs and daily operating costs per animal will be presented for facilities, waste handling machinery, waste treatment and the total system cost.

Most of the cost figures are based upon prices of facilities or equipment in central Oklahoma. Some prices are the suggested list price of the manufacturers. The basic hourly wage used in the analysis was $2.50 per hour.

BUILDING COSTS

As mentioned in Chapter VII, there are many possible types of buildings. Buildings differ in type of structural components, as well as shape and arrangement of facilities. Because of the infinite variety of facilities, only a few basic structures were subjected to analysis in this study. The structure can be divided into two segments: shell, and floor and foundation. Further subdivision of building types was made to include both warm confinement and cold confinement buildings and the solid and slotted floors.

Shell Costs

The shell costs for various warm confinement buildings for 500 head are presented in Table 34 and for cold confinement buildings for 500 head in Tables 35 and 36. The 500 head capacity building was selected because it was a frequently encountered size observed during the field observations, primarily in the Corn Belt states. The cost of the buildings was based upon 20 sq ft per animal for slotted floor buildings and 30 sq ft per animal for solid floor buildings. The animal resting area was assumed to remain constant at a width of 32 feet for all of the buildings. The 32 foot width was consistent with the width of some of the buildings observed, was dimensionally suited to the width for some of the waste treatment facilities, particularly the oxidation ditch, and to the span of most concrete floor slats. The length of the buildings were 315 feet for a slotted floor

Table 34. Costs of Various Warm Confinement Buildings for 500 Head

	Concrete Floor, Steel Shell, Mechanical Feed Bunk, 30 ft^2/an., 32' x 473'	Slotted Floor, Deep Pit, Steel Shell, Mechanical Feed Bunk, 20 ft^2/an., 32' x 315'	Slotted Floor, Shallow Pit, Steel Shell, Mechanical Feed Bunk, 20 ft^2/an., 32' x 315'
Shell, $/lin. ft	20.99	19.11	19.11
Floor, $/lin. ft	34.39	82.36	54.86
Waterers, $/lin. ft	1.57	1.70	1.70
Lighting, $/lin. ft	0.30	0.34	0.34
Materials cost, $/ft	57.25	103.50	76.00
Total materials cost, $	27,081	32,602	23,939
Total cost, (including 30% labor cost)	41,071[a]	48,961[a]	36,583[a]
Cost per animal day	.0435[b]	.0521[b]	.0387[b]

[a] Includes ventilation fan costs of $2373 for 7 fans
[b] Ventilation costs of $.0015 per animal day included

Table 35. Costs of Various Cold Confinement Buildings for 500 Head

	Steel Shell, Shed Roof, Slotted Floor, Shallow Pit, Fenceline Feed Bunk (32' x 315')	Wood Frame, Gable Roof, Slotted Floor, Shallow Pit, Fenceline Feed Bunk (20' x 600')	Wood Frame Shed Roof, Slotted Floor, Deep Pit, Fenceline Feed Bunk (48' x 208')
Shell, $/lin. ft	12.60	7.72	13.84
Floor, $/lin. ft	70.84	34.02	56.16
Waterers, $/lin. ft	1.70	1.29	2.26
Lighting, $/lin. ft	0.34	0.21	0.51
Total materials, $/lin. ft	85.47	43.24	72.76
Total materials cost, $	26,924	25,944	15,135
Total cost, $ (including 30% labor cost)	38,474	37,060	21,627
Cost per animal day	0.0418	0.0305	0.0237

Table 35. Continued

	Wood Frame, Gable Roof, Slotted Floor, Shallow Pit, Fenceline Feed Bunk (48' x 315')	Wood Frame, Gable Roof, Partial Slotted Floor, Deep Pit, Center Mechanical Feed Bunk, (54' x 185')
Shell, $/lin. ft	22.54	43.58
Floor, $/lin. ft	71.29	91.75
Waterers, $/lin. ft	1.70	2.46
Lighting, $/lin. ft	0.34	0.57
Total materials, $/lin. ft	95.86	138.36
Total materials cost, $	30,195	25,597
Total cost, $ (including 30% labor cost)	43,149	36,579
Cost per animal day	0.0469	0.0401

Table 36. Costs of Solid Floor Cold Confinement Buildings for 500 Head

	Wood Frame, Shed Roof, Dirt Floor, Canvas and Screen Sides, Fenceline Feed Bunk (66' x 300')	Steel Shell, Open Front, Dirt Floor, Wood Bunk, (32' x 473')
Shell, $/ lin. ft	28.66	13.73
Floor, $/lin. ft	13.37	3.53
Waterers, $/lin. ft	2.13	1.57
Lighting, $/lin. ft	0.48	0.30
Total materials, $/lin. ft	44.64	19.13
Total materials cost, $	13,392	9,050
Total cost, $ (including 30% labor cost)	19,137	12,932
Cost per animal day	0.0210	0.0140

building and 473 feet for a solid floor building due to the differences in space allowance per animal.

The computer output for the shell cost was in terms of dollars per linear foot so only those buildings with the same lengths can be compared easily using the data in the tables. The total costs for each of the buildings is presented, however, and can be compared easily.

In the computer program, there was a choice of siding material that could be used. The siding materials and respective cost per square foot are: steel, 11¢; wood, 15¢, screen, 9¢; and canvas, 11¢. Insulation, used for warm confinement buildings, was estimated at $.0175 per sq ft per inch thickness for fiber glass and $.08 per sq ft per inch thickness for plastic foam insulation. Footing costs for poles were estimated at $1.50 per footing and the cost for digging the holes was estimated to be $1.00. Steel columns were estimated at $1.72 per foot of length. Wood pole costs were obtained from local suppliers. An equation was determined to estimate pole costs based upon length and diameter of the pole. Splash boards were estimated to cost $.1175 per board foot. An equation was developed to estimate the costs of various types of trusses and roof materials.

Other facilities included in the analysis were: feed bunk, waterers, lighting, and electrical service. Feed bunk costs were estimated as follows: $2 per linear foot for wood, $6.25 per linear foot for concrete, and $7.50 per linear foot for mechanical feed bunks. Waterers were estimated as follows: $115 per 200 animals plus 60¢ per foot of barn length. Lighting was estimated at 15¢ per 20 square feet of barn surface or floor area. The service entrance costs were estimated at $30.34 for the building for lighting and general purpose, but not for large electric motors.

The two major types of flooring used in this analysis were solid concrete floors and concrete slats of approximately 8 foot length with costs of $0.45 per sq ft and $1.00 per sq ft respectively. No cost was attributed to dirt floors. Deep pit costs were estimated to be $1.00 per sq ft and shallow pit costs were $.50 per sq ft.

The total cost of the building was assumed to include a 30% labor cost. Construction costs for residential and commercial buildings frequently have over a 50% labor cost. However, agricultural structures do not require as much finish type of construction and therefore a 30% labor cost was used. This is consistent with reports of similar construction.

Comparison of Confinement Buildings

Warm Buildings--The costs of three types of warm confinement buildings for 500 head are compared in Table 34. One building has a concrete floor with a steel shell and mechanical feed bunk, a space allowance of 30 square feet per animal, and building dimensions of 32 feet by 473 feet. The total cost of this building was estimated to be $41,000 with an operating cost of $0.0435 per animal day. The second building has a slotted floor with a deep pit, steel shell, mechanical feed bunk and a space allowance of 20 square feet per animal, and building dimensions of 32 feet by 315 feet. The total cost for this building was estimated to be $36,580 with an operating cost of $0.0387 per animal day.

The costs for the three buildings included ventilation fan costs of $2,373 for seven fans with an operating cost of $0.0015 per animal day. The ventilation system was designed on the basis of Mid-West Plan Service recommendations and manufacturers' literature. The number of fans was determined on the basis of 215 cfm per animal and the use of 17,000 cfm rated fans. For operating cost calculations, it was assumed that the fans operated 80% of the time throughout the year.

The investment costs per animal for the three buildings were approximately $82, $98, and $73 for the solid concrete floor, slotted floor with deep pit, and slotted floor with shallow pit. Of these three buildings, the slotted floor building with the shallow pit was the least expensive. This building was designed to include a cable scraper system or an oxidation rotor in a 24 inch deep ditch.

Cold Buildings--The costs for 500 head cold confinement buildings are compared in Tables 35 and 36. These buildings were described in Chapter VII. Essentially, the buildings have open sides, either open to the south or in some cases open on both sides of the building with provision for enclosing all but one side during the winter. Five of the buildings have slotted floors with either shallow or deep pits and one has only a partially slotted floor with deep pit. Two of the buildings have dirt floors. There are also differences in the building construction and the type of feed bunk. Some of the fenceline feed bunks are located along the outside of the building, whereas other buildings have a drive 16 feet wide inside the building for feeding. When shallow pits are used, it is assumed that a cable scraper system is installed to remove the waste materials or an oxidation rotor is used. For deep pits, the slurry is removed periodically, usually two times per year.

The buildings with the least cost were the dirt floor buildings with a total cost of about $12,900 for a dirt floor open-front building with a steel shell and wood fenceline feed bunk with outside drive. The wood frame building with dirt floor and canvas and screen sides with fenceline feed bunk inside the building had a total cost of $19,000. Thus, the total investment cost for these buildings was about $26 per animal and $38 per animal, respectively.

The least expensive slotted floor cold confinement building was one having a shed roof, wood frame, interior wood poles, partially slotted floor with deep pit, and fenceline feed bunk with an inside drive. The cost of this building was approximately $21,600 or about $43 per animal. The next least expensive building was a building designed specifically for a cable scraper system. The building had a width of 20 feet with a shallow pit over 12 feet of this width. Thus, the penned area was 20 feet by 500 feet. The building had a wood frame with a gable roof and a fenceline feed bunk with exterior drive. No siding was used on this building. The cost of the building was estimated to be approximately $25,800 for 500 head or approximately $51 per animal.

Buildings with narrow widths are cheaper to construct than wider ones. This is primarily true for buildings requiring truss rafters. Buildings having interior wood poles spaced according to pole building construction practices are less expensive than clear span buildings. Also, buildings that use wood for framing and feed bunks have lower costs.

In a comparison of beef cattle feedlot production alternatives, Gilbertson (21) used a $1.25 per sq ft value for the cost of the basic structure of a confinement housed feeding facility. For a solid floor system with 30 sq ft per animal, the cost of the basic structure was $25,000. For 20 sq ft per animal, the cost of a slotted floor system was $16,500. In addition to the basic structure cost, the cost for a six inch concrete floor for 500 animals was $4,290 and for a slotted floor system with an eight foot deep pit the cost for 500 animals was $9,290. Thus, the material costs for confinement buildings for 500 head were $29,290 for a solid concrete floor building and $25,780 for a slotted floor building with an eight foot deep pit. These figures included land cost, fencing, gates, roads, and feed bunks. The material costs that he found for the partially slotted floor building compared closely with the data obtained in this study for a wood frame gable roof, partially slotted floor building with a deep pit.

Other comparisons of the costs of beef feeding buildings have been conducted in Iowa (5). One comparison was for a wood frame, gable roof, slotted floor building with shallow pit and fenceline feed bunks. This building cost $44,500 compared with this investigation's calculated value of $43,150, but did not include pen material costs. Another building using a cable scraper system located underneath a slotted floor and shallow pit was examined in Iowa. This building was 20 feet wide and 600 feet long with a wood frame, gable roof and fenceline feed bunk. The basic cost for this building in Iowa was approximately $41,000 minus the heating system and the cable scraper system. The computed cost in this analysis was $37,060, or slightly lower than actual costs in Iowa.

WASTE HANDLING COSTS

The buildings described in the above section served as the initial collection facility for the animal waste. The type of building dictates the type of waste management system that is used. For instance, a slotted floor building with a deep pit has to have an associated slurry handling system. On the other hand, a solid floor building where bedding is used has to have a solid waste handling system. After removal from the building the waste can be either treated or transported to an ultimate disposal location.

Solid Waste Handling Systems

Solid floor systems require solid waste handling methods. The four basic methods used in this analysis were a tractor loader plus dump truck, commercial loader plus dump truck, tractor front-end loader plus pull spreader, and commercial loader plus spreader truck. The operating costs of these pieces of equipment were determined by using a computer program developed by Paine (71).

The initial costs of the equipment are presented in Table 19 in Chapter VI. The tractor with a front-end loader had an estimated initial cost of $8,900 and had an estimated capacity of 37.2 yards per hour. The dump truck had an estimated initial cost of $9,700 with an estimated capacity of 39.6 yards per hour. The spreader truck had an estimated cost of $12,800 with an estimated capacity of 67.5 yards per hour. The pull-type spreader had an estimated cost of $1,434 with an estimated capacity of 38 yards per hour. The commercial loader had an initial cost of $31,100 with a capacity of 168 yards per hour.

The operating cost per animal and the investment costs are illustrated in Figures 41 and 42 for various feedlot capacities. In this particular analysis, the machinery was assumed to be used 20 days per year and the hauling distance was one-quarter mile. The 20 days per year of machinery use coincided with the desire of many feedlot operators to have the material removed in a short period of time.

The tractor front-end loader with a pull-type spreader was the best combination for removing animal waste from solid floor confinement buildings below 2,000 head of animals. Above 2,000 head, a commercial loader with spreader truck had a lower operating cost. However, the investment cost for a commercial loader and spreader truck is several times higher than a tractor front-end loader plus pull-type spreader. The tractors for both the loader and the spreader are assumed to operate on the waste handling activities for only 20 days per year and are free for other operations the remainder of the year. Therefore, the total investment cost for the tractors was partitioned into that associated with the waste handling activity and that due to other activities. It was assumed that the tractors would operate 500 hours per year. Other waste handling equipment such as a commercial loader, dump truck, and spreader truck are specialized pieces of equipment and were assumed not to be used for other enterprises during the year. The handling systems utilizing dump trucks had both a higher operating cost and a higher initial investment cost than the other two systems. This was primarily due to the low capacity of the dump truck. Waste handling times and quantities were taken from data observed under field operations and from data obtained from manufacturers' literature.

Some of the larger feedlots using solid floor confinement have to remove the waste on a year-round basis. The operating costs and investment costs for the four solid waste handling systems as affected by days of use per year are presented in Figures 43 and 44 for a 20,000 head lot and assuming a one-quarter mile hauling distance. For 20,000 head the commercial loader with a spreader truck had the lowest operating cost, however, it had the highest initial investment cost. The operating cost became a minimum between 100 and 200 days of use per year for all of the systems. For fewer days of use per year more machines are required causing the costs to increase. As the days of use per year increase, the maintenance cost for the machinery becomes high and the operating costs therefore start rising. The systems utilizing the dump truck had the highest operating costs with the tractor loader and a pull-type spreader having the second lowest operating cost and also a lower investment cost than

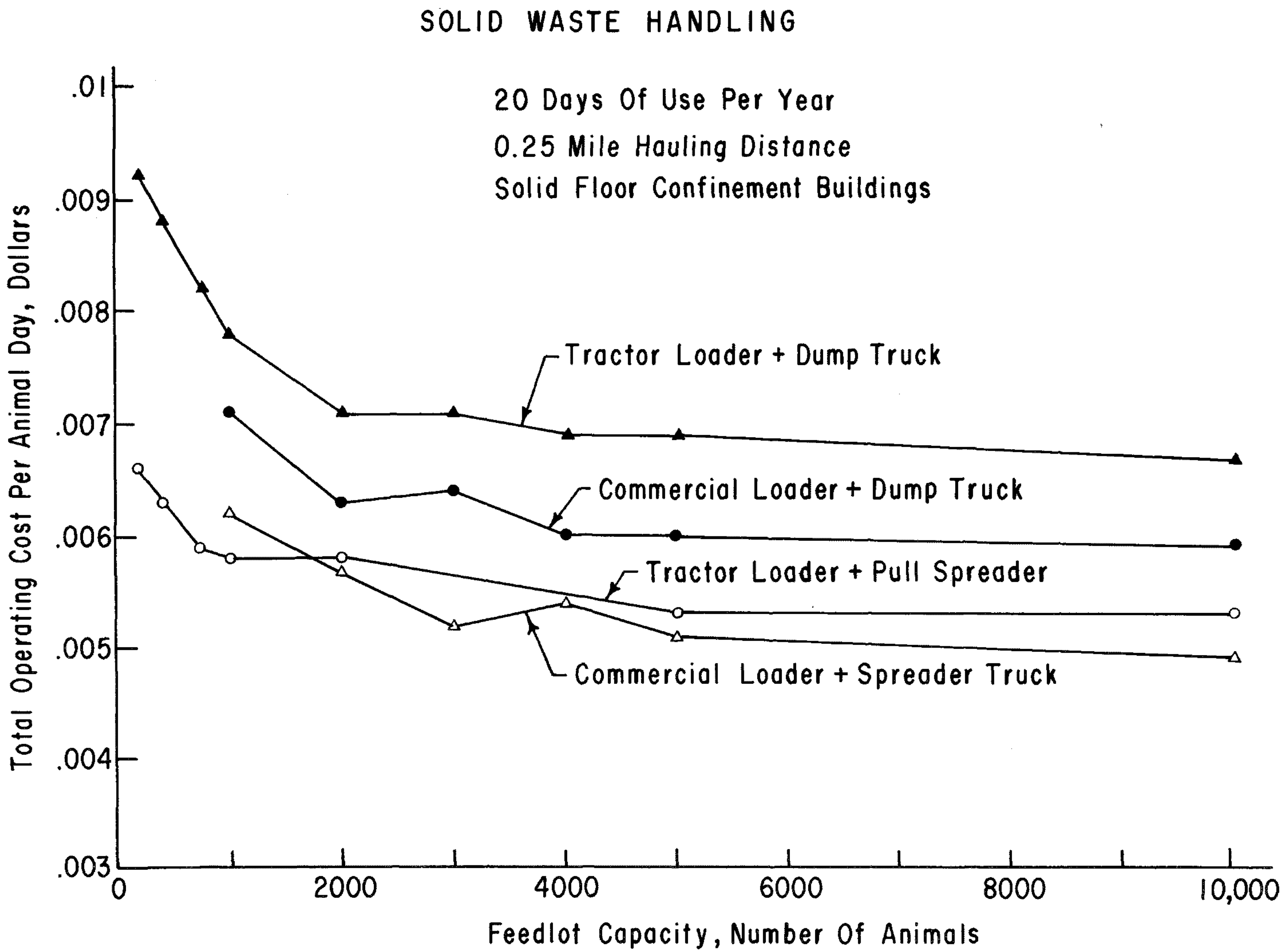


Figure 41. Solid waste handling: operating cost vs. feedlot capacity

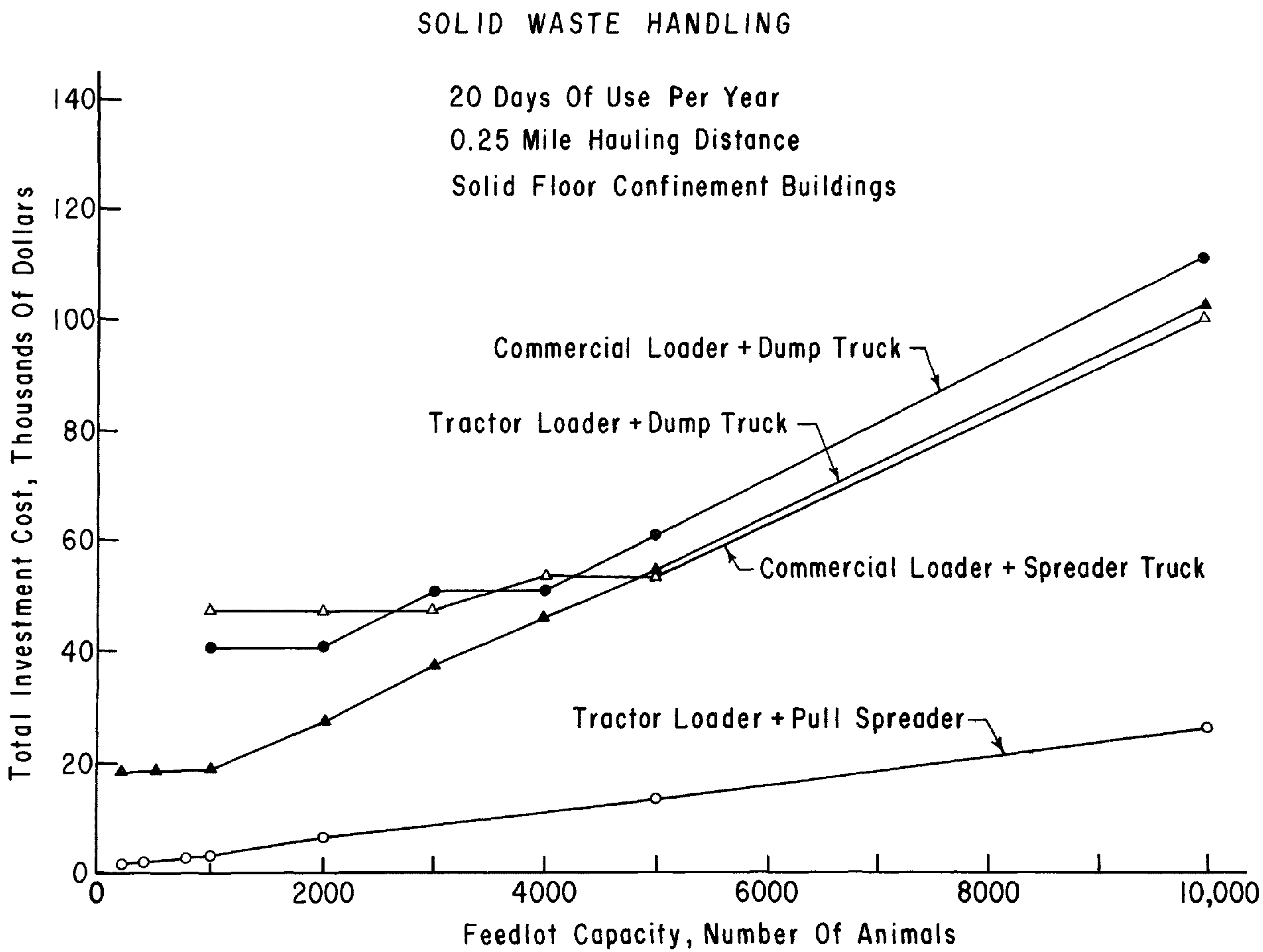


Figure 42. Solid waste handling: operating cost vs. feedlot capacity

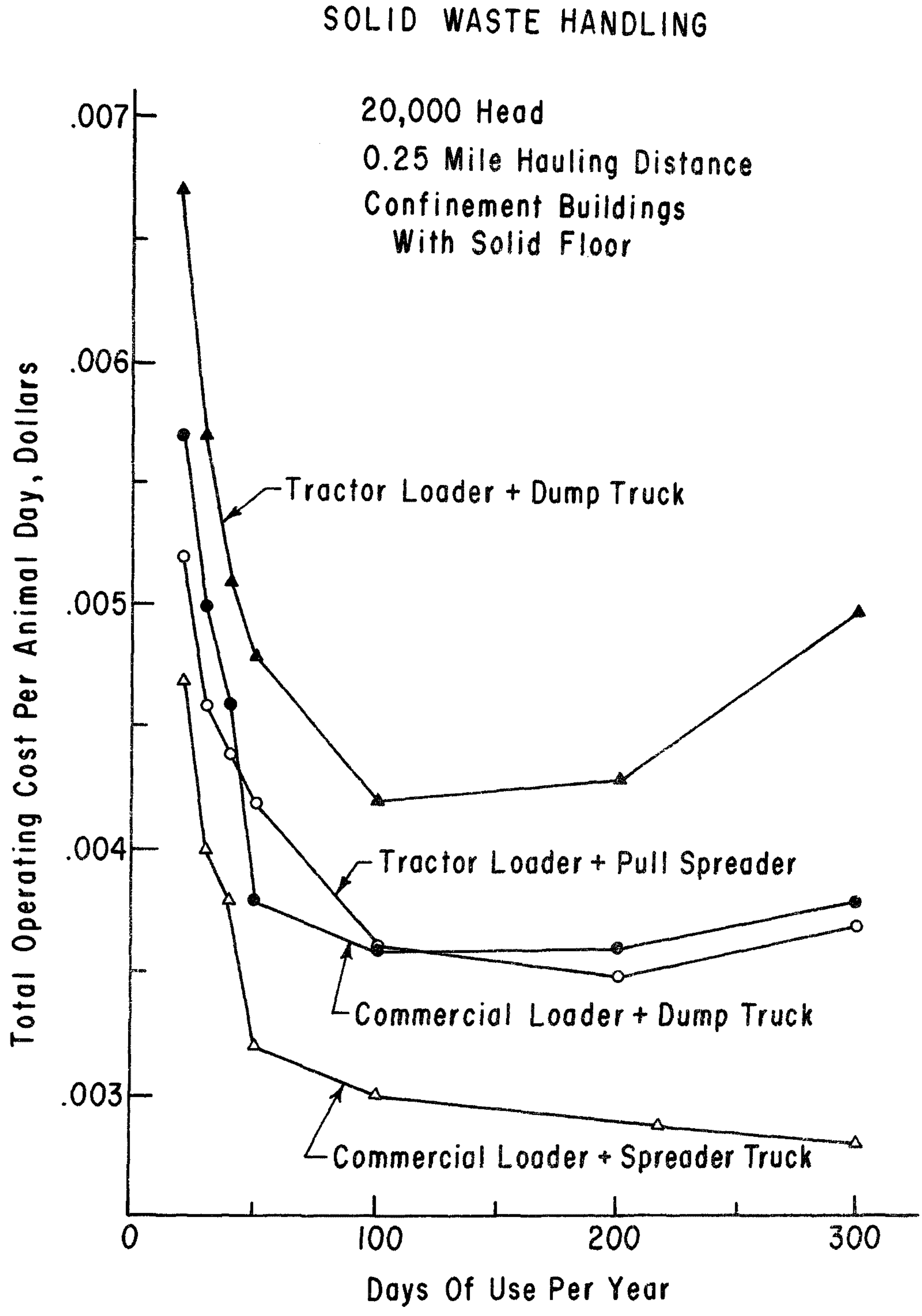


Figure 43. Solid waste handling: operating cost vs. days of use per year

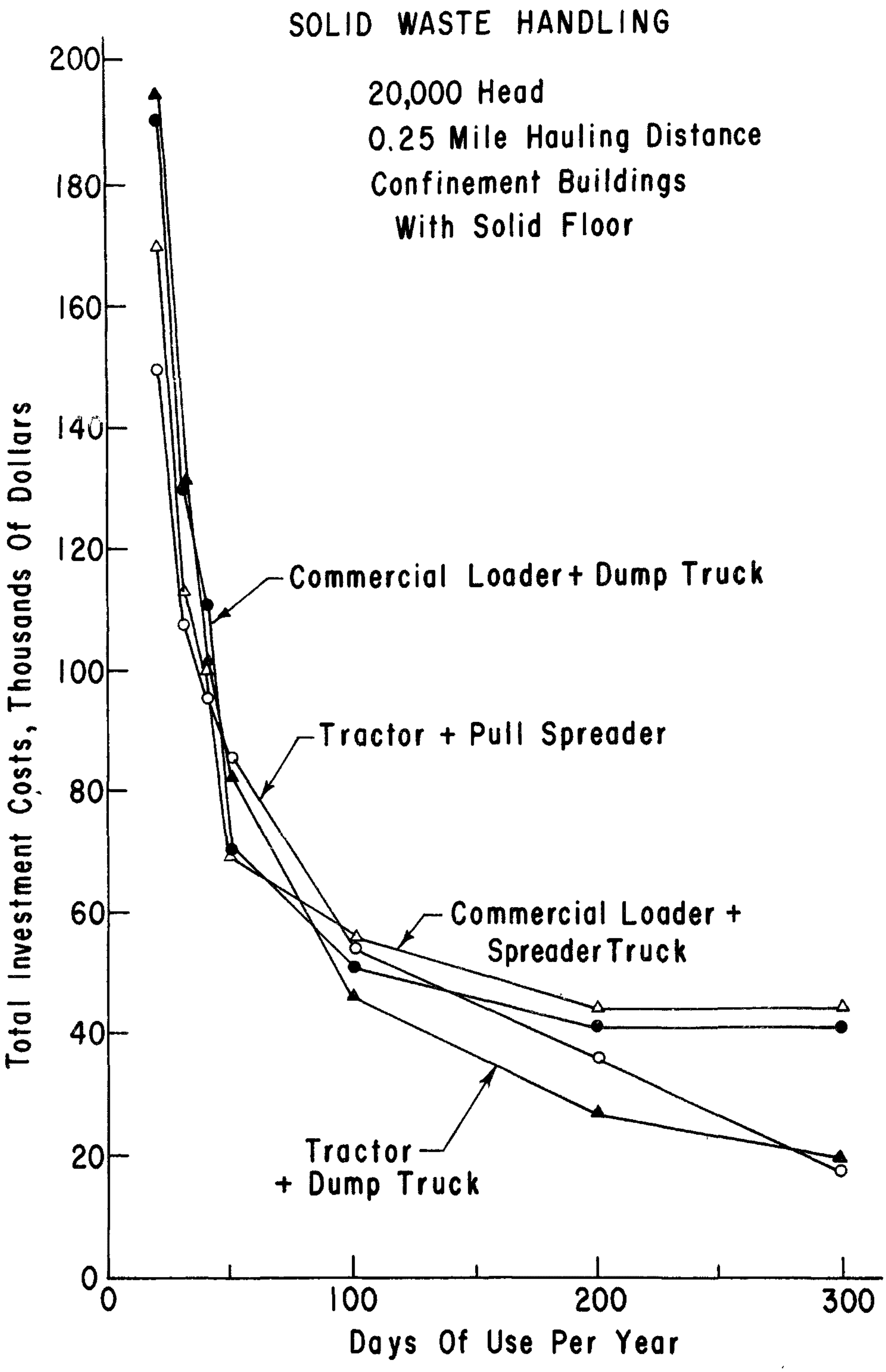


Figure 44. Solid waste handling: investment cost vs. days of use per year

the commercial loader and spreader truck after 100 days of use per year.

Hauling distances for the solid waste had an effect on the cost of operation for 20,000 head as indicated in Figures 45 and 46. The commercial loader and spreader truck had the lowest operating cost as distance increased for both 20 days and 100 days of use per year. It had a nearly constant investment cost as distance increased. The commercial loader with dump truck was second best for distances of 2 miles or greater for operating costs and had the lowest investment cost as distance increased.

Tractor scrapers have an operating cost of approximately \$0.00018 per day per animal and an investment cost of approximately \$245. The total machine investment cost, including tractor, varies from \$279 for a 200 head lot to \$3,866 for a 20,000 head lot. This is based upon the scraper being utilized for other operations and used mainly for a 20 to 50 day period per year for waste handling.

A summary of the operating and investment costs for various solid handling and slurry handling systems are presented in Figures 47 and 48 for feedlot capacities between 200 and 1,000 animals. This assumes one-quarter mile hauling distance and 20 days of use per year. Of the solid handling systems, the tractor front-end loader and pull-type spreader is most economical. The tractor front-end loader plus spreader truck had the second lowest operating cost but had the highest initial investment.

Slurry Handling Systems

Housing systems utilizing a slotted floor with a deep storage pit require a slurry handling system. The system consists of a pump driven by a tractor or electric motor and a liquid spreader to convey the slurry to the field. The pump and tractor operating (and also electric motor) cost remains relatively constant at \$0.0005 per animal day regardless of feedlot capacity.

The basic systems used in this analysis were the pull-type liquid spreader with an injector to discharge the material into the soil, a pull-type liquid vacuum spreader requiring no external pumps, a liquid truck spreader and a pull-type liquid spreader without a soil injector.

The four slurry handling methods are compared in Figures 47 and 48 as affected by feedlot capacity between 200 and 1,000 animals. The pull-type liquid spreaders without

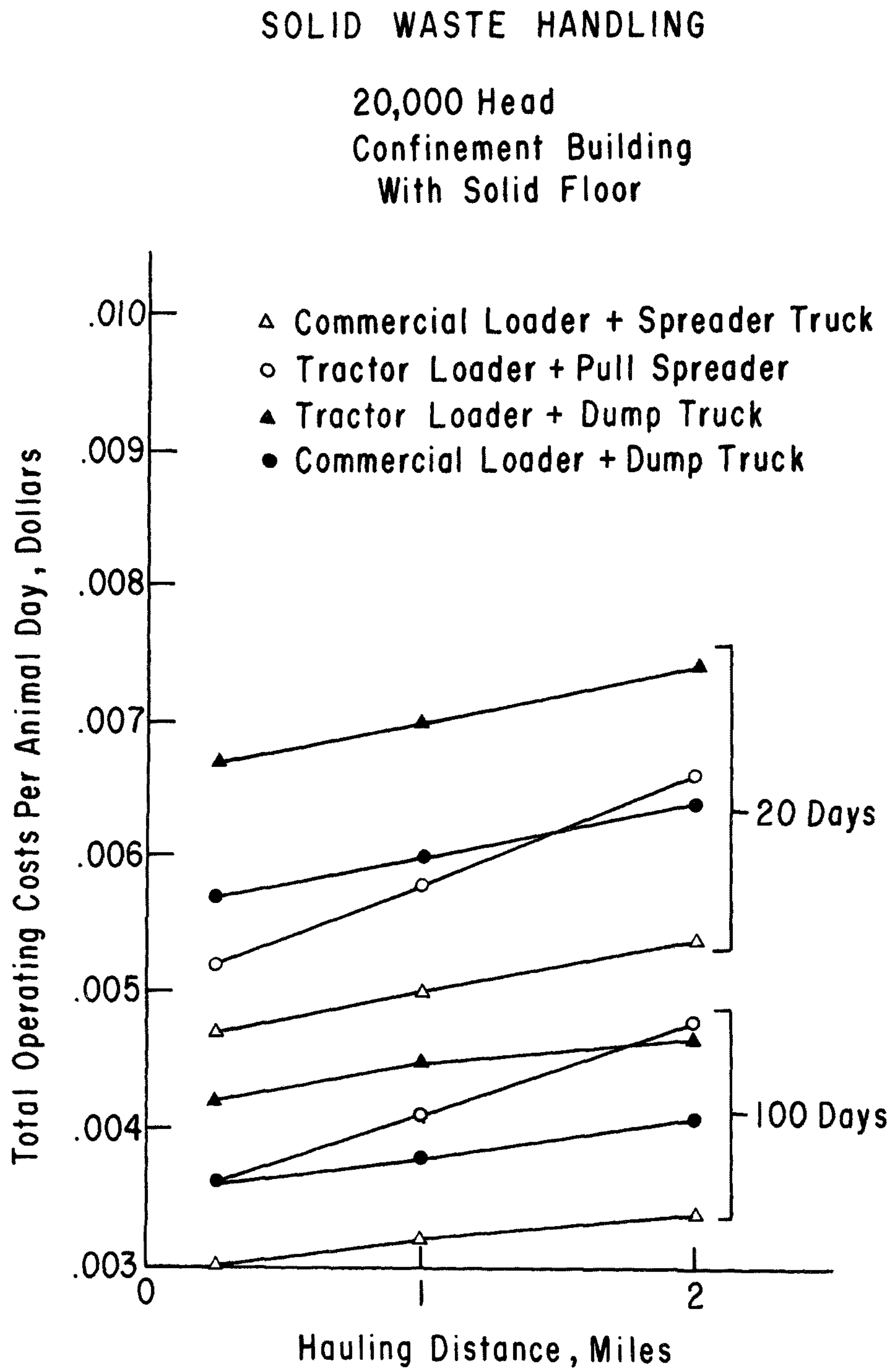


Figure 45. Solid waste handling: operating cost vs. hauling distance

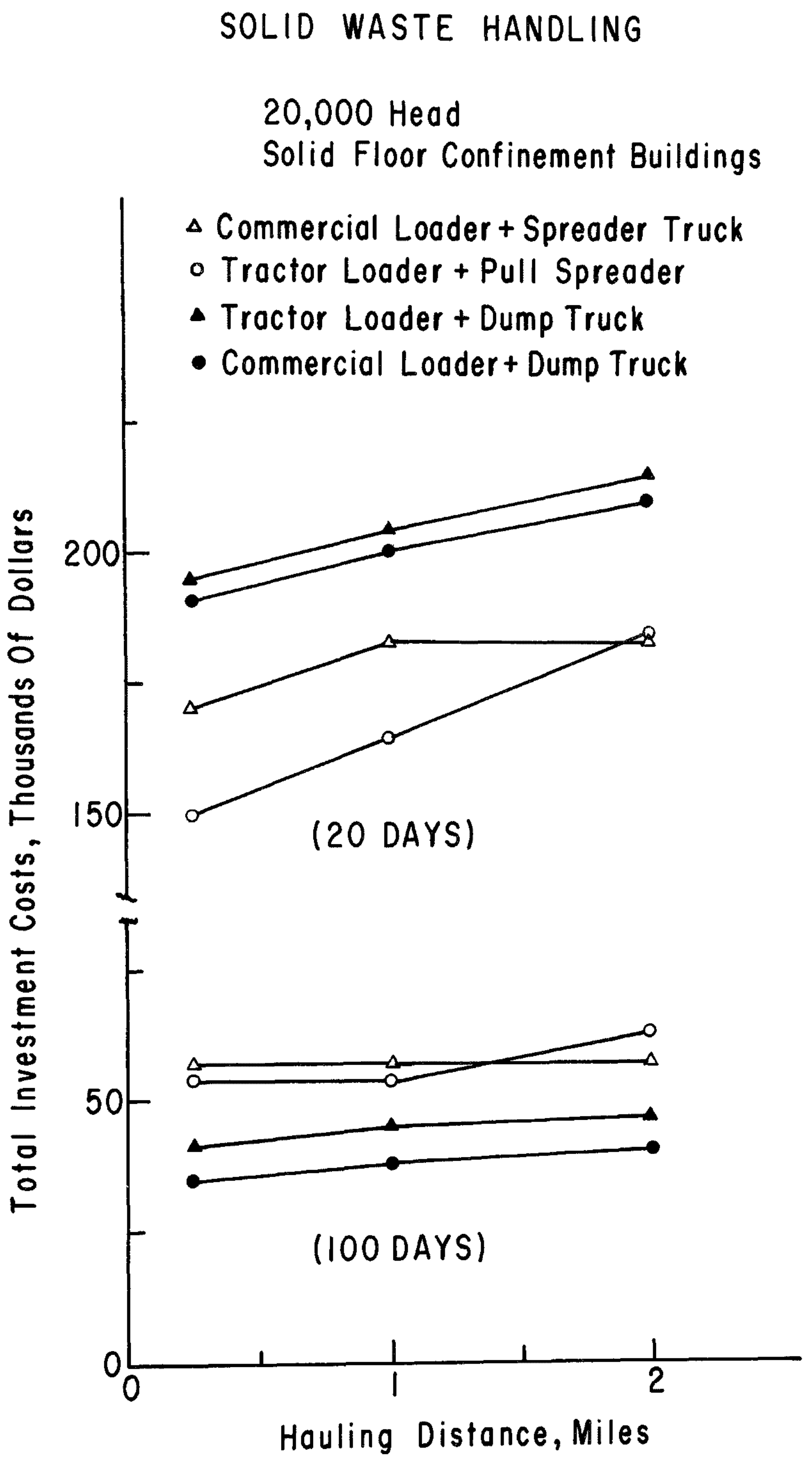


Figure 46. Solid waste handling: investment cost vs. hauling distance

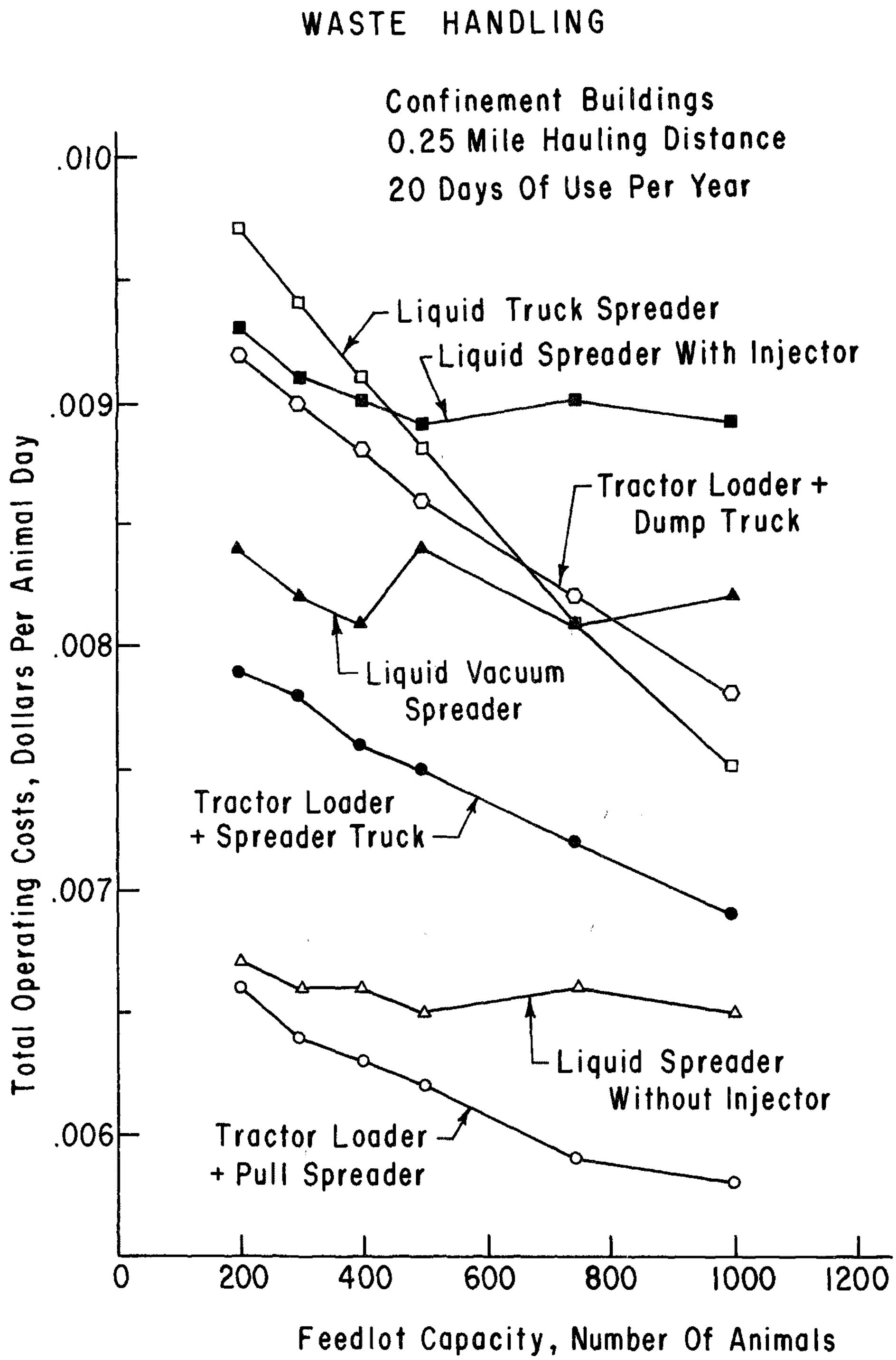


Figure 47. Waste handling: operating costs vs. feedlot capacity for solid and slurry handling systems

WASTE HANDLING

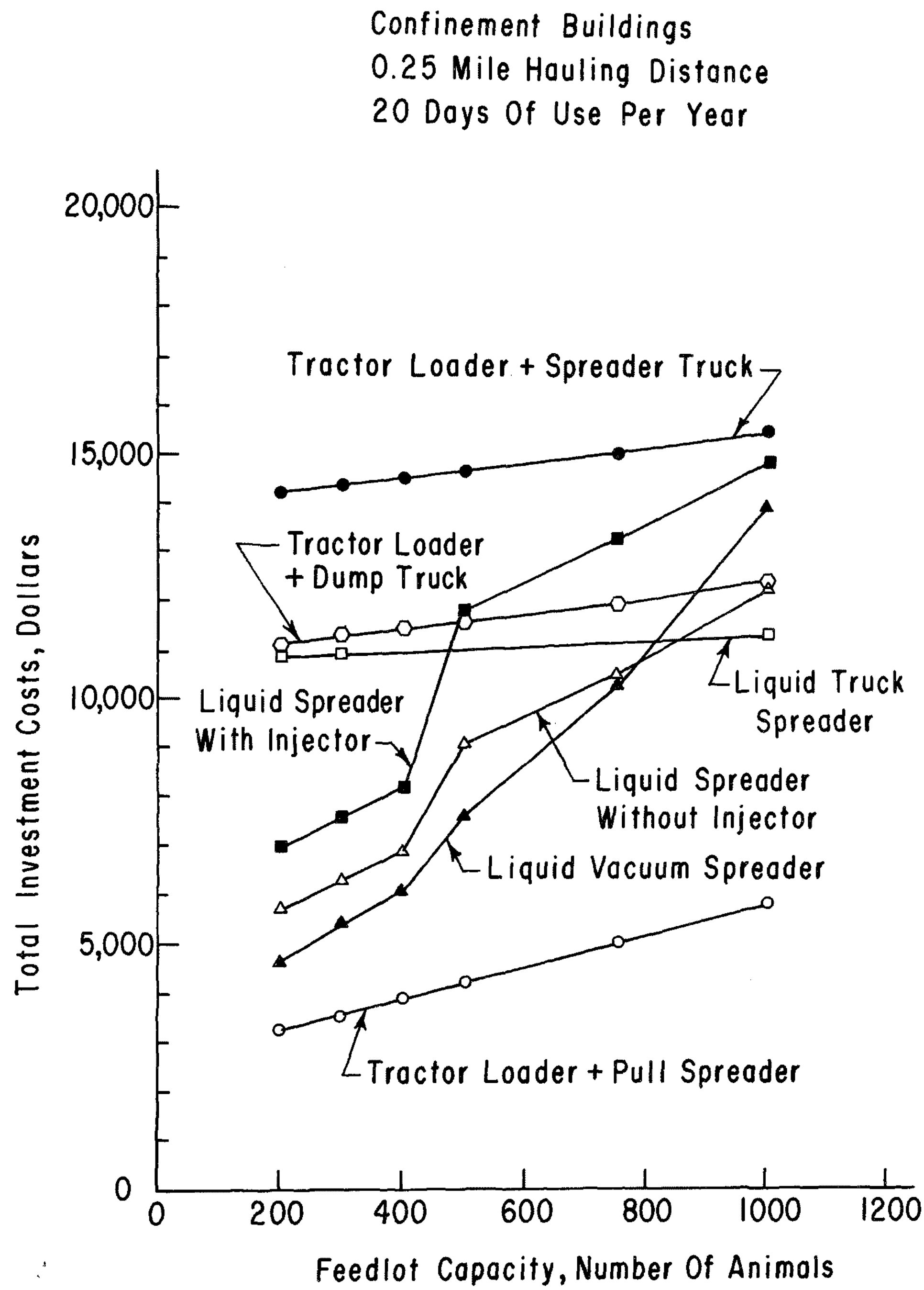


Figure 48. Waste handling: investment costs vs. feedlot capacity for solid and slurry handling systems

injector had the lowest operating cost and second lowest investment cost. The liquid vacuum spreader had the lowest investment cost but next to the highest operating cost. The liquid spreader with the injector had the highest operating cost and also highest investment cost. However, this method does incorporate the material onto the soil so that odors and pollution problems are reduced considerably, but it is much slower in putting waste onto the fields. This particular analysis assumes 20 days of use per year and a one-quarter mile hauling distance.

The effect of number of days of use per year on the operating cost for a 500 head unit for one-quarter mile hauling distance is presented in Figure 49. The liquid spreader without an injector had a considerably lower operating cost than the other three methods. The costs generally decreased as days of use per year increased. Truck spreader costs remained approximately constant between 10 and 30 days of use per year for 500 head. The costs fluctuate as more or less machinery is used to meet the waste hauling demands.

The effect of hauling distance on the operating cost of four liquid slurry handling systems are presented in Figure 50. The hauling costs for all four systems increase linearly with distance. The pull-type spreader without injector is the lowest among the pull-type spreaders and is lower than the truck spreaders for less than one mile hauling distance.

The operating costs for a 20,000 head unit having confinement buildings with deep pits are presented in Figure 51 for the four different slurry handling systems as affected by days of use per year. The total investment costs are presented in Figure 52. As the days of use per year increases, the spreader operating costs decrease up to about 100 days of use per year. Then the spreader with injector and the vacuum spreader costs remain relatively constant or increase slightly due to increased maintenance and wearout. A tank truck and spreader without injector remain as those systems having the lowest operating cost. After about 30 days of use per year, the tank truck has the lowest total investment cost with the spreader without injector being the second lowest investment cost. This remains true until the days of use exceeds 200 days per year; at this point tank truck investment cost remains relatively constant while the spreader costs continue to decline.

The operating costs for various slurry handling systems are presented in Table 37. A complete breakdown of the operating and investment costs and the hours of use and

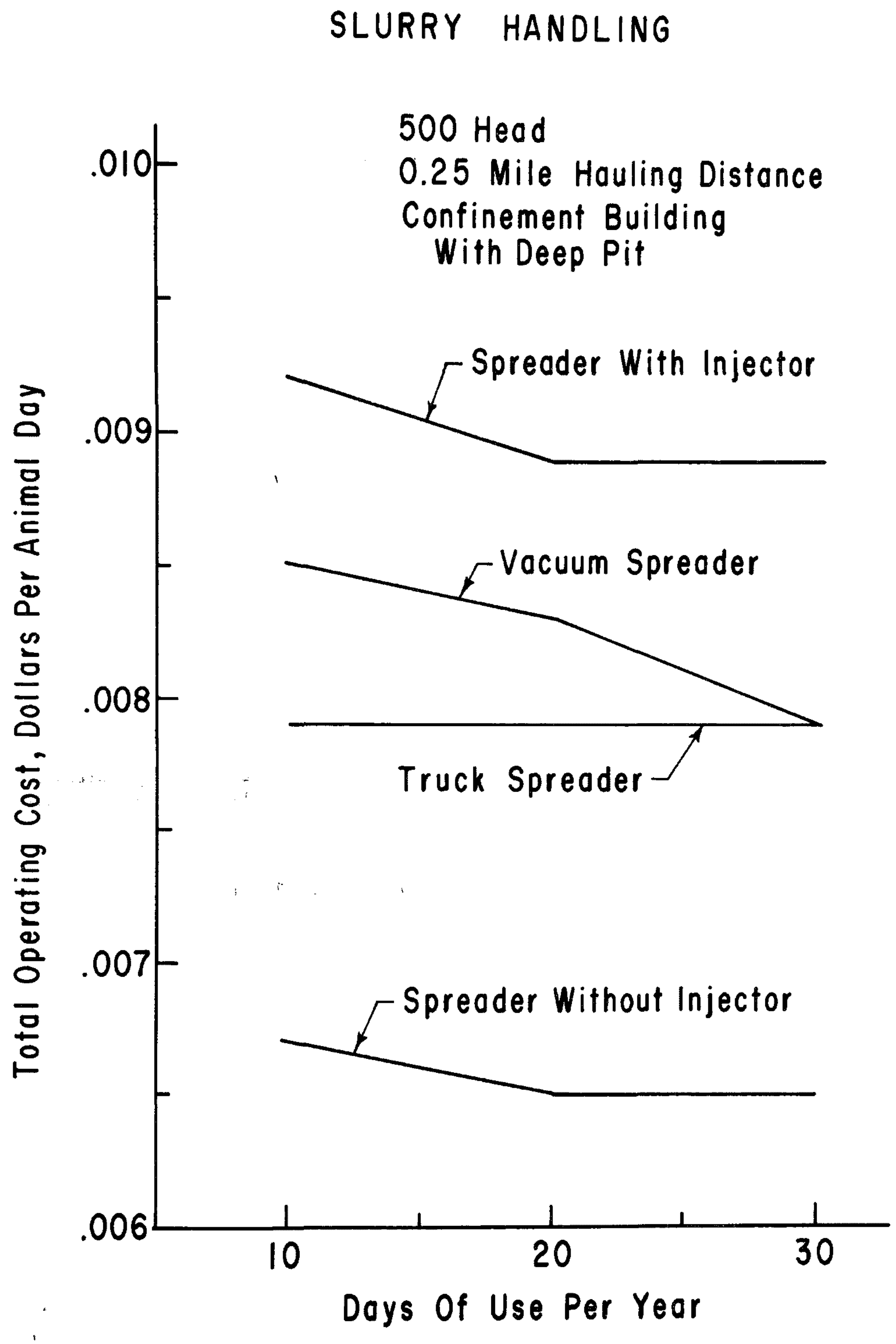


Figure 49. Slurry handling: operating costs vs. days of use per year

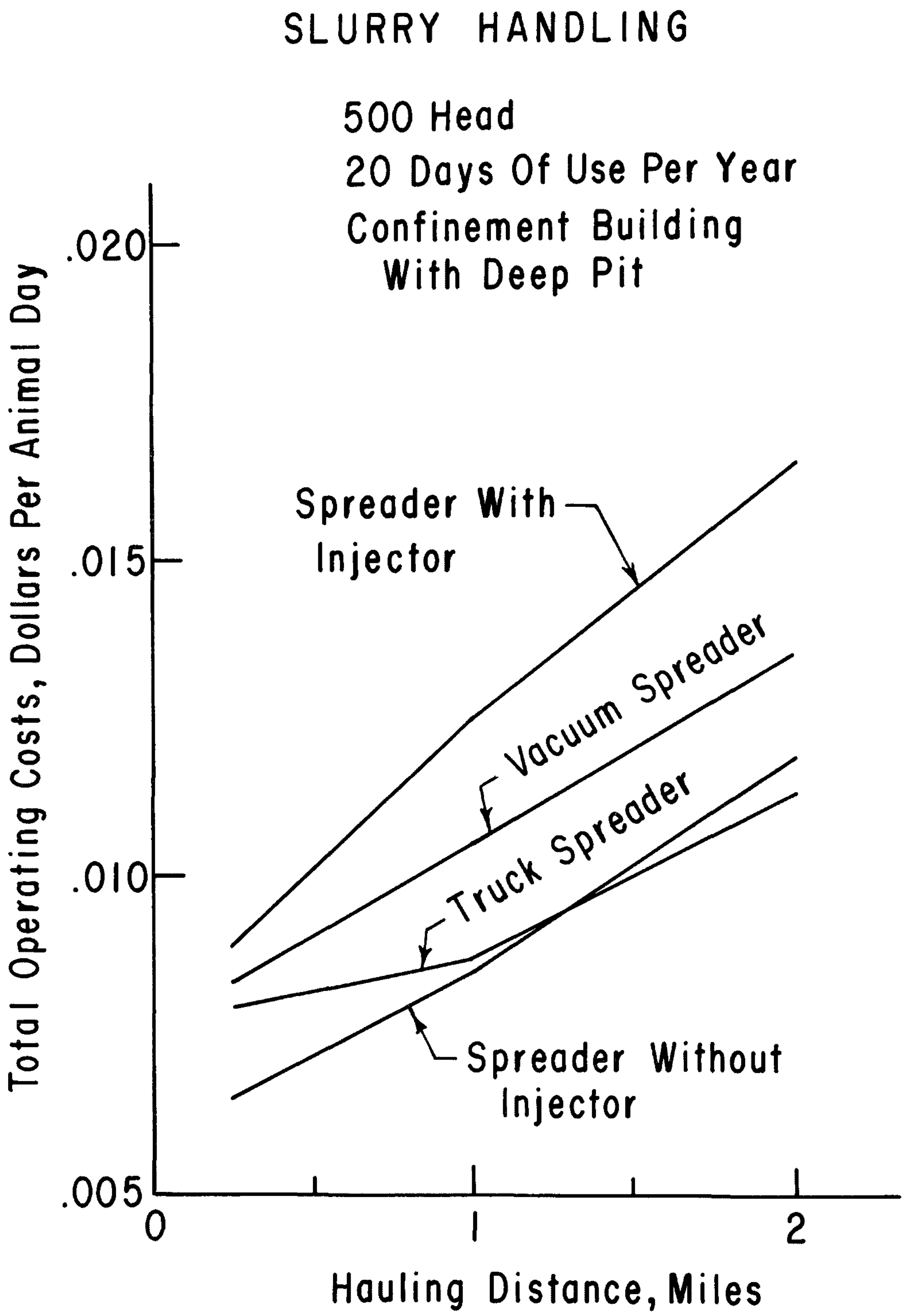


Figure 50. Slurry handling: operating costs vs. hauling distance

SLURRY HANDLING

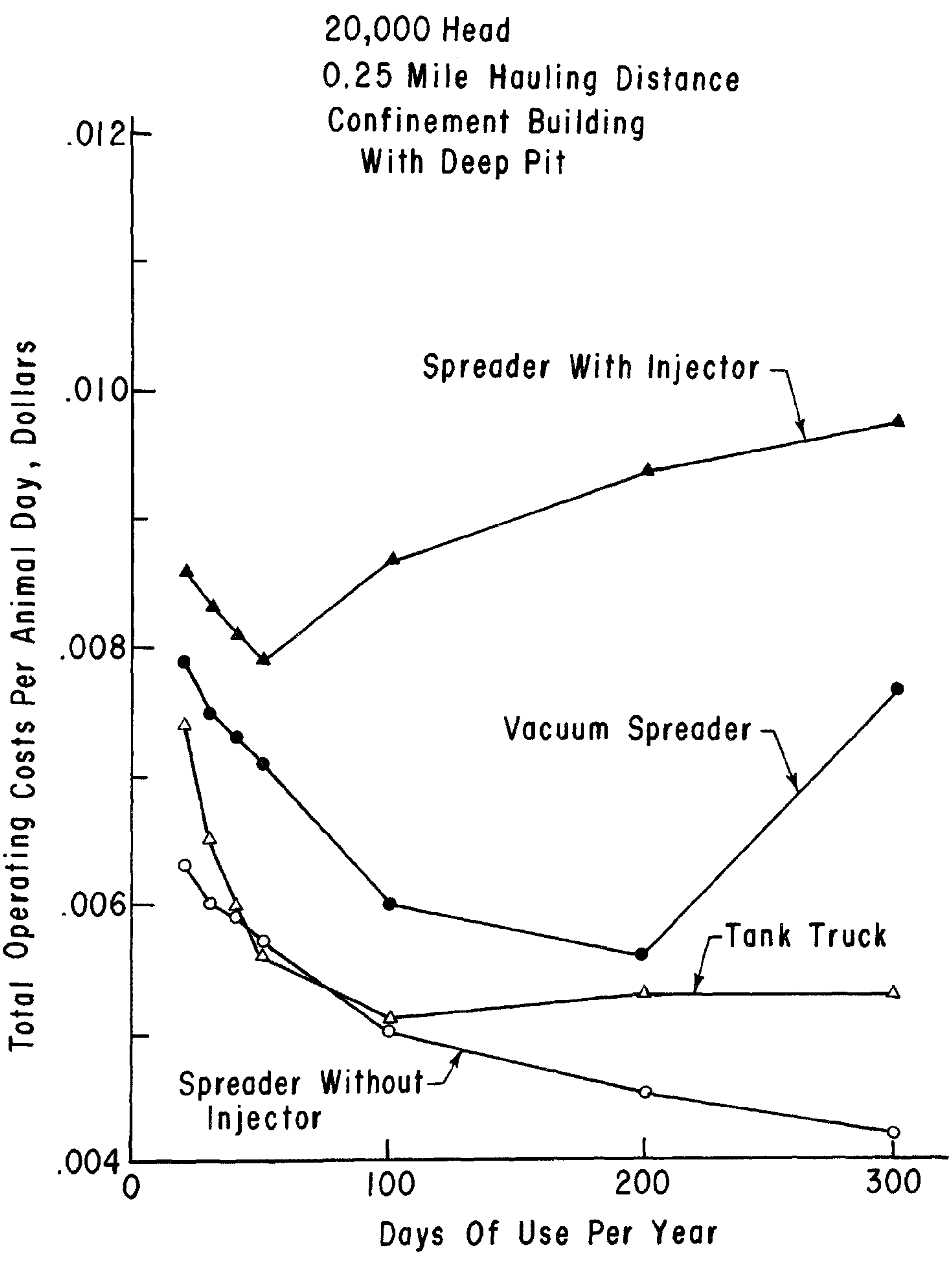


Figure 51. Slurry handling: operating costs vs. days of use per year for 20,000 head

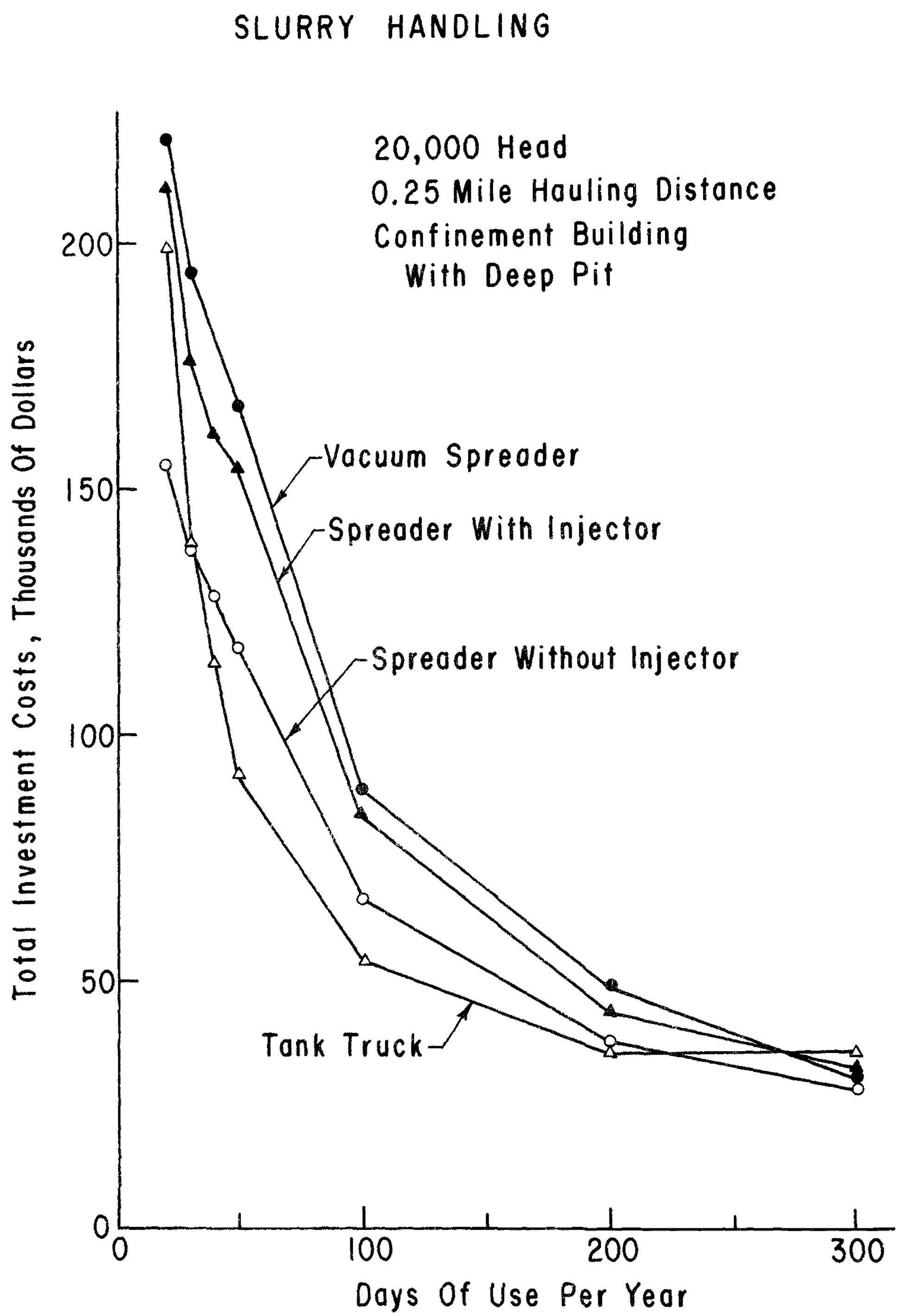


Figure 52. Slurry handling: investment cost vs. days of use per year for 20,000 head

Table 37. Total Operating Costs for Various Slurry Handling Systems for 500 Head Confinement Building, 10 to 30 Days of Use per Year, 0.25 to 2.0 Mile Hauling Distance

Days per Year	Hauling Distance	Pull-Type Vacuum Spreader	Pull-Type Spreader without Injector	Pull-Type Spreader with Injector	Tank Truck with Spreader
10	0.25	.0085	.0067	.0092	.0079
	1.0	.0108	.0089	.0126	.0096
	2.0	.0140	.0120	.0171	.0107
20	0.25	.0083	.0065	.0089	.0079
	1.0	.0105	.0085	.0124	.0086
	2.0	.0134	.0118	.0164	.0113
30	0.25	.0079	.0065	.0089	.0079
	1.0	.0099	.0085	.0117	.0086
	2.0	.0134	.0111	.0164	.0113

numbers of machines for the various systems are presented in tables in the Appendix.

Confinement buildings with a shallow pit from 18 to 24 inches deep can use either a cable scraper system to remove the waste or use an oxidation rotor to stir oxygen into the waste and convey it around the pit. The costs for operating a cable scraper system for 500 head are presented in Table 38 as affected by days of use per year. In this analysis, it is assumed that the hauling distance is one-quarter mile for the liquid spreader. One of the assests of this system is the daily scraping which reduces the odor and fly problem. The system consists of a cable scraper, a pump and tractor or electric motor, and a pull-type liquid spreader without injector. The total operating and investment costs remain relatively constant regardless of the days of use per year. The operating costs for the system are $0.0102 per animal day and the total investment cost is $12,074. The total operating costs for a 20,000 head unit utilizing a cable scraper, pump and tractor, and various liquid spreaders are presented in Table 41. The cable scraper alone costs $2,280. A pull-type spreader without injector had the least operating costs of the four different hauling systems. The truck spreader had the second lowest operating costs as a system.

WASTE TREATMENT COSTS

Oxidation Rotor

Some confinement buildings with shallow pits contain an oxidation rotor for treating the animal wastes. The costs for operation of a rotor were based upon the design presented in Chapter III on Waste Treatment Alternatives. The basic cost of the oxidation rotor was $2,228. As indicated in Table 39, the operating cost declined slightly as the number of animals in the feedlot increased from 500 to 20,000 from $0.0568 per animal day to $0.0488 per animal day.

Lagoon

Another treatment for animal waste is to provide a lagoon. In Table 40 some anaerobic lagoon costs for 500 to 50,000 head capacity are presented. The total volume in cubic feet, total area in square feet, investment cost in dollars, and the operating cost in dollars per animal day are presented. The investment costs increase linearly and, of course, are dependent upon the construction costs and the volume of earth that has to be removed or transported to create the lagoon. The operating costs remain constant at

Table 38. Total Operating Costs per Animal Day for Cable Scraper, Pump and Tractor, and Various Liquid Spreaders for 20,000 Head, 0.25 Mile Hauling Distance, 200 to 350 Days per Year

Days per Year	Cable Scraper Costs per Animal Day	Pump Cost* per Animal Day	Total Cost Pull-Type Spreader	Total Cost Pull-Type Vacuum Spreader	*** Total Cost Pull-Type Spreader with Injector	Total Cost Truck Spreader
200	.0037	.0004	.0082	.0098	.0094	.0090
250	.0037	.0004	.0081	.0090	.0098	.0090
300	.0037	.0004	.0081**	.0090**	.0098	.0090
350	.0037	.0004	.0081**	.0090**	.0100	.0090

* Total pump costs are approximately the same for tractor driven or electric driven pump
** Spreaders need replacing before 300 days of use at 10 hours per day
*** External pump and power source not needed

Table 39. Costs for Oxidation Rotor for Confinement Buildings, 500 to 20,000 Head

Number of Animals	Number of Rotors	Cost per Animal Day	Total Investment Cost
500	3	.0568	6,684
1,000	6	.0568	13,368
2,000	11	.0521	24,508
5,000	26	.0493	57,928
10,000	52	.0493	115,856
20,000	103	.0488	229,484

Table 40. Lagoon Costs for 500 to 50,000 Head

Number of Animals	Total Volume ft^3	Total Area ft^2	Investment Cost, $	Operating Cost per Animal Day, $
500	750,000	57,900	8,300	.0084
1,000	1,500,000	106,300	16,700	.0084
2,000	3,000,000	198,900	33,300	.0084
3,000	4,500,000	289,000	50,000	.0084
4,000	6,000,000	378,000	66,700	.0084
5,000	7,500,000	466,300	83,300	.0084
10,000	15,000,000	901,100	166,700	.0084
20,000	30,000,000	1,757,700	333,300	.0084
30,000	45,000,000	2,607,000	500,000	.0084
40,000	60,000,000	3,452,400	666,700	.0084
50,000	75,000,000	4,295,400	833,300	.0084

$0.0084 per animal day for a lagoon depth between 12 and 20 feet.

Vibrating Separator

A vibrating separator can be used to remove solids from slurries or flushed wastes. According to results in California for dairy waste flushing systems, solids are reduced from 40% for the liquified waste to 36% for the effluent. This indicates about a 10% reduction in total solids for a 20 mesh screen. It is possible that more solids may be taken out with a higher mesh screen, however, the flow of the liquids through the screen may not be as satisfactory. The washed manure or solids contain considerable fiber content and can be used for bedding purposes. This system would be particularly useful where hay is included in the ration.

The daily operating cost for a vibrating separator for a slurry with 90% moisture content is approximately $0.0011 per animal day for 1,000 head lot and $0.00015 per animal day for a 10,000 head lot. For a 20,000 head feedlot, two separators, costing about $2,700 each, would have to be used eight hours per day. These costs assume 365 days per year operation.

EVAPORATION

An evaporation lagoon can permit moisture from the animal waste to evaporate as rapidly as possible. Major factors affecting the size and costs of evaporation lagoons are the annual average precipitation for the area, the annual average lake evaporation, the moisture content of the slurry, the depth of the lagoon, and the number of animals that the lagoon serves. The effect of these various factors on the lagoon operating and investment costs are illustrated in Figures 53 through 56. The data for these curves are in the Appendix. The shallower depths offer the possibility of having the most water evaporate, leaving fairly solid residue for possible cleaning out during dry periods of the year. However, the lagoon should be deep enough to contain the runoff from large storms or provide for a storage period during times of year when the evaporation rate is low. Areas of the country where there is a large moisture deficit (annual average evaporation minus average precipitation) have the greatest potential for using this method for ultimate disposal of the waste. As the moisture content of the slurry rises, the operating and investment costs rise. The increase in cost is particularly sharp as the moisture content goes above 95%, wet basis.

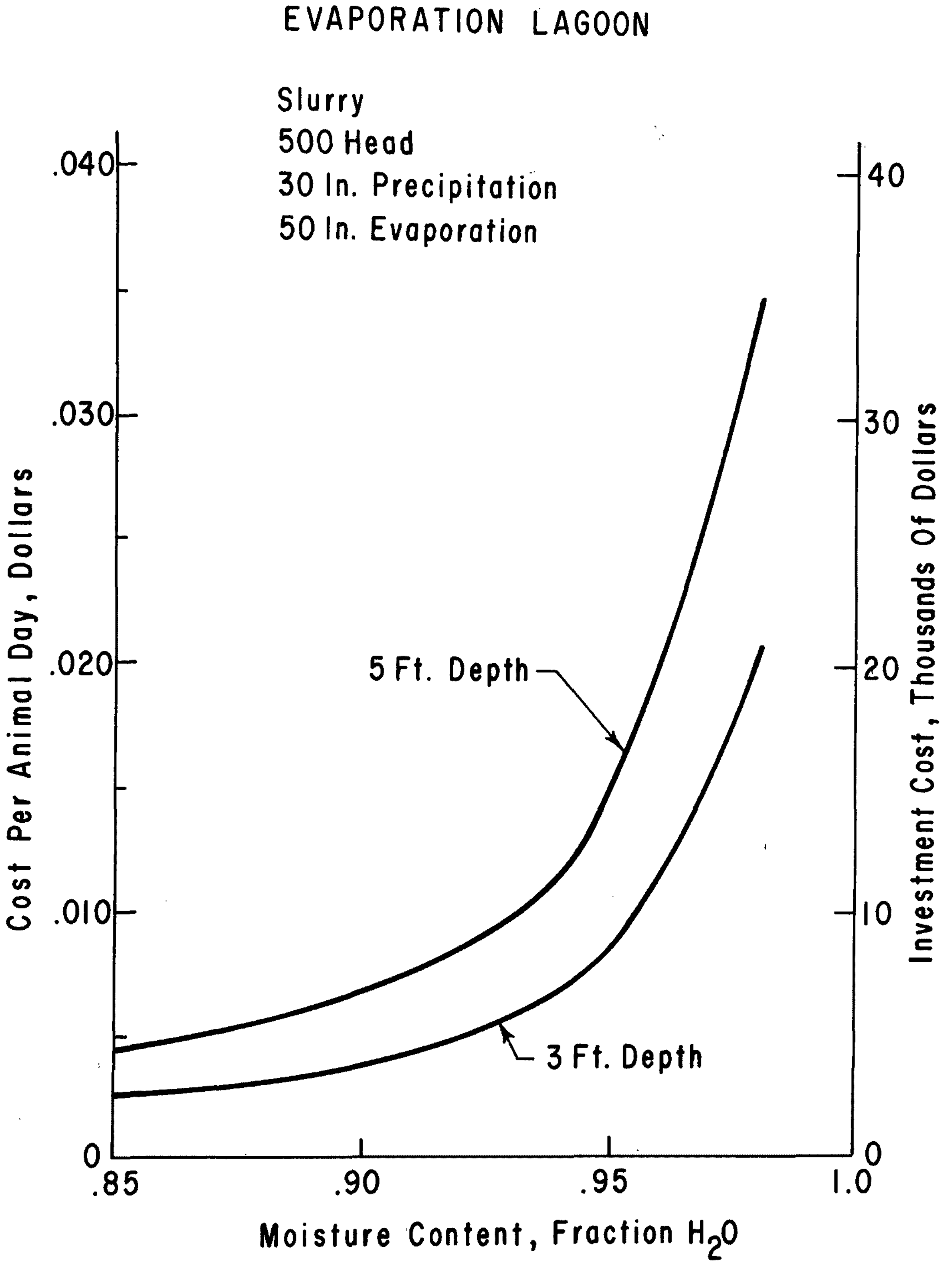


Figure 53. Evaporation lagoon: cost per animal day vs. moisture content of slurry

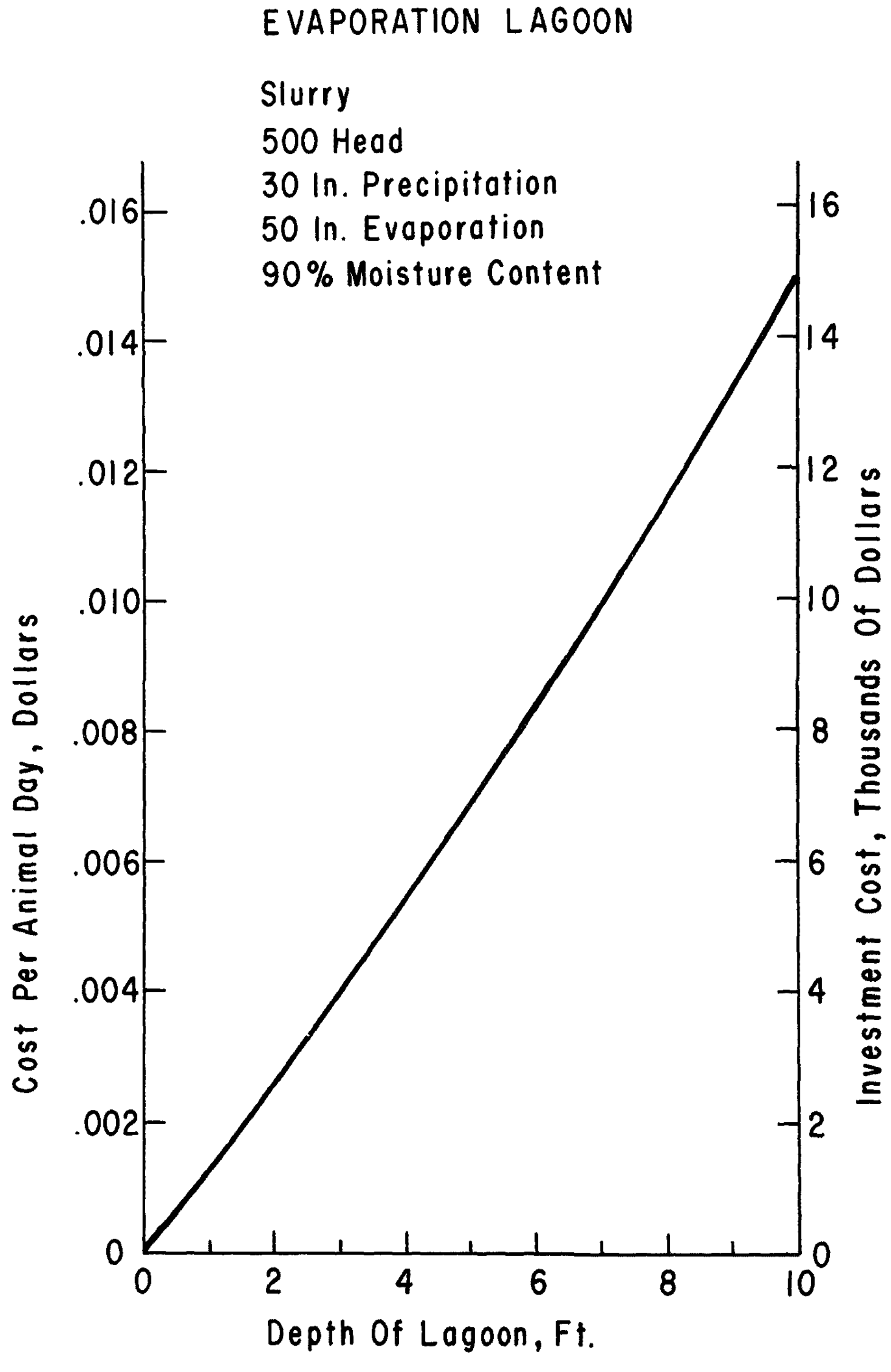


Figure 54. Evaporation lagoon: cost per animal day vs. depth of lagoon

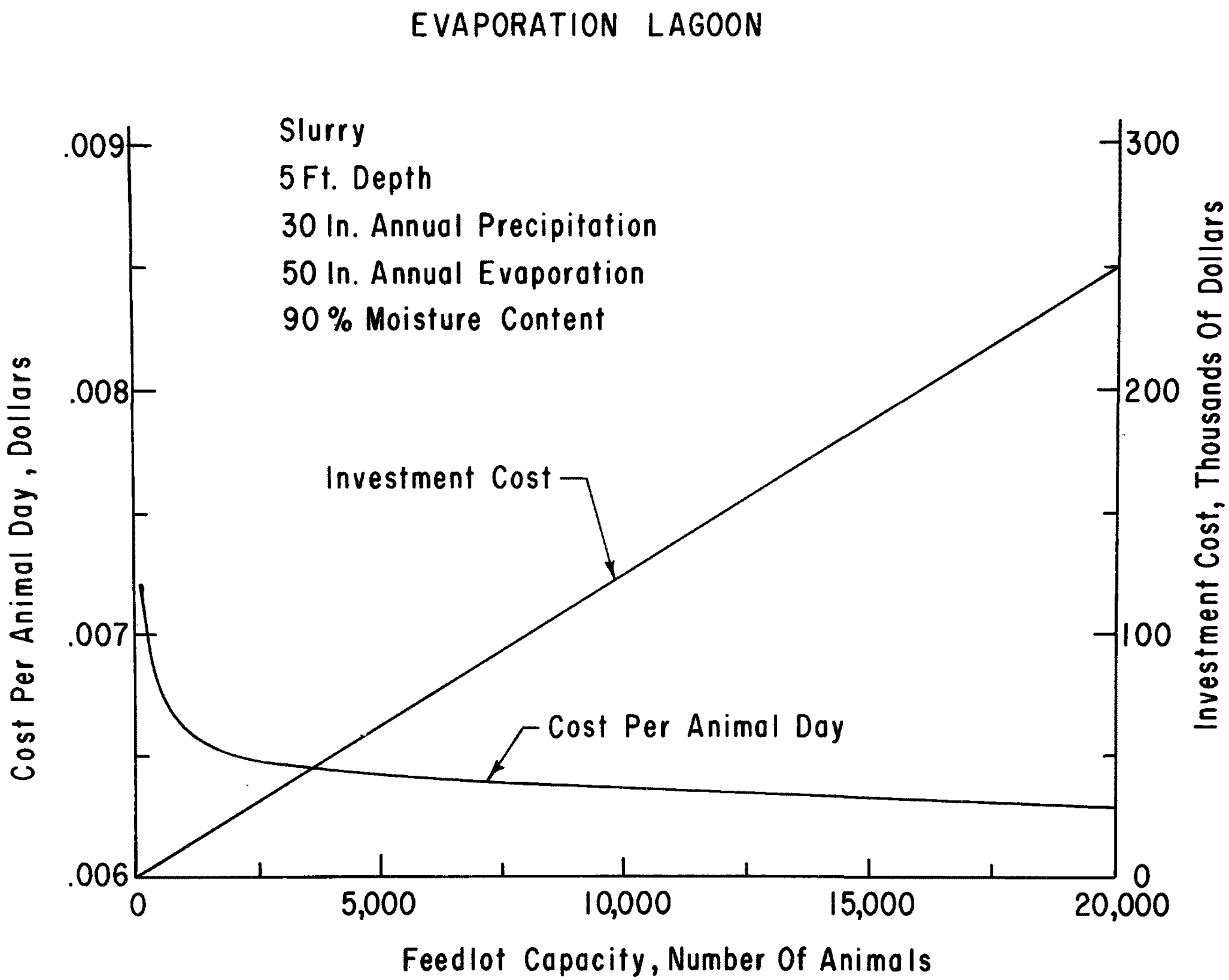


Figure 55. Evaporation lagoon: cost per animal day and investment cost vs. feedlot capacity

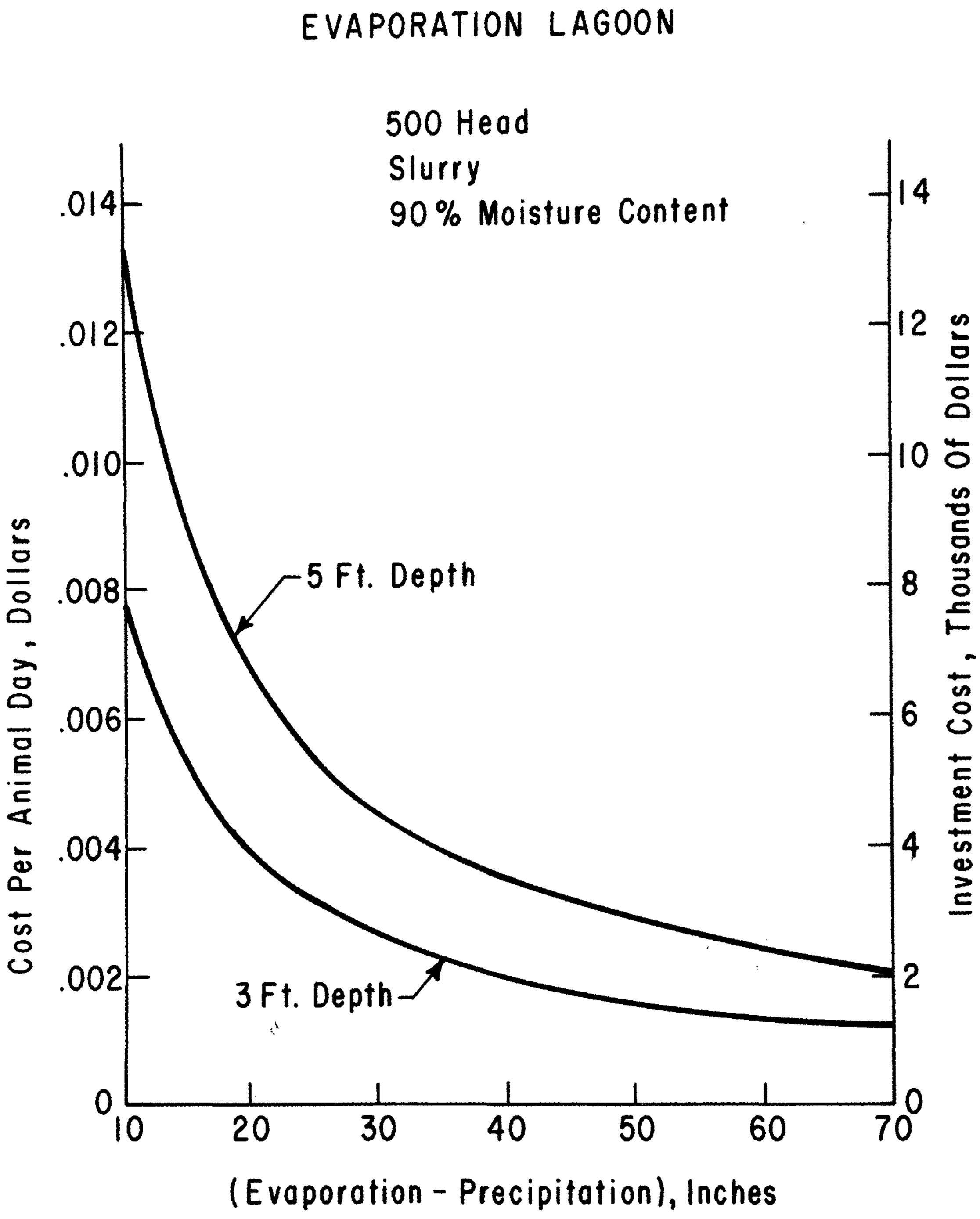


Figure 56. Evaporation lagoon: cost per animal day vs. moisture deficit

MANURE IRRIGATION

One possible means of transporting the slurries to the field for ultimate disposal is to use a chopper pump, four inch aluminum irrigation pipe, and a big gun type of sprinkler. The cost of such a system is $4,666, assuming one-quarter mile distance to convey the material. The system has the advantage of low labor requirements and also slightly increased evaporation because the slurry is sprayed into the air.

The operating cost of the system is approximately $0.0033 per animal day for a 500 head capacity lot and approximately $0.0010 per animal day for above 5,000 head capacity lot. Only one system is required below a 5,000 head lot. At 10,000 head, a second system will have to be used if manure irrigation is practiced for 300 days per year or less. If manure irrigation is practiced 350 days per year, a second system is not needed until 20,000 head capacity is reached.

The moisture content of the slurry also affects the cost of the system. Assuming an 85% slurry can be pumped satisfactorily, the operating cost was $0.0025 per animal day. At a 90% moisture content slurry, the operating cost was $0.0033 per animal day, and by the time the slurry reached a moisture content of 98% the operating cost had increased to $0.0056 per animal day. To make a slurry having 90% moisture content, 215 pounds of water have to be added to an 85% slurry initially weighing 100 pounds. Thus, about three times the volume has to be pumped for 98% moisture content slurry as for 85% content slurry. A moisture content of around 90% is suggested for easy pumping. This represents an additional 50 pounds of water from the initial 100 pounds of 85% moisture content slurry. This represents an increase in volume to be pumped of about 35%.

WASTE MANAGEMENT COSTS

FOR PARTIAL CONFINEMENT BUILDINGS

Partial confinement buildings are those in which shelter is provided and the animals have access to an outside lot where the feeding is usually done. The building floors and outside lot may be either dirt or paved. However, for this analysis it is assumed that the outside lot is paved, thus providing better conditions for the animals during inclement weather. A space allowance of 30 square feet per animal and 75 square feet per animal are commonly used for the shelter and outside lot respectively.

The facility and waste handling costs for the partial confinement housing system are presented in Table 41. Two types of shelters are used in this analysis: one with a concrete floor, gable truss roof, and one open side constructed of wood framing; and the other building with a dirt floor, gable truss roof, and open front with wood frame construction. The calculated costs for these buildings were $23,700 for the concrete floor building and $13,900 for the dirt floor building. The operating cost for these buildings was $0.0257 and $0.0151 per animal day.

Three types of lots were compared:

1. Paved lot with 75 square feet per animal and a mechanical feed bunk.

2. Paved feedlot with 75 square feet per animal with a fenceline feed bunk.

3. Paved feedlot with 50 square feet per animal with a mechanical feed bunk.

The respective costs were $23,300, $21,820, and $17,400. The operating costs for the respective lots were $0.0255, $0.0239, and $0.0191.

In determining the handling costs for cleaning the building, the waste removal operation was assumed to use 20 days per year with a one-quarter mile hauling distance for a tractor with front-end loader plus a pull-type spreader. Handling costs for the outside lot were determined by assuming that the lot was cleaned daily, one-quarter mile hauling distance, and using a tractor scraper with front-end loader plus a pull-type spreader. The operating cost for removing the wastes from the 500 head lot was $0.0014 per animal day for the shelter and $0.0048 per animal day for the outside lot. The total investment cost for the equipment needed to clean the building was $10,570 and to clean the lot was $11,247. The total cleaning costs including both the lot and the shelter was $0.0062 per animal day.

For a typical 500 head system utilizing a concrete floor building, paved feedlot for 75 square feet per animal with mechanical feed bunk, the total investment cost for facilities and machinery is approximately $58,300 and the operating cost is $0.0643 per animal day.

This did not include the daily bedding cost. A study of bedding costs for a manure scrape building in west central Minnesota by Bates (6) indicated that bedding cost was

Table 41. Facility and Waste Handling Costs for Partial Confinement Facility with Outside Lot and Shelter (32' x 473') for 500 Head

Facility Costs	Concrete Floor, Gable Trussed Roof, One Open Front, Wood	Dirt Floor, Gable Trussed Roof, One Open Front, Wood
Cost/lin. ft	15.15	15.08
Floor cost/ft	18.08	3.68
Waterers cost/ft	1.57	1.57
Lighting cost/ft	0.30	0.30
Material cost/ft	35.10	20.63
Total material cost	16,601	9,757
Total cost (30% labor)	23,723	13,943
Cost per animal day	0.0257	0.0151

Lot Costs	Paved Feedlot for 75 ft^2/ Animal with Mechanical Feed Bunk	Paved Feedlot for 75 ft^2/ Animal with Fenceline Feed Bunk
Lot area (ft^2)	67,220	67,220
Pen costs	23,321	21,821
Cost per head	46.64	43.64
Cost per animal day	0.0255	0.0239

Table 41. Continued

Lot Costs	Paved Feedlot for 50 ft^2/Animal with Mechanical Feed Bunk
Lot area (ft^2)	51,720
Pen costs	17,442
Cost per head	34.88
Cost per animal day	0.0191

Handling Costs	Handling Costs for Cleaning Building, 20 Days per Year, 0.25 Miles Hauling Distance, Tractor with Front-End Loader plus Pull-Spreader	Handling Costs for Daily Cleaning of Outside Lot, 0.25 Miles Hauling Distance, Scraper Tractor, with Front-End Loader plus Spreader
Scraper		
no.		1
cost/an. day		.00007
Front-end loader		
no.	1	1
cost/an. day	.0011	.0031
Spreader		
no.	1	1
cost/an. day	.0003	.0010
Total cost/an. day	.0014	.0048
Total investment cost	10,570	11,247

approximately $4 per head for a conventional housing system and $5 per head for a manure scrape building. This is for a housing system with the animals housed between 250 and 270 days. Thus, the cost of bedding is approximately $.02 per animal day. Therefore, the total operating cost is approximately $0.115 per animal day for the facility, waste handling, and bedding costs.

TOTAL SYSTEMS COSTS

The total systems cost for slurry handling from 500 head capacity confinement buildings with deep pits are summarized in Table 42. Based upon this analysis, the cold confinement building with a wood frame, interior poles and a fenceline feed bunk using a spreader without injector was the minimum cost system. It had a total handling and facility operating cost of $0.0302 per animal day and an investment cost of $30,773. The daily waste handling cost per animal represented about 1/5 of the daily total system operating cost. The waste handling investment was about 1/3 of the total system investment cost.

The total system cost for slurry handling from a 500 head confinement facility with shallow pit and cable scraper, assuming 300 days of machine use per year, was minimum for the cold confinement building with the wood frame and outside fenceline feed bunk, Table 43. The spreader without injector was the lowest cost waste handling system with an operating cost of $0.0142 per animal day and an investment cost of $47,773.

For all confinement building waste management systems, the waste handling costs were approximately 1/4 of the total system operating cost and the waste handling investment cost was approximately 1/5 of the total investment for the system. Thus, facility costs are the major costs for slurry handling systems.

The waste handling cost could be further reduced by using a manure irrigation system. For the deep pit buildings, the operating cost could be reduced from $0.0065 per animal day for the spreader without injector to approximately $0.0033 per animal day for the manure irrigation system or approximately one-half. The investment costs are reduced about one-half from $9,100 to approximately $4,700.

The total system costs for solid waste handling for a 500 head confinement building with a solid floor are summarized in Table 44. The cold confinement, steel shell building with a dirt floor and wood fenceline feed bunk and using a handling system consisting of a tractor loader and pull

Table 42. Total System Costs for Slurry Handling from 500 Head Capacity Confinement Buildings with Deep Pit, 0.25 Mile Hauling Distance, 20 Days of Machine Use per Year

Facility Costs	Warm, Steel Shell, Mechanical Feed Bunk	Cold, Wood Frame, Fenceline Feed Bunk Inside	Cold, Wood Frame, Partial Slotted Floor, Mechanical Feed Bunk
Cost/an. day	.0521	.0237	.0401
Investment cost	48,961	21,627	35,579
Total Handling & Facility Costs			
Vacuum spreader w/o injector			
Cost/an. day	.0604	.0320	.0484
Investment cost	56,616	29,282	44,234
Spreader w/o injector			
Cost/an. day	.0586	.0302	.0466
Investment cost	58,107	30,773	45,725
Spreader with injector			
Cost/an. day	.0610	.0326	.0490
Investment cost	60,709	33,375	47,627
Truck spreader			
Cost/an. day	.0609	.0325	.0489
Investment cost	60,009	32,675	46,627

Table 43. Total System Costs for Slurry Handling from a 500 Head Confinement Facility with Shallow Pit and Cable Scraper, 0.25 Mile Hauling Distance, 300 Days of Machine Use per Year

Facility Costs	Warm, Steel Shell, Mechanical Feed Bunk	Cold, Wood, Frame, Fenceline Feed Bunk Inside	Cold, Wood Frame, Inside Fenceline Feed Bunk
Costs/an. day	.0387	.0305	.0469
Investment cost	36,583	37,060	43,149
Total Handling & Facility Costs			
Vacuum spreader w/o injector			
Cost/an. day	.0542	.0460	.0624
Investment cost	47,455	47,932	54,021
Spreader w/o injector			
Cost/an. day	.0494	.0412	.0576
Investment cost	47,296	47,773	53,862
Spreader with injector			
Cost/an. day	.0519	.0437	.0601
Investment cost	48,450	48,927	55,016
Truck spreader			
Cost/an. day	.0513	.0431	.0595
Investment cost	53,366	53,843	59,932

Table 44. Total System Costs for Solid Waste Handling from 500 Head Capacity Building with Solid Floor, 0.25 Mile Hauling Distance, 20 Days of Machine Use per Year*

Facility Costs	Warm, Concrete Floor, Steel Shell, Mechanical Feed Bunk	Cold, Wood Frame, Dirt Floor, Canvas and Screen Sides, Concrete Fence-line Feed Bunk
Cost/an. day	.0435	.0210
Investment cost	41,071	19,137
Total System Cost		
Tractor loader + pull spreader		
Cost/an. day	.0497	.0272
Investment cost	45,291	23,357
Tractor loader + dump truck		
Cost/an. day	.0521	.0296
Investment cost	52,681	30,747
Tractor loader + spreader truck		
Cost/an. day	.0510	.0285
Investment cost	55,781	33,847

*Bedding costs of $.02/animal day could be added to the total systems costs if bedding cost $15/ton

Table 44. Continued

Facility Costs	Cold, Steel Shell, Dirt Floor, Wood Fenceline Feed Bunk	Cold Shelter (30 ft^2/animal), Concrete Floor, Paved Lot (75 ft^2/ animal, Mechanical Feed Bunk
Cost/an. day	.0140	.0512
Investment cost	12,932	47,044
Total System Cost		
Tractor loader + pull spreader		
Cost/an. day	.0202	.0574
Investment cost	17,152	51,264
Tractor loader + dump truck		
Cost/an. day	.0226	.0598
Investment cost	24,542	58,654
Tractor loader + spreader truck		
Cost/an. day	.0215	.0587
Investment cost	27,642	61,754

*Bedding costs of $.02/animal day could be added to the total system costs if bedding cost $15/ton spreader had the minimum cost. The total system operating costs were $0.0202 per animal day and the total system investment costs were $17,152. This solids handling system was the least cost system of all the systems analyzed in the study. The building had the lowest operating and initial investment costs which, combined with relatively low waste handling costs, made it an attractive system. The major problem with this system is the high labor requirement and ultimate disposal of the solid waste collected. The analysis assumes that the wastes are placed on adjacent fields. The cost of bedding should be added to the solid waste handling costs, approximately $0.02 per animal day. With bedding costs added, the solid waste handling costs were approximately the same as the slurry systems using the shallow pit and cable scraper. The slurry handling system using the deep pit and spreader without injector is approximately $0.01 per animal day cheaper than the solid waste handling system or the cable scraper system.

Instead of a field disposal system for the slurry, an evaporation lagoon could be used in areas where the annual lake evaporation exceeds the annual average precipitation. For a 500 head feedlot and a 90% moisture content slurry, the operating costs of an evaporation lagoon are between $0.0080 per animal day and $0.0020 per animal day, depending upon the evaporation-precipitation difference. The pumping and conveyance or transporting costs are approximately $0.0030 per animal day with an investment cost of $4,000 for 500 head. Thus, an evaporation lagoon for slurry disposal costs less than $0.01 per animal day with an investment of approximately $8,000 for a 500 head unit. There may, however, be some odors arising from this system because of the high solids content and bacterial action.

SECTION IV

SYSTEM ANALYSIS

CHAPTER IX

EVALUATION OF WASTE MANAGEMENT SYSTEMS

In evaluating a waste management system, many factors have to be considered. The systems have to be analyzed on the basis of economic considerations, engineering feasibility, and pollution control. The engineering design aspects were discussed in Chapters V and VII on open feedlots and confinement buildings and were based upon current research and the state of the art. In Chapters VI and VIII, an economic analysis was made of the various waste handling, treatment, and ultimate disposal components. Operating costs and investment costs were calculated as affected by various factors, such as size of feedlot, hauling distance, days of use per year, and rainfall.

In this chapter, the systems will be viewed as to their potential for controlling air and water pollution. Systems that appear workable will be emphasized. Some systems are still in the research stage and some may have odor problems or low pollution control potential and therefore will not be emphasized. This does not mean that systems that have been excluded will not be satisfactory. They may work under a particular set of circumstances or may not have been observed by the authors. This evaluation is intended mainly as a guideline.

In this investigation, waste management systems were divided into two broad classifications: open feedlot waste management systems and confinement building waste management systems. In this evaluation, both systems will be considered separately and then the two systems will be compared. Some factors that may affect the design of feedlot and waste management systems or a choice of the systems will be discussed.

OPEN FEEDLOT WASTE MANAGEMENT SYSTEMS

Open feedlots are used in the western sections of the United States for year-round feeding of beef animals. Generally they have no environmental control to improve environmental conditions for animal production, except some have shades, wind breaks, or mounds. Open feedlots are generally unpaved, although paved feedlots permit the animal density to be increased. Through proper design and management, water pollution arising from open feedlots can be abated.

For open feedlots, two waste management systems, solid waste and runoff, have to be considered. The solid wastes have to be removed from the feedlot surfaces periodically, usually at the end of each feeding period. The runoff-carried wastes have to be controlled in such a manner as not to pollute streams or water supplies. For paved feedlots, flushing and slurry handling systems offer another possibility. Flushing during warm weather or in warm climates can be done every few days to remove the waste accumulated in the lot. The flushed wastes can then be handled by slurry hauling methods or pumped to fields.

The ultimate disposal of the waste is of prime concern for both the solids handling system and the runoff or flushing system. It should be ultimately placed in a location where it will not contribute to the pollution of surface or ground waters. At the present time, there are two principle choices as to the fate of the waste material:

1. The material can be utilized for crop production and the nutrients re-cycled in the form of animal feed.

2. The wastes can be disposed in the most economical manner without consideration for economic return from the waste.

Optimum Feedlot Design and Waste Management Systems

The layout of an unpaved open feedlot is illustrated in Figure 57. This feedlot is designed for pollution control with recycling of the waste materials through crop production. Other systems may work equally as well. However, this illustration points out some of the main features that are desirable for pollution control of the runoff-carried waste. Several of the areas of the feedlot are not given in detail, e.g., feed mill and grain storage area, receiving and shipping area, maintenance area, office, cattle handling and corral facilities, and pen and feed road locations. The main features on this layout are the drainage paths and treatment and ultimate disposal of the runoff-carried wastes. This feedlot was assumed to be located on a quarter section of land with one-half section available for crop production and irrigation. This feedlot would be capable of handling between 20,000 and 30,000 head at one time.

The first consideration in controlling the runoff from an open feedlot is to divert all outside water from entering the feedlot and becoming polluted. This is done by diversion ditches. Next, an adequate pen drainage system is needed (Chapter II). Collection drains then have to be designed to receive the runoff from the pens and convey it

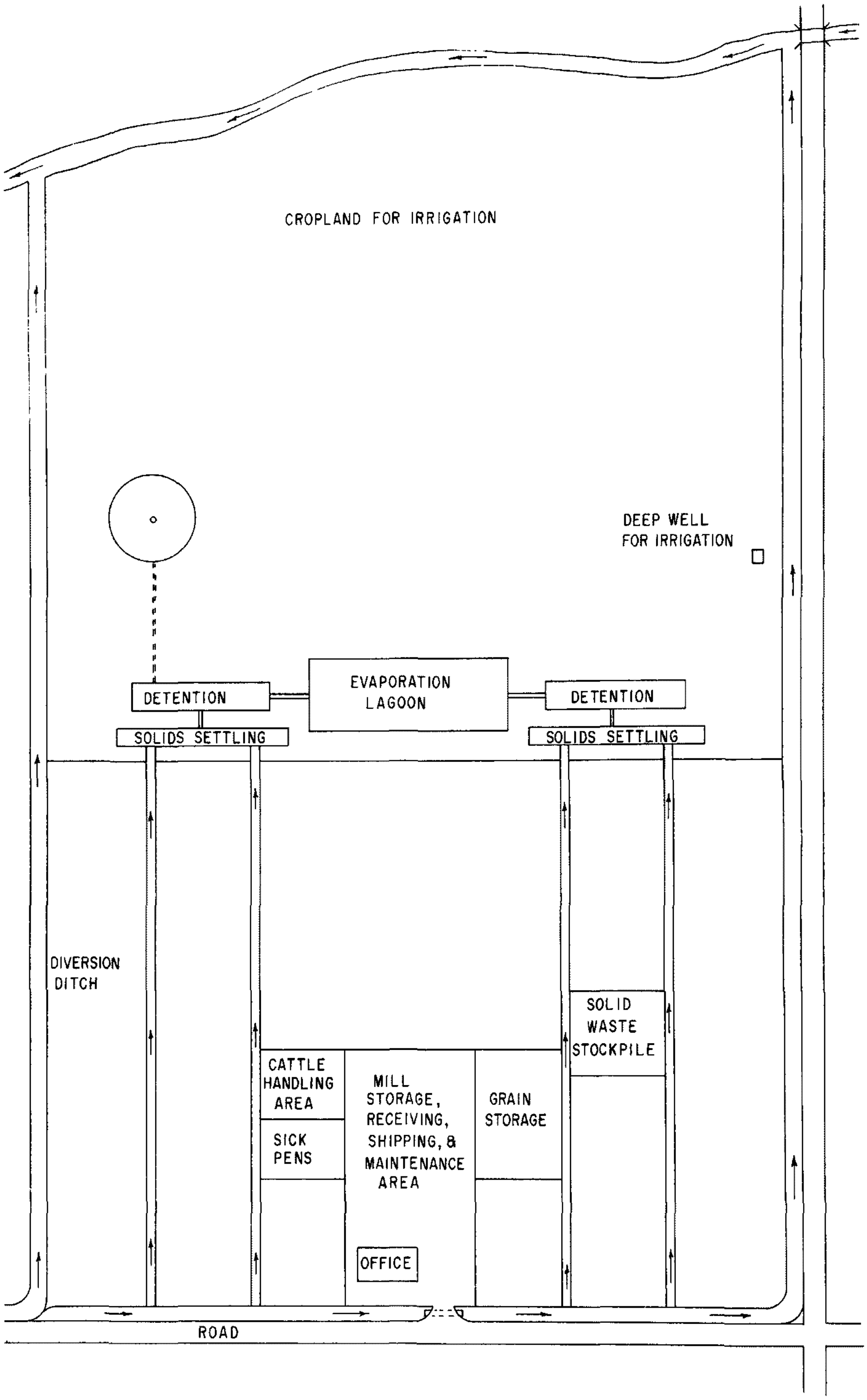


Figure 57. An open feedlot layout with runoff control

to a solids settling basin where the settleable solids are separated from the liquid waste. The collection ditch may also serve as a solids settling basin. The solids settling basins need to be cleaned periodically after the liquids have had a chance to drain away and evaporate. The liquids then go on to the storage reservoirs where the waste can be pumped within a few days for irrigation purposes or, in case of extreme rainfall conditions, go to evaporation lagoons. Evaporation lagoons can be used primarily in the Great Plains states (North Dakota to Texas) and some other western states. East of the Great Plains states, storage structures will have to be designed large enough to contain the runoff-carried wastes during wet periods of the year and then dispose of the wastes by irrigation during more optimum periods of the year.

Two types of irrigation systems can be used for disposing of the runoff-carried wastes:

1. Sprinkler irrigation system, primarily using the big gun type sprinkler head.

2. Gated pipe irrigation system.

The irrigation systems should have access to fresh water from a deep well, a lake or detention pond that contains unpolluted runoff water. Fresh water will be needed for irrigation during dry seasons, to dilute the slurry or runoff-waste water, and to clean irrigation equipment. Tail water would have to be collected and recycled if it contained cattle waste or lagoon effluent.

A summary of the costs for this unpaved open feedlot with pollution control is presented in Table 45. The total system investment cost is approximately $420,000 and the operating cost is $0.133 per animal day. This does not include land costs or costs associated with the feed mill, feed storage, office, maintenance area, or specialized cattle handling facilities. The feeding facilities amount to about 65% of the investment cost, the runoff control system about 10%, and the solids handling about 25% of the total system costs. This assumes that the waste will be applied to the fields for crop production. It does not assume an economic return from the nutrients in the waste material. It assumes a three inch design rainfall, a 20 inch annual precipitation and approximately 60 inches of annual lake evaporation which approaches conditions found in the southern High Plains beef feeding areas.

Areas with low annual precipitation and high evaporation have a good potential for using evaporation lagoons for

Table 45. Summary of Costs for Unpaved Open Feedlot with Pollution Control for 20,000 Head, 3 Inch Design Rainfall, and 20 Inch Annual Precipitation

Feeding Facilities	Investment Cost	Operating Cost, $/animal Day
Pen, bunk, waterers, roads	315,400	.0086
Runoff Control Systems		
Pen drainage and collection	20,000	.00016
Settling basin + detention reservoir	16,800	.00043
Settling basin cleaning (drag line leased)	------	.00030
Irrigation (241 acres)	23,260	.00050
Total runoff control costs	60,060	.00139
Solids Handling		
For cleaning and stockpiling only Elevating scraper (100 days/yr)	37,000	.0014
For cleaning, hauling and field application Commercial loader + spreader truck	45,000	.0033
Total System Costs		
For field application of all wastes	420,460	.0133

*This does not include land costs or costs associated with feed mill, feed storage, office, or specialized cattle handling facilities disposing of liquid runoff wastes. The operating costs are below $0.0018 per animal day for areas that have greater than 30 inch moisture deficit annually. The costs are 50% higher for areas that have a 20 inch moisture deficit and approximately three times as great for areas with 10 inch moisture deficit. With evaporation ponds, there is no possibility of gaining further benefits from the water and nutrients and there may also be some odor problems at times. For a 40 inch moisture deficit area, the evaporation lagoon area is approximately one-third of the total feedlot area.

Solids Handling

For 20,000 head and one-quarter mile hauling distance, the elevating scraper had the lowest operating cost of the systems examined for over 50 days of use per year. Below 50 days of use per year, the rotary scraper with the tractor had the lowest operating cost.

The size of feedlot also affected the operating costs of the solid waste handling systems. Above a 10,000 head capacity lot, the elevating scraper had the lowest operating cost per animal day for one-quarter mile hauling distance and 100 days of use per year. Below 10,000 head, the rotary scraper with tractor had the lowest operating cost per animal day.

For distances below two miles, an elevating scraper had the lowest operating cost. Over two miles, the commercial loader plus spreader truck has the lowest cost for hauling wastes to fields for a 20,000 head feedlot.

The optimum choice of equipment for removing, hauling and depositing solid waste at the ultimate disposal site depends upon the size of the feedlot, days of operation per year, and hauling distance. For feedlots over 10,000 head capacity, the rotary scraper and elevating scraper have cost advantages for short hauls and stockpiling. For distances over two miles, the commercial loader plus spreader truck has the lowest operating cost.

Paved Feedlots

While paved feedlots may have higher facility costs, they do offer some potential for pollution control. With paved feedlots, ground water pollution underneath the feedlot surface is abated. Also, there is reduced area for runoff and therefore any runoff control structure is smaller and less costly than those for unpaved feedlots. The solid waste handling costs are similar to the costs for unpaved feedlots.

Paved feedlots allowing 50 sq ft per animal reduce the total pen area by one-third compared to the unpaved feedlots with 200 sq ft per animal. However, the investment cost of $32.11 per animal for paved lots, pen and feeding facilities is about double that of the unpaved feedlots. Likewise, runoff control systems costs for paved feedlots average about one-third as much as for the unpaved feedlots because one-third the amount of runoff has to be handled.

Paved feedlots also offer the possibility for using the liquid flushing system. These can be used in climatic areas where freezing conditions are seldom encountered for more than a day or two at a time. This system would have a relatively low labor requirement as flushing would be done periodically, such as every week to 10 days. By flushing different pens each day, there would be an almost continuous flow of the waste into a treatment system. This system also offers the possibility of re-using some of the waste water for flushing purposes. Excess water can be utilized by irrigating crop or pasture land on a nearly year-round basis. Despite some of the apparent pollution control advantages, this system has not been use prevalently. Many of the northern or high rainfall areas of the country could not use this system on a year-round basis.

Land Area Requirements

For an unpaved 20,000 head feedlot with 200 sq ft per animal, the pen area is approximately 108 acres. With the total drainage area plus pollution control area included, the feedlot area becomes 144 acres. The land area required for irrigation from the runoff will be 290 acres for an area with a 20 inch annual precipitation. The total land area required for this unpaved feedlot with a pollution control system is approximately 434 acres. This does not include a solids disposal area. A summary of the land area requirements and facility costs for various components of beef feeding and waste management facilities for 20,000 head are presented in Table 46.

A comparable paved feedlot for 20,000 head and 50 sq ft per animal would require 37.3 acres for the pens only. With the total feedlot area and pollution control structures area added, the total runoff area becomes 50 acres. The number of acres required for irrigation for 20 inch annual precipitation for this system is 101 acres and the total acreage is 151 acres. Thus, the total land area for

Table 46. Land Area Requirement and Facility Costs for Various Components of Beef Feeding and Waste Management Facilities for 20,000 Head

Feedlot Component	Land Area, Acres	Investment Cost, Dollars
Feeding & Housing Facilities:		
Open feedlot unpaved		
100 ft^2/head	60.9	293,400
150 ft^2/head	84.5	304,400
200 ft^2/head	108.2	315,400
400 ft^2/head	202.7	359,400
Open feedlot paved		
50 ft^2/head	37.2	642,300
Partial confinement building (30 ft^2/head) and outside lot (50 ft^2/head)	79.1	1,255,400
Cold confinement buildings		
dirt floor, 30 ft^2/head	37.2	766,480
slotted floor, deep pit, 20 ft^2/head	20.9	865,080
slotted floor, shallow pit, cable scraper, 20 ft^2/head	28.4	1,504,000
Warm confinement building, 20 ft^2/head	29.3	1,960,000
Runoff Control Structures:		
Detention pond only		
2 inch rain	22.3	4,170
4 inch rain	23.3	12,880
6 inch rain	24.8	22,540

Table 46. Continued

Feedlot Component	Land Area, Acres	Investment Cost, Dollars
Batch detention, Colorado		
2 inch rain	67.2	4,170
4 inch rain	162.7	12,880
Settling basins & detention pond		
2 inch rain	35.7	13,680
4 inch rain	36.7	20,300
6 inch rain	37.8	27,630
Broad basin terraces		
2 inch rain	27.2	5,920
4 inch rain	35.6	14,800
6 inch rain	44.0	23,680
Evaporation lagoon		
10 inch annual rainfall		
20 inch moisture deficit	43.3	53,191
40 inch moisture deficit	21.6	26,754
60 inch moisture deficit	14.4	17,918
20 inch annual rainfall		
20 inch moisture deficit	86.6	105,936
40 inch moisture deficit	43.3	53,191
30 inch annual rainfall		
20 inch moisture deficit	130.0	158,609
40 inch moisture deficit	65.0	79,577
Treatment:		
Lagoon, 1500 ft^3/animal	170.2	333,333

Table 46. Continued

Feedlot Component	Land Area, Acres	Investment Cost, Dollars
Ultimate Disposal:		
Field irrigation runoff		
10 inch annual rainfall	120.4	23,260
20 inch annual rainfall	240.7	23,260
30 inch annual rainfall	361.7	23,260
40 inch annual rainfall	481.5	23,260
Field disposal of solid wastes		
open lot		
15 tons/acre	3334	
30 tons/acre	1667	
solid floor confinement building		
15 tons/acre	3334	
30 tons/acre	1667	
Field disposal of slurry wastes		
slurry from deep pit		
20 tons/acre	7500	
40 tons/acre	3750	

the comparable paved feedlot is about one-third that of the unpaved feedlot.

The solids disposal area for the two 20,000 head capacity feedlots should be comparable. For mechanically removing the solid wastes after each pen of cattle have been fed, 1,666 acres of cropland are needed for a 30 tons per acre application rate.

CONFINEMENT BUILDING WASTE MANAGEMENT SYSTEMS

Confinement buildings offer a high potential for completely controlling the animal waste and abating pollution. Most confinement buildings are located in the upper Midwest where they may be located on family farms ranging from 500 head to commercial facilities with 20,000 head. Confinement buildings not only serve as a means of protecting the animals from the weather but also serve as the initial collection point of the waste material. With the animals confined in the building at all times, runoff-carried wastes are eliminated. Confinement buildings may be classified as warm or cold. Warm confinement buildings are totally enclosed, insulated, and mechanically ventilated for complete environmental control. Cold confinement buildings generally have one or more sides open and make no attempt to control the temperature inside the building. Some beef animals are fed in partial confinement facilities where the animals have access to a cold confinement building and to an outside lot where feeding is usually done.

The waste management system selected is dependent upon the flooring type; either solid floor or slotted floor constructed with concrete slats. The waste management system then resolves itself into either a slurry handling system or a solid handling system. Slurry handling systems are used with slotted floor buildings and solid handling systems are utilized for the solid concrete or dirt floor buildings. Partial confinement buildings use mainly the same waste handling concepts as open feedlots: solid waste handling and runoff-control systems.

Optimum Systems

In determining the optimum waste management system for confinement buildings, there is a choice between economic optimum and pollution control optimum. The two are not compatible in terms of cost. Obviously, optimum pollution control costs more. In this examination, waste management systems are considered that have some degree of pollution control and some that offer a high degree of pollution control. By pollution control it is meant that a maximum attempt will be made to prevent air and water pollution. Thus, some value judgements are made as to the system's capability for reducing odors and water pollution. Most confinement barns have an advantage over open feedlots regarding pollution control because of the initial containment or collection of the wastes.

The type of feeding facility not only dictates the nature of the waste management system but also is a major cost of the total system. If the effect of environmental temperature is not considered as influencing the animal performance appreciably, then cold confinement buildings are the most economical. Cold confinement buildings can be used in many areas of the United States where severe winter weather is not encountered. By having the roofs over the feeding facilities, rainfall runoff will not be contaminated by the animal wastes. The shelters also provide protection for the animals during wet and cold weather and reduce the effects of solar radiation during summer months. The least cost building is one that has a dirt floor and is a pole frame building. As concrete floors and concrete slats are added, the costs increase appreciably. Some cold confinement buildings costs are presented in Tables 47 through 49. These are costs of buildings that gave the least cost based upon Oklahoma prices and wages and were similar to existing production facilities.

<u>Economic Optimum</u>

In examining various waste handling methods for confinement buildings, it was found that the solids handling system combined with a solid floor cold confinement building had the least total system cost if bedding costs are not included. This was partially true because of the lower investment costs for the dirt floor building and also because the tractor loader and the tractor for the pull spreader was assumed to be used for other jobs around the farmstead and therefore the costs were prorated.

The next least cost waste management system consisted of a cold confinement barn with a deep pit and utilized a liquid spreader without soil injection. These total systems costs were approximately 50% higher than for the solid floor and solid waste handling system costs. Both of these systems assumed that the waste would be removed within a 20 day period each year and that the waste would be hauled no more than one-quarter mile.

A disadvantage for both the solids and slurry handling systems are odor problems arising during hauling and field

Table 47. Summary of Costs for Shallow Pit Cold Confinement Building Waste Management System Using a Cable Scraper for 500 Head

Facility	Investment Cost	Operating Cost, $/animal Day
Cold confinement building, shallow pit, cable scraper	37,100	.0305
Waste Handling		
Spreader without soil injection	10,700	.0107
Manure irrigation system	4,700	.0033
Total System Costs		
For slurry hauling	47,800	.0412
For manure irrigation	41,800	.0338

Table 48. Summary of Costs for Deep Pit Cold Confinement Building Waste Management System for 500 Head

Facility	Investment Cost	Operating Cost, $/animal Day
Cold confinement building, wood frame, interior poles, fenceline feed bunk, deep pit	21,600	.0237
Waste Handling		
Spreader without soil injection	9,200	.0065
Total System Costs		
	30,800	.0302

Table 49. Summary of Costs for Solid Floor Cold Confinement Building Waste Management System for 500 Head

Facility	Investment Cost	Operating Cost, $/animal Day
Cold confinement building, dirt floor, steel siding and roof, wood feed bunk	12,900	.0140
Waste Handling		
Tractor loader + pull-spreader	4,300	.0062
Total System Costs		
	17,200	.0202*

*Bedding costs of up to $0.02 per animal day should be added spreading. Fly problems may also be a problem during warm weather months. It was assumed that both of these systems haul waste to the fields and plow or disk it into the soil soon after application. If the bedding costs of $0.02 per animal day are added to the solid waste handling system for solid floor buildings, then its cost will be greater than the costs for the slurry handling system for the deep pit. In addition, bedding may be difficult to obtain in some localities and the costs of handling the bedding would have to be considered.

Pollution Control Optimum

A promising system for near optimum pollution control for cold confinement buildings is the system that utilizes the shallow pit underneath a slotted floor and a cable scraper. The cable scraper systems scrape the pit daily, thus removing the waste and the potential for odor and fly problems. Currently this system costs 30 to 50% more than a comparable system using a deep pit and slurry hauling. This system does, however, offer the potential for a completely mechanized waste handling operation. Currently, the slurry is hauled nearly every day of the year to fields using some of the same hauling methods as for deep pit slurry systems.

A slurry conveying system that appears to be compatible with the cable scraper system is a manure irrigation system. By using this system, the waste handling costs are reduced to about one-third of the cost of hauling and spreading with a spreader without soil injection. This would also permit the entire waste handling operation to be mechanized. Using this type of system the total investment cost for a 500 head unit facility and waste management system would be approximately $42,000 and the operating cost approximately $0.03 per animal day. There may be problems with this system during cold weather periods when the slurry may freeze in the shallow pits or cannot be conveyed to the fields because of snow and/or potential runoff from the fields because of snow melting or rainfall. This system offers a high potential for areas of the country where the waste can be utilized by crops or pasture on a nearly year-round basis.

The cable scraper system offers the potential for utilization of continuous flow treatment processes. Also, the shallow pit offers the possibility of using a flushing system instead of the cable scraper. Some re-use of waste water from lagoons could be utilized in the flushing process. It is assumed that solids would be separated and that the waste water would have undergone some treatment and possibly dilution with fresh water.

Confinement buildings with shallow pits also offer the potential for using an oxidation rotor for treating the animal waste and thus reduce odors arising from the feeding facility. The operating costs for oxidation rotors are approximately $0.05 per animal day. This is considerably higher than some of the other treatment and waste handling methods, for instance anaerobic lagoon costs are approximately $0.008 per animal day.

Land Area Requirements

The land area required for confinement feeding facilities is reduced considerably from that for the open feedlot. Cold confinement buildings with slotted floors allow 20 sq ft per animal and buildings with solid floors allow 30 sq ft per animal compared with 150 sq ft to 400 sq ft per animal for unpaved open feedlots. The spacing between buildings is a major factor controlling the surface area requirements for a group of confinement beef feeding facilities. Facilities utilizing a feed bunk located along one outside wall for fenceline feeding and having only the width of an outside drive between the buildings is the system requiring the least land area. For a cold confinement building with shallow pit and cable scraper and minimum spacing between buildings, the land area requirement for the feeding facilities is approximately 28 acres for a 20,000 head unit.

Land area requirements for waste management system are minimal for most confinement buildings because all of the wastes are collected within the building and there is no runoff. Exceptions to this are where lagoons or detention structures are used for partial confinement facilities with outside lots. For 20,000 animals in partial confinement, an anaerobic lagoon of approximately 170 acres is required. This completely dwarfs the feeding facilities area. Reductions in size of this lagoon can be made for warmer climatic areas, and where the slurry wastes are treated prior to entering the lagoon or where solids are separated from the slurry wastes.

Land disposal area requirements for a 20,000 head feeding facility for solid wastes are approximately 1,667 acres using an application rate of 30 tons per acre. Similarly, the acreage required for placing slurry upon the land is 7,500 acres using the 20 tons per acre rate that is commonly used in the upper Midwest for slurry applications. Obviously, the slurry and the solid wastes will have to be placed upon the soil at heavier rates to reduce the land area requirements. However, this increases the potential for pollution of surface and underground water. It exceeds the nutrient requirements of many of the crops that are grown. Also, there are problems associated with application of the wastes during non-growing periods of the year.

EVALUATION OF OPEN FEEDLOT AND CONFINEMENT BUILDING WASTE MANAGEMENT SYSTEMS

Designing a beef feeding facility for a particular location is a unique problem. The design has to be individualized based upon many local factors such as terrain, soil and climate. Some of the factors affecting the design of the feeding facilities and waste management systems have been mentioned in previous sections of this report. In this section, a comparison of the two general feeding systems, open feedlots and confinement building, will be made. Factors affecting the type of facilities and waste management systems will be discussed. It is assumed that the facilities are located under comparable climatic and geographic conditions.

Effect of Climate

Climate affects the selection of the type of beef feeding facility and waste management system. Major climatic factors affecting beef cattle performance and waste management systems are air temperature, relative humidity, rainfall, evaporation, solar radiation, and wind. Different climatic zones were developed by using three of these variables, as illustrated in Figures 58 and 59. The zones are based upon an 80°F average July temperature line, a 32°F average January temperature line, a 20°F average January temperature line and moisture deficit lines of 30 inches and 10 inches.[1] The 80°F average July temperature was selected because 80°F appeared to be an upper limit for beef cattle performance. Above this temperature, beef animal production declined for most breeds. The 32°F average January temperature line was selected because of the desirability to keep certain waste management systems above freezing conditions as much as possible. The 20°F average January temperature line was selected because it appears to be the lower temperature limit before beef animal performance begins to decline. Between 20°F and 80°F the animal should be in a comfort zone. The 30 inch moisture

[1]The average monthly temperatures are based upon curves presented in the book by Blair (9).

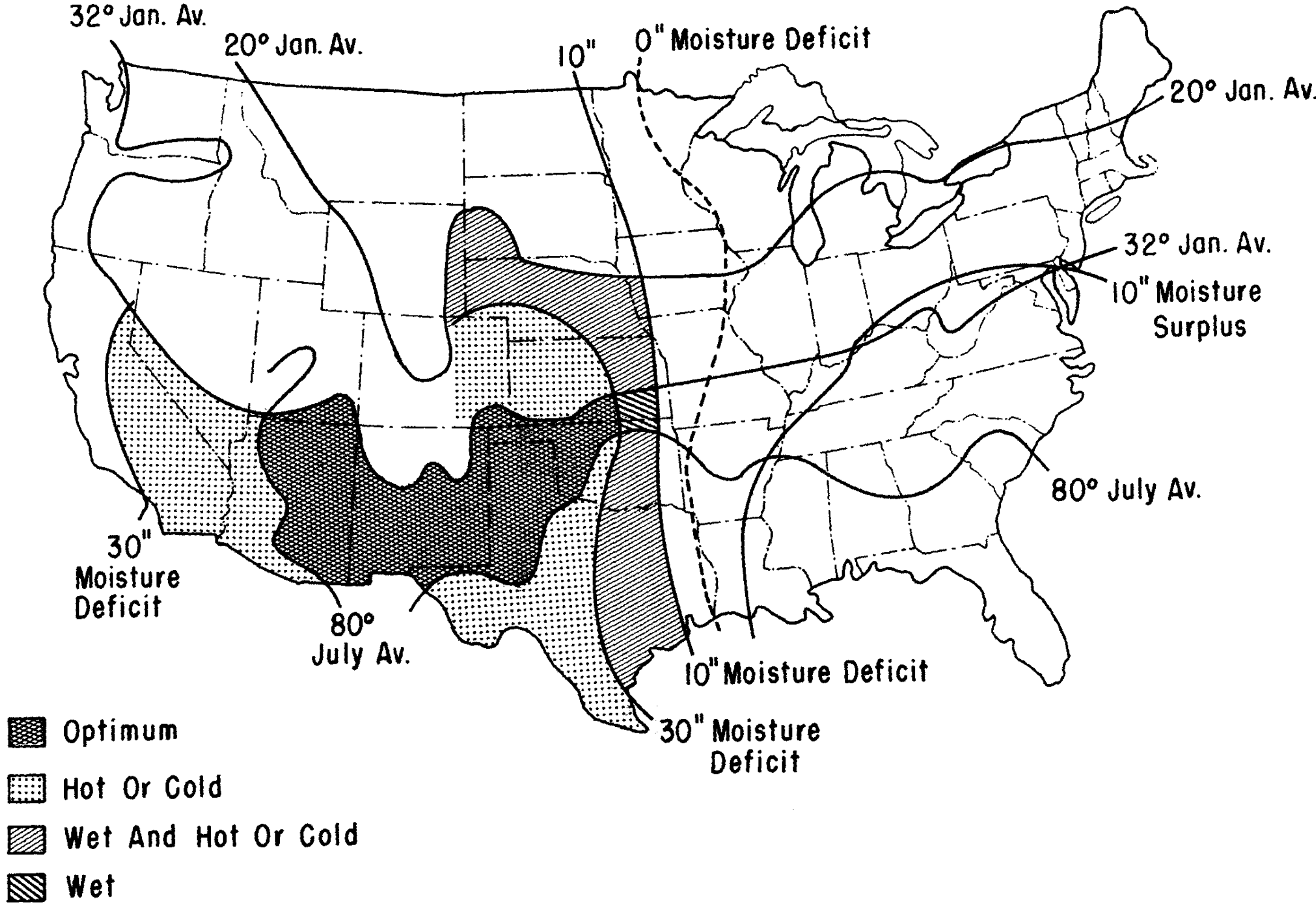


Figure 58. Beef cattle feeding areas based upon climate

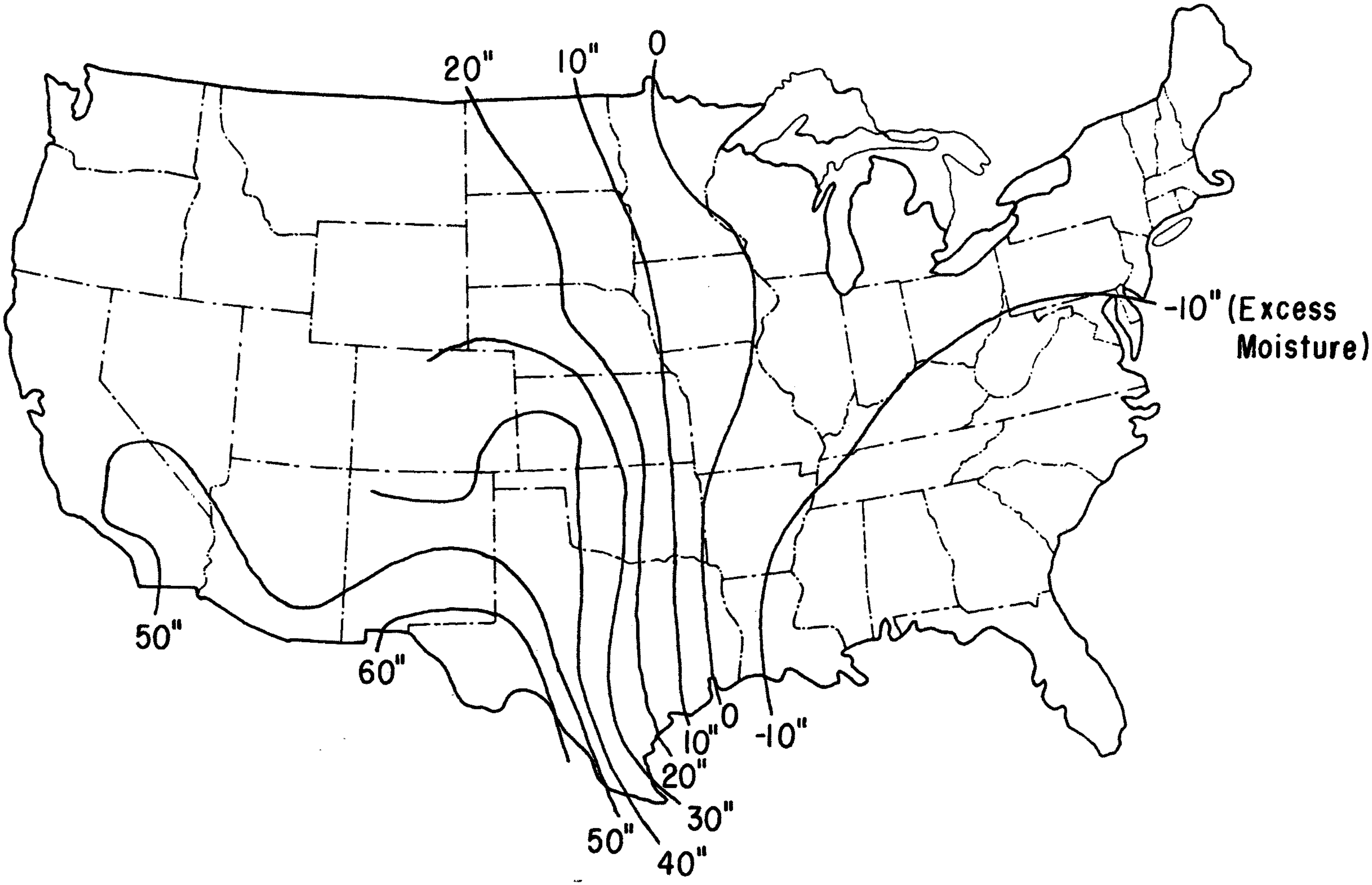


Figure 59. Lines of moisture deficit for the 48 adjacent states

deficit line was determined by subtracting the annual precipitation from the annual lake evaporation. The 30 inch moisture deficit line was selected primarily on the basis of decided advantages for evaporation of liquids from evaporation ponds, other waste management systems, and feedlot surfaces. With less than 10 inches of moisture deficit, the required surface area for evaporation ponds increases very rapidly and it becomes more difficult to dispose of the excess waste water. Some of the other climatic factors are integrated in these basic parameters, for instance, solar radiation and wind influence evaporation rate. Solar radiation also affects the average air temperatures. Precipitation and evaporation are included in the moisture deficit lines.

According to this climatic analysis, the optimum area for year-round beef feeding in outside open lots is in the region defined on its southern boundary by an 80°F average July temperature line, its northern boundary by the 32°F January average temperature line, its eastern boundary by the 30 inch moisture deficit line and its western boundary by the 80°F average July temperature line. This area includes a portion of Kansas, western Oklahoma, northwestern Texas, a sizeable portion of New Mexico, and the northeastern two-thirds of Arizona. It is realized that there may be local conditions within this region that may not be conducive to open beef feedlot feeding facilities. It should also be pointed out that one possible detrimental factor affecting feedlots in this region would be that of dust produced during the dry season.

Other areas of the country may also be good production areas but do not have perhaps as optimum conditions for year-round production. For instance, dry areas in Texas west of the 30 inch moisture deficit line and dry areas in California, Arizona, and Nevada have higher than the 80°F average July temperature. These areas would have to make some modifications to provide more environmental protection from solar radiation and the high temperatures than some of the other areas. Another near optimum area lies in Kansas, Nebraska and Colorado west of the 30 inch moisture deficit line. This area is below the 32°F average January temperature line. Thus, for short periods during the winter this area may not be optimum and modifications may have to be made to provide protection from the wind such as windbreaks, mounds or shelters. This area would have more freezing problems which would affect the performance of the waste management system and the performance of the livestock. Also, evaporation would be reduced during these periods of the year and wet sloppy conditions may exist at times. Another small area with optimum temperatures, but higher rainfall and less moisture deficit is a small area in southeast Kansas and northeast Oklahoma.

A secondary area that is between the 30 inch and 10 inch moisture deficit lines also provides good potential for open feedlot beef production at certain times of the year. One of these areas is north of the 32°F average January temperature line but south of the 20°F January temperature line. This area includes northeast Kansas, most of Nebraska, and portions of South Dakota, Wyoming, Colorado, and Iowa. Another secondary area is located in a warmer area of south central Oklahoma and eastern Texas. This could be classified as a hot and moderately wet area. There is good potential during certain periods of the year for evaporation of moisture from feedlot surfaces and evaporation lagoons in these areas.

As we go east of the 10 inch moisture deficit line, the disposal of liquid waste becomes more difficult. Also, higher humidities and rainfall affect the performance of animals in outside feedlots. Thus, confinement buildings begin to have some advantages in terms of animal performance east of the 10 inch moisture deficit line. For waste management systems in this area, the liquids essentially have to be filtered through the soil in order to dispose of the excess liquids.

The zones of various climatic conditions are illustrated in Figure 60. The area consisting of most of the Corn Belt region can be classified as a cool, wet area. This would indicate that possibly cold confinement buildings that have open fronts could be used. This would protect the animals from the higher rainfall and the animals would still be within the temperature comfort zone.

A zone consisting of northern Iowa, Minnesota and Wisconsin can be classified as a cold, wet zone. In this zone, totally enclosed, insulated, and environmental controlled confinement buildings may have the best advantage for providing optimum environmental conditions for beef animal performance. Also, more storage capacity for the waste has to be provided during the winter months in this zone before field application.

Another zone that has a high evaporation is the zone consisting of the Dakotas, Montana and a considerable portion of Wyoming which can be classified as a cold, dry zone. This area would have some advantages in terms of disposing of excess liquid waste by means of evaporation. However, during certain periods of the year the temperatures are below 20°F average January temperature (which is approxi-

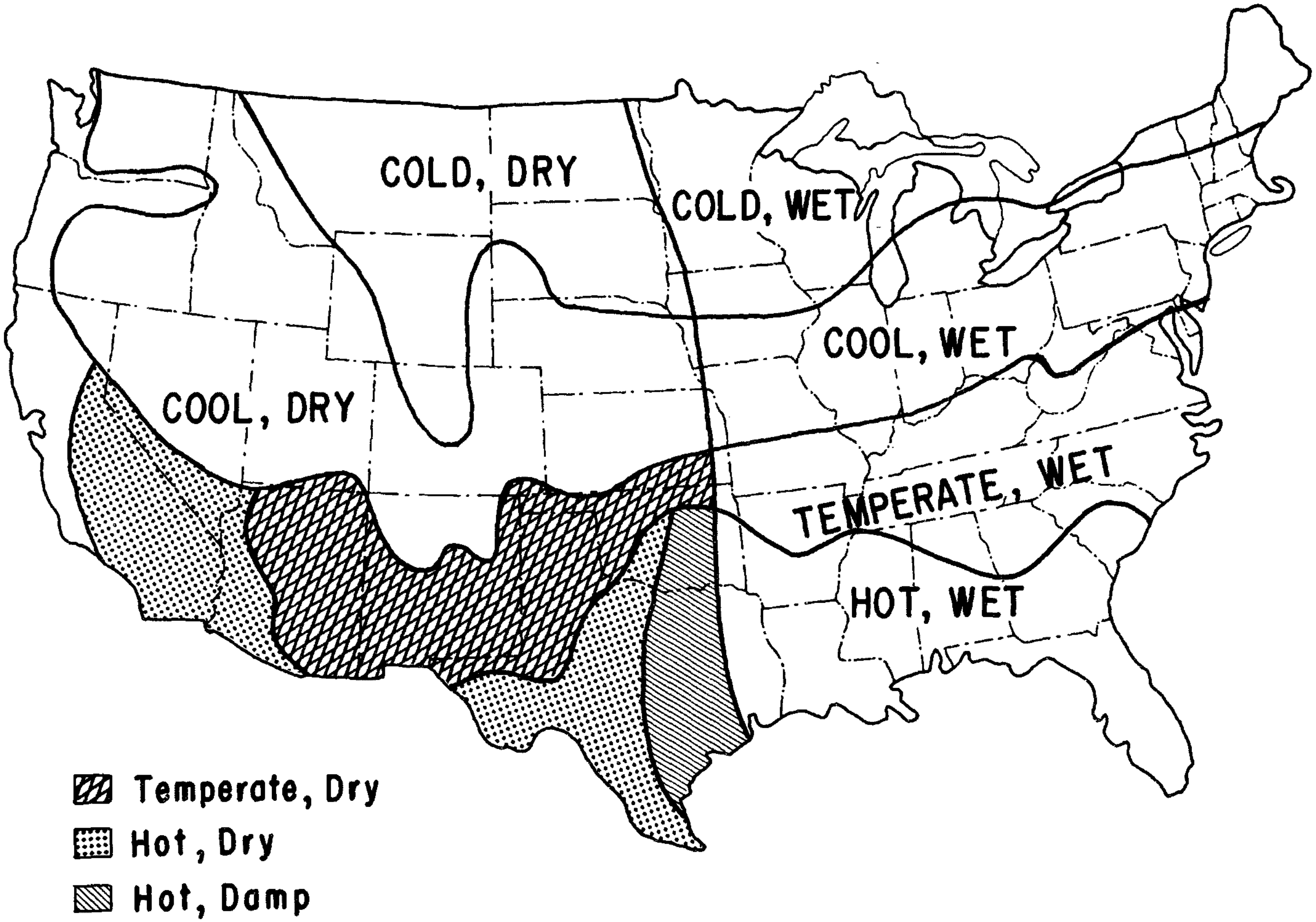


Figure 60. Climatic zones for beef feeding and waste management system selection

mately the lower limit for comfort zone of beef animals). Thus, some protection during the winter months should be made so that the animals would be protected from the wind and cold temperatures. During other times of the year, beef animal production in outside lots would be favorable.

Beef animal feeding facilities in the southeastern portion of the United States would have more difficulties to overcome because of hot, humid conditions. These hot humid conditions affect the performance of the beef animals. The higher rainfall area would cause more problems regarding pollution control from feeding facilities.

Other areas of the country, such as the Intermountain regions of Washington, Oregon, Idaho, Nevada, Utah and Colorado, may have some potential for beef feeding facilities. These areas have a high moisture deficit and therefore waste management would have fewer problems than in more humid and higher rainfall areas. However, most of the region is between the 32°F average January temperature line and the 20°F average January temperature line. Thus, for a portion of the year freezing conditions would exist which would affect the performance of lagoons and surface conditions of the feedlot.

Cost Comparison

For comparing costs between confinement building and open feedlot systems, a 20,000 head capacity lot was considered. This was considered to be a common size which is being attempted in the upper Midwest. The costs for 20,000 head confinement building operation cannot be extrapolated from a 500 head unit because roads and alleys have to be constructed between buildings and around the feedyard. This analysis considered the additional area needed. The area required for feed mill and feed handling operation was assumed to be the same for both open feedlots and confinement building facilities.

Land area requirements and investment costs for various beef feeding facilities and waste management systems for 20,000 head are presented in Table 50. The dirt-surfaced open feedlot had the lowest total system cost of the systems examined. The warm confinement beef feeding and waste management system for 20,000 head had the highest cost (approximately five times higher than the open feedlots). This analysis did not include the cost for the land area required for ultimate disposal of waste on crop land. The land area for ultimate disposal was determined from the amount of waste produced by 20,000 head and using the application rates that

Table 50. Land Area Requirements and Investment Costs for Various Beef Feeding Facilities and Waste Management Systems for 20,000 Head

	Land Area, Acres	Investment Cost, Dollars
Open Feedlot		
Lot, 200 ft^2/animal	108.2	315,400
Detention reservoir, 4 in. rain	23.3	12,880
Irrigation system, 20 in. annual rain	240.7	23,260
Solid waste handling, 1.0 mile, 50 days/year	1667.	70,000
	2,039.2	421,540
Cold Confinement Building		
Slotted floor, deep pit	37.2	865,080
Slurry handling, tank truck	7500	115,000
		980,080
Cold Confinement Building		
Dirt floor, 30 ft^2/animal	37.2	766,480
Solids handling, spreader truck	1667	70,000
		836,480
Cold Confinement Building		
Shallow pit, slotted floor	28.4	1,504,000
Cable scraper		
Slurry handling	7500	217,970
		1,721,970

Table 50. Continued

	Land Area, Acres	Investment Cost, Dollars
Warm Confinement Building		
Deep pit, slotted floor	29.3	1,960,000
Slurry handling	7500	115,000
		2,075,000
Partial Confinement		
Building and lot	79.1	1,255,400
Waste handling	1667	449,880
		1,705,280

approximately satisfy the nitrogen requirement of the field crops. Neglecting the bedding costs, the cold confinement building with dirt floor had the next lowest cost, approximately twice the cost of an open feedlot.

A system that was considered to have near optimum pollution control was the cold confinement building with a shallow pit and cable scraper. This system had an investment cost approximately four times higher than the open feedlot cost.

Manure irrigation systems for confinement buildings reduce the waste handling cost to approximately one-third of the cost of hauling slurry or solid wastes. However, the waste handling costs represent only about 25 percent of the total costs for confinement buildings with facility costs as the remaining portion.

Effect of Land Cost

A plot of investment cost versus land cost is made in Figure 61. The investment cost in this analysis does not include the cost of the ultimate disposal area for field application of the solid, slurry or runoff-carried wastes. The intercept values indicate the facility costs when the land cost is zero. As land cost increases, the cost for open feedlot systems increases rapidly. The cost for the confinement systems rises slowly. At approximately $800 per acre, the cold confinement barn with the dirt floor becomes economical in comparison with a dirt open surfaced feedlot with 400 sq ft of space per animal. The open feedlots were assumed not to have environmental control structures, such as shades or windbreaks. With the addition of these structures, the cost of the open feedlots would be higher.

SELECTION OF WASTE MANAGEMENT SYSTEM

BASED UPON POLLUTION CONTROL

The selection of feeding facility design and waste management system should be made with regard to the effect on the environment and the ultimate disposal of the waste material. Ideally, the system should not pollute the air or water. Thus, an ideal system collects the wastes soon after they are received by the feeding floor. These wastes would then be properly treated and disposed in a satisfactory manner. This may also mean recycling some of the nutrients that may be in the waste to crops or by processing the waste for animal feed.

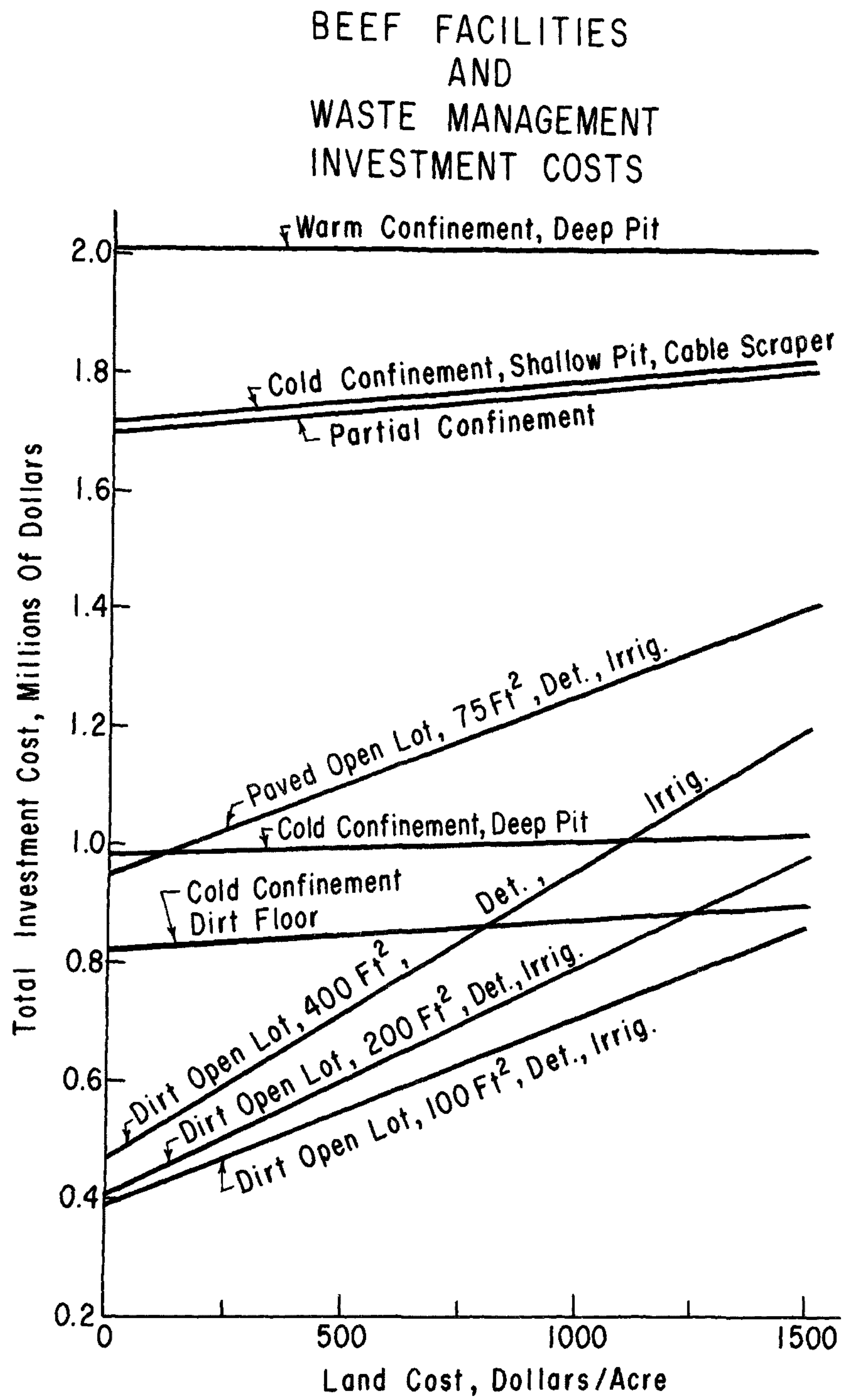


Figure 61. Investment cost vs. land cost for various feeding and waste management systems

In view of the above ideals, a ranking of waste management systems in regard to pollution control can be made as follows:

1. Cable scraper, with shallow holding pit and treatment by means of lagoon, manure irrigation on pasture or crop land, or spray-runoff irrigation system.

2. Oxidation ditch treatment of the waste underneath a slotted floor building, with overflow going to a lagoon, and then manure irrigation.

3. A deep pit underneath a slotted floor feeding facility for cold or warm confinement building, slurry hauling with a soil injection system.

4. Solid floor confinement, solid waste handling, composting or field application.

5. Paved feedlot with a flushing system and manure irrigation.

6. Unpaved feedlot with settling basins and storage reservoirs and irrigation of the runoff waste water onto crop land.

7. Unpaved feedlot with detention reservoirs or lagoons only and dependent upon evaporation for removal of excess liquid waste.

A comparison of the suggested rankings of selected waste management systems is presented in Table 51 regarding their potential for pollution control and least cost.

The first four systems mentioned above are associated with confinement beef feeding barns. These total systems are more costly than the open feedlot systems, however, they offer a higher potential for pollution control. The cable scraper, oxidation ditch, and flushing systems reduce odors over systems that do not treat or remove the waste promptly. Also, they provide the opportunity for using a nearly continuous flow treatment system. The unpaved feedlots with storage reservoirs only have the least degree of control of pollutants. Storage reservoirs are subject to overflows when storm rainfalls are above the design rainfalls. Also, odors may arise and settleable solids may fill the reservoir.

These systems have been suggested mainly on the basis of their potential for pollution control. There may be other

Table 51. Ranking of Waste Management Systems According to Potential for Pollution Control and Least Cost

Rank	Pollution Control	Economic
1	Cable scraper, with shallow pit and lagoon or irrigation	Unpaved open feedlot with detention reservoirs or lagoons only, evaporation
2	Oxidation ditch, lagoon and irrigation or evaporation	Unpaved open feedlot with settling basins, detention reservoirs, irrigation
3	Deep storage pit under slotted floor, slurry hauling with soil injection	Solid floor building, solid waste handling only, composting or field application
4	Solid floor building, solid waste handling only, composting or field application	Deep storage pit under slotted floor, slurry hauling
5	Paved open feedlot with flushing system and irrigation	Paved open feedlot with flushing system and irrigation
6	Unpaved open feedlot with settling basins, detention reservoir, irrigation	Cable scraper with shallow pit and lagoon or irrigation
7	Unpaved open feedlot with detention reservoirs or lagoons only, evaporation	Oxidation ditch, lagoon and irrigation or evaporation

systems that could do equally well or better. However, many of the other systems not mentioned here are either more costly, do not provide satisfactory control for water pollution abatement, or may be subject to the development of odors.

NEEDED RESEARCH

This investigation has found many areas needing further research to improve beef waste management to reduce pollution potential and odors. Research is needed to determine how weather related variables affect animal performance on open feedlots or confinement buildings and also how the weather affects the waste management systems. While there have been a few studies on feedlot hydrology, there is still much more that needs to be known. Currently it is difficult to predict exactly the amount or quality of the runoff coming from an open feedlot.

Much of the research to date has been rather piece-meal and has looked at mainly one or two components in the total feeding facility-waste management system. The entire system needs to be examined from the collection on through to the ultimate disposal. This current investigation was mainly a beginning, to evaluate the entire system based upon the state of the art. More needs to be known on how one portion or component of that system reacts with other components. This needs to be done on a research basis, possibly pilot-size, to examine the effects of different parameters on the performance of each of the components and the total system. It may be possible that some components may be reduced in size if used with some other key components. For instance, the separation of the settleable solids from runoff-carried or slurry wastes would reduce the size of an anaerobic lagoon.

Another potential research area is that of re-using or recycling the solid or liquid waste. Currently, the land offers the best method for the application of the waste material. The nutrients in the waste material can then be utilized by crops and the crops recycled back through the livestock. Much more needs to be known about optimum application rates for crop production. Also, it may be possible to maximize the disposal of the waste on the soil. Information is needed on maximum disposal rates on the soil without considering optimum crop yields, but rather determining the minimum land area and still preventing pollution of underground or surface waters. Another possibility is to use the land as a filter. Locations where the soil types and climatic conditions are favorable for soil filtering need to be determined.

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APPENDICES

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Appendix A. Summary of Feedlot Visits

State	Feedlot	Date	Capacity	Major Points of Interest
Arizona	Arizona Feed Co. P. O. Box 70 Casa Grande	8-13-70	56	Experimental confinement barn, steel slats, pit, liquid-haul
	Benedict Feeding Co.	8-13-70	20,000	Open feedlot, shades, sprinklers for dust control, solids waste removed by contractors
	T & C Cattle Co. 4851 E. Washington Pheonix	8-13-70	10,000	Open feedlot over 15 years old, slotted shades, sprinklers, sell composted manure, "Gro-Green", $4.50/yard in bulk
	Cowdon Cattle Co. Tolleson	8-14-70		Some experimental slotted floor confinement buildings with aeration lines located in pit, aeration didn't work well with 1 inch line with 1/8 inch holes 14 feet apart and lines about 6 feet apart
	E. S. Erwin & Assoc. 102 S. 94th Dr. Tolleson	8-14-70		Research and consulting business for feedlots in nutrition facility design
	Spur Feeding Co. P. O. Box 837 Glendale	8-14-70	25,000	Open feedlot, shades, truck sprinkler, located near Sun City, lawsuit against feedlot for odors, attempts at odor control with deodrizer injected into air from duct around feedlot perimeter

State	Feedlot	Date	Capacity	Major Points of Interest
California	Imperial Valley Field Experiment Station, University of California, El Centro	8-15-70		Research on shades and reducing hot weather effects on cattle, some waste management research
	Far Western Agricultural Industries, Inc. Holtville	8-15-70	6,000	Open feedlot with shades, wind machine + sprinkler, wood construction, solid wastes cleaned and hauled by contractor, charge to feedlot $0.25 per ton
	Alamo Cattle Feeders Inc., Division Western Beef, Inc. Calipatria	8-15-70		Open feedlot with shades, truck sprinkler, steel post and cable fence, concrete precast feedbunks, solid wastes contracted for cleaning and hauling
	Beefeeders Division of Comanche Feeding Corp. P. O. Box 98 Thermal	8-15-70	40,000	Open feedlot with shades-many innovations in feedlot design and facilities, contractor cleans, hauls and sells composted solids at $4/ton to citrus orchards
	Haflinger's Dairy Warren Road San Jacinto	8-17-70	240	Dairy facility with use of rinse and wash water for flushing alley in free stall barns, solids separated from liquids by a vibrating screen separator, solids in compost pile, liquids to lagoon and irrigation

State	Feedlot	Date	Capacity	Major Points of Interest
	Altadena Dairy Altadena	8-17-70	1,700	Experimental composting of waste, mix 1 1/2 dry compost with 1 part wet manure for bedding and foot cushioning material
	Western Consumers Industries Ontario	8-17-70	8,600	Confinement barn with slotted floor, scraper removes slurry daily from pit, slurry pumped to holding tank, then hauled to 2,000 acre farm, manure dryer no longer in operation
Colorado	Farr Feedlots Freeley	11-16-70	35,000	Open feedlot, double-swale drainage in pens, collection ditch at low slope to settle solids in runoff, runoff into long, narrow lagoons, irrigation from lagoons within 10 days after runoff, solids removed from ditches and lagoon with dragline
	Monfort of Colorado	11-16-70	120,000	Open feedlot, slight slope, drainage collection and lagoon, solid wastes hauled back to farms by silage farmers (in contract), 300,000 tons of waste in 1969 from 270,000 head feedlot
	Monfort of Colorado	11-16-70	105,000	Open feedlot, similar to old lot, drainage to lagoon

State	Feedlot	Date	Capacity	Major Points of Interest
	SWRD, ARS, Ft. Collins	11-17-70		Research on runoff and water balance from small feedlots, lysimeters, sample runoff quality
Illinois	James McGrew R #2 Avon	6-25-70	425	Cold confinement barn with slotted floor, concrete and steel slats, deep pit, slurry hauled twice per year in 1500 gallon tank wagon
	Jim Willrett Malta	7-06-70	1,100	Two warm confinement barns with slotted floor, 6.5 foot deep pit, hauls most twice per year in 2,000 gallon tank to corn field
Iowa	Iowa Beef Processors Dennison	9-24-70	510	Cold confinement barn, totally slotted floor, oxidation ditch, four rotors, inside fenceline feed bunks, water added continuously, sump pump pumps to lagoon
	Laverne Gustafson Holstein	9-24-70	30,000	Cold confinement barn with partially slotted floor, shallow pit, manure scraper, scraped daily, 40,000 gallon holding pit, slurry moved to fields daily, newly constructed, some under construction
	Pioneer Beef Cattle Johnston	9-25-70	400	Cold confinement barn with total slotted floor and deep pit, slurry hauled to corn land

State	Feedlot	Date	Capacity	Major Points of Interest
Kansas	Pratt Feedlot Pratt	7-21-70	35,000	Open feedlot on old air-field site, Kansas State University conducting re-search on runoff, solid waste handling, solid and runoff waste application to corn, irrigation good drain-age and runoff control
	Winter Feed Yards Box 115 Dodge City	7-22-70	21,000	Open feedlot with series of detention structures, re-cently constructed evapora-tion ponds for runoff control
	Brookover Feed Yards Garden City	7-22-70	35,000	Open feedlot with shallow settling basin and final evaporation pond with 43 acre-feet total capacity, for manure cleaning and hauling $1.25 per ton under 5 miles
Michi-gan	Cy Claflin Liberty Stables Marcellus	12-23-70	600	Partial confinement, shelter with concrete floor and out-side concrete lot, manure scrape from outside lot and hauled to fields, runoff con-trol facilities designed by SCS with drop structure to lagoon, irrigation
	Lyle Cunningham R #1 Concord	6-30-70	2,200	Three total confinement barns with dirt floor bedding, tractor and spreader hauling of waste, some open feedlot

State	Feedlot	Date	Capacity	Major Points of Interest
	Paul Bishop R #1 Grand Ledge	6-30-70	600	Partial confinement barns with concrete floor and concrete outside lot, with little slope, lot scraped weekly, waste hauled to nearby fields
	Great Markwestern Packing Co. Qunicy	6-30-70	20,000	Eight cold confinement barns with slotted floors and shallow pit, scraper removal of slurry, haul to fields daily, Reed canary grain, about half of cattle in open feedlot with runoff control facilities and two lagoons, irrigation from lagoons
	Jack Raymond	6-30-70	400	Warm confinement barn with partially slotted floor, deep pit, slurry hauled in tank wagon to corn fields, some additional inside-outside feeding
	Sonny Center Farms R #1 Vermontville	6-30-70	650	Partial confinement, shelter with concrete floor plus concrete lot, runoff collected in pit and hauled to corn field, solid waste scraped and hauled to field
Minnesota	George Rauenhorst Troy Farms Olivia	7-10-70	700	Solar confinement barn for 120 animals, heat exchanger to warm outside incoming air to assist in drying out manure pack, solid dirt floor, no

State	Feedlot	Date	Capacity	Major Points of Interest
				manure removal in 2 years, supplemental heat in winter, also cold confinement barn with solid concrete floor
	West Central Experiment Station, University of Minnesota, Morris	7-10-70		Research with different types of housing for beef feeding, warm and cold confinement with slotted floor, partial confinement with outside lot, total confinement solid floor manure scrape, open feedlot
Missouri	Flint McRoberts Monticello	6-25-70	400	Cold confinement barn with partially slotted floor with 8 foot deep pit, twice per year cleaning and hauling of slurry
Nebraska	Meade	7-16-70		Research conducted by USDA and University of Nebraska of beef animal waste management for open feedlots, runoff control, solids separation with continuous flow and batch concepts
	Gretna	7-16-70		Research by USDA on monitoring water balance and runoff from one acre feedlot with cooperating farmer
New Mexico	Matt Irwin Clayton	8-10-70	2,000	Open feedlot, cattle in irrigated bermuda grass, 160 acre Valley Irrigation System with

State	Feedlot	Date	Capacity	Major Points of Interest
	Union County Feedlot Clayton	8-10-70	25,000	Open feedlot, runoff into evaporation pond, solids temporarily stockpiled
	7A Feedlot, Inc. Tucumcari	8-11-70	20,000	Open feedlot, some new pens being developed with drainage control, old lot had runoff control problems, solid manure sold at $0.25 per ton
	Pecos Valley Feed Yard, Division of Diamond A Roswell	8-12-70	40,000	Open feedlot, low rainfall area, low slopes in pens, run-off into collection ditch
North Dakota	Fargo	7-13-70		Research facilities at N. D. State University on warm con-finement barns, pit scraper system and deep storage pit
Ohio	Ohio Feedlots Box 386 S. Charleston	7-2-70	20,000	Eight total confinement build-ings with compacted dirt floor, shredded wood bark bedding, canvas drape ventilation con-trol to permit maximum drying of bedding, total containment of animal waste; no runoff and no percolation, expect to com-post with digester and market compost
Okla-homa	Roy Schoeb and Sons Cherokee	7-21-70	8,000	Open feedlots, mounds, pens well drained, runoff into evap-oration ponds, some irrigation, solid waste removed by rotary scraper and carried directly

State	Feedlot	Date	Capacity	Major Points of Interest
				to nearby bermuda grass pasture for young stock
	Sooner Beef Producers RR #2 Guymon	7-23-70	30,000	Open feedlot, drainage collection system, drain to playa, farmer irrigates corn with runoff wastes, solid wastes: patrol scraper or paddle scraper then loaded into trucks, contracts for cleaning, give manure to contractor
	Comanche Feedyard Boise City	7-23-70	15,000	Open feedlot, extensive landforming for drainage control, borrow pit used for lagoon, culverts under roads, new feedlot
	Cimarron Feedlots, Ltd. Boise City	7-23-70	14,000	Open feedlot, some landforming on draws, low water paved or concrete dams across roads instead of culverts, retention dam under construction, new feedlot
Texas	Randall County Feed Yards Farm Road 2219E Umbargar	7-24-70	70,000	Open feedlot, runoff from feedlot into playa lake, some solids stockpiled near playa, some solids composted on a pilot plant operation
	Fletcher Sims RR #2 Canyon	7-24-70		Operates pilot composting operation, expects to sell at $20 per ton with special soil bacteria

State	Feedlot	Date	Capacity	Major Points of Interest
	USDA Southwestern Great Plains Research Center Bushland	7-24-70		Research on manure application rates effect on soil and crop response, nitrate movement studies on playas receiving runoff wastes
	Stratford Feedlot Stratford	7-23-70	70,000	Open feedlot, detention lagoon near draw, large stockpile of solid waste
	Morales Feedlot Divine	1-13-70	12,000	Open feedlot, completely paved, sun shades wastes flushed every 10 days, drains to collection pit, wastes pumped onto coastal bermuda grass nearby, highly permeable soil
	Cox Feedlot Divine	1-13-70	8,000	Open feedlot, dirt lot, runoff to lagoon, sandy soil
	Meat Producers McKinney	1-14-70	12,000	Open feedlot, runoff into evaporation lagoons, litigation because of fish kills, some experimental spray application of runoff wastes from lagoon at end of long winding low-slope ditch
Washington	Wineberg Farms Hwy 99 N R #6 Vancouver	8-19-70	200	Dairy farm with flushing system for waste cleaning, 200 cows, 27,000 gallon manure pit, manure irrigation daily using Mitchell chopper pump and big gun irrigation, 3 acres of grass covered in one

State	Feedlot	Date	Capacity	Major Points of Interest
				location, 10 gallons per cow wash water
	Tomlinson Dairy Pasco	8-20-70	1,200	Dairy for milking 700 head per side, under construction, flush down behind free stalls, grooves, 2 1/2% slope, over $370 per cow investment in entire facilities
	Golob and Sons Rt. 2, Box 52 Sunnyside	8-20-70	5,000	Open feedlot, dirt surface, mound for winter, clean mound and remove in spring, solid waste placed in irrigated wheat, alfalfa, and mint
	Needham Yards Sunnyside	8-20-70	10,000	Open feedlot, dirt surface, mound in winter, bed with shavings and sawdust at $.50/ton, plow the very largest pens, 1 foot deep into sand during winter, solid waste onto hops, corn, asparagus at 10 to 25 tons per acre
	McGregor Feedlot Box 607 Pasco	8-20-70	30,000	Open feedlot, dirt surface, sand, deep plow in winter, a strip (3 bottoms) plowed each day in each lot, deep lots 400 feet by 400 feet with 400 to 450 cattle per pen, contracts for solid removal in summer, one month to clean all pens (74) with Hancock 292 scraper, stockpile solid wastes now, relatively new lot, lagoon

Appendix B. Tables of Results

Table 1. Costs for Commercial Loader and Spreader Truck for Removing Wastes from an Open-Lot Feedlot, .25 Mile Hauling Distance, 1,000-20,000 Head, 20 Days per Year

No. of Head	Commercial Loader			Spreader Truck			Total Cost per An. Day	Total Investment Cost
	Hrs per day	No.	Cost per An. Day	Hrs per day	No.	Cost per An. Day		
1,000	1.13	1	.0028	2.89	1	.0033	.0062	43,900
2,000	2.26	1	.0027	5.79	1	.0030	.0057	43,900
3,000	3.39	1	.0026	8.68	1	.0027	.0052	43,900
4,000	4.53	1	.0024	5.79	2	.0030	.0054	56,700
5,000	5.66	1	.0023	7.24	2	.0028	.0051	56,700
10,000	5.66	2	.0023	9.64	3	.0026	.0049	100,600
20,000	7.54	3	.0021	9.64	6	.0026	.0047	170,100

Table 2. Costs for Commercial Loader and Spreader Truck for Removing Wastes from an Open-Lot Feedlot, .25 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

Days per Year	Commercial Loader: Hrs per Day	Commercial Loader: No.	Commercial Loader: Cost per An. Day	Spreader Truck: Hrs per Day	Spreader Truck: No.	Spreader Truck: Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	7.54	3	.0021	9.65	6	.0026	.0047	170,100
30	7.54	2	.0018	9.65	4	.0022	.0040	113,400
40	5.66	2	.0018	9.65	3	.0020	.0038	100,600
50	9.05	1	.0012	7.72	3	.0020	.0032	69,500
100	4.53	1	.0012	5.79	2	.0017	.0030	56,700
200	2.26	1	.0012	5.79	1	.0016	.0028	43,900
300	1.51	1	.0012	3.86	1	.0016	.0028	43,900

Table 3. Costs for Commercial Loader and Spreader Truck for Removing Wastes from an Open-Lot Feedlot, 1.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

	Commercial Loader			Spreader Truck				
Days per Year	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	7.54	3	.0021	8.94	7	.0029	.0050	182,900
30	7.54	2	.0018	8.34	5	.0025	.0043	126,200
40	5.66	2	.0018	7.82	4	.0023	.0041	113,400
50	9.05	1	.0012	8.35	3	.0021	.0033	69,500
100	4.53	1	.0012	6.26	2	.0018	.0031	56,700
200	2.26	1	.0012	6.26	1	.0017	.0029	43,900
300	1.51	1	.0012	4.18	1	.0017	.0029	43,900

Table 4. Costs for Commercial Loader and Spreader Truck for Removing Wastes from an Open-Lot Feedlot, 2.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

	Commercial Loader			Spreader Truck				
Days per Year	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	7.54	3	.0021	9.84	7	.0030	.0052	182,900
30	7.54	2	.0018	9.18	5	.0027	.0045	126,200
40	5.66	2	.0018	8.60	4	.0024	.0042	113,400
50	9.05	1	.0012	9.17	3	.0022	.0034	69,500
100	4.52	1	.0012	6.88	2	.0020	.0032	56,700
200	2.26	1	.0012	6.88	1	.0018	.0030	43,900
300	1.51	1	.0012	4.59	1	.0018	.0030	43,900

Table 5. Costs for Operating a Rotary Scraper with Tractor for Removing Solid Wastes from Open Feedlots, 1,000-50,000 Head, 100 Days per Year, .25 Mile Hauling Distance

No. of Animals	Scraper Costs: Hrs per Day	Scraper Costs: No.	Scraper Costs: Cost per An. Day	Tractor Costs: No.	Tractor Costs: Cost per Day	Total Cost per An. Day	Total Investment Cost
1,000	0.85	1	.0027	1	.0007	.0034	7,214
2,000	1.70	1	.0025	1	.0007	.0032	8,533
3,000	2.55	1	.0023	1	.0007	.0030	9,852
4,000	3.39	1	.0022	1	.0007	.0029	11,170
5,000	4.24	1	.0021	1	.0007	.0028	12,489
10,000	8.49	1	.0018	1	.0006	.0024	13,665
20,000	8.49	2	.0018	2	.0006	.0024	27,330
30,000	8.49	3	.0018	3	.0006	.0024	40,995
40,000	8.49	4	.0018	4	.0006	.0024	54,660
50,000	8.49	5	.0018	5	.0006	.0024	68,325

Table 6. Costs for Operating a Rotary Scraper with Tractor for Removing Solid Wastes from a 20,000 Head Open Feedlot, .25 Mile Hauling Distance 20 to 200 Days per Year

Days per Year	Scraper Costs			Tractor Costs		Total Cost per An. Day	Total Investment Cost
	Hrs per Day	No.	Cost per An. Day	No.	Cost per Day		
20	9.43	9	.0025	9	.0007	.0032	79,433
30	9.43	6	.0023	6	.0007	.0030	61,748
40	8.49	5	.0022	5	.0007	.0029	55,853
50	8.49	4	.0021	4	.0007	.0028	49,958
60	9.43	3	.0019	3	.0007	.0026	40,995
100	8.49	2	.0018	2	.0006	.0024	27,330
150	5.66	2	.0018	2	.0006	.0024	27,330
200	8.49	1	.0019	1	.0005	.0024	13,665

Table 7. Costs for Operating a Rotary Scraper with Tractor for Removing Solid Wastes from a 20,000 Head Open Feedlot, 1.0 Mile Hauling Distance, 20 to 200 Days per Year

	Scraper Costs			Tractor Costs			
Days per Year	Hrs per Day	No.	Cost per An. Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	9.70	14	.0039	14	.0011	.0050	124,735
30	9.05	10	.0037	10	.0011	.0048	101,155
40	9.70	7	.0034	7	.0011	.0045	83,470
50	9.05	6	.0033	6	.0011	.0044	77,575
60	9.05	5	.0031	5	.0011	.0042	68,325
100	9.05	3	.0028	3	.0010	.0038	40,995
150	9.05	2	.0029	2	.0008	.0037	27,330
200	6.79	2	.0029	2	.0008	.0037	27,330

Table 8. Costs for Operating a Rotary Scraper with Tractor for Removing Solid Wastes from a 20,000 Head Open Feedlot, 2.0 Mile Hauling Distance, 20 to 200 Days per Year

Days per Year	Scraper Costs: Hrs per Day	Scraper Costs: No.	Scraper Costs: Cost per An. Day	Tractor Costs: No.	Tractor Costs: Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	9.87	69	.0196	69	.0057	.0252	618,388
30	9.70	14	.0055	14	.0017	.0072	145,838
40	9.26	11	.0052	11	.0017	.0069	128,152
50	9.05	9	.0049	9	.0017	.0066	116,362
60	9.70	7	.0046	7	.0016	.0062	95,655
100	8.15	5	.0043	5	.0014	.0058	68,325
150	9.05	3	.0043	3	.0013	.0056	40,995
200	6.79	3	.0043	3	.0013	.0056	40,995

Table 9. Costs for Using Elevating Scraper for Removing Wastes from an Open Feedlot, 1,000-50,000 Head, .25 Mile Hauling Distance, 100 Days per Year

No. of Animals	Hrs. per Day	No.	Cost per An. Day	Total Investment Cost
1,000	0.42	1	.0056	37,226
2,000	0.83	1	.0050	37,226
3,000	1.25	1	.0045	37,226
4,000	1.67	1	.0041	37,226
5,000	2.08	1	.0037	37,226
10,000	4.16	1	.0023	37,226
20,000	8.33	1	.0014	37,226
30,000	6.25	2	.0016	74,452
40,000	8.33	2	.0014	74,452
50,000	6.94	3	.0015	111,678

Table 10. Costs for Using Elevating Scraper for Removing Wastes for an Open Feedlot, 20,000 Head, .25 Mile Hauling Distance, 20 to 200 Days per Year

Days per Year	Hrs. per Day	No.	Cost per An. Day	Total Investment Cost
20	8.33	5	.0041	186,130
30	9.25	3	.0031	111,678
40	6.94	3	.0031	111,678
50	8.33	2	.0023	74,452
60	6.94	2	.0023	74,452
100	8.33	1	.0014	37,226
150	5.55	1	.0014	37,226
200	4.16	1	.0014	37,226

Table 11. Costs for Using Elevating Scraper for Removing Wastes for an Open Feedlot, 20,000 Head, 1.0 Mile Hauling Distance, 20 to 200 Days per Year

Days per Year	Hrs. per Day	No.	Cost per An. Day	Total Investment Cost
20	9.66	6	.0053	223,356
30	9.66	4	.0043	148,904
40	9.66	3	.0034	111,678
50	7.73	3	.0034	111,678
60	9.66	2	.0024	74,452
100	5.79	2	.0024	74,452
150	7.73	1	.0020	37,226
200	5.79	1	.0020	37,226

Table 12. Costs for Using Elevating Scraper for Removing Wastes from an Open Feedlot, 20,000 Head, 2.0 Mile Hauling Distance, 20 to 200 Days per Year

Days per Year	Hrs. per Day	No.	Cost per An. Day	Total Investment Cost
20	9.96	8	.0072	297,808
30	8.85	6	.0062	223,356
40	9.96	4	.0046	148,904
50	7.97	4	.0046	148,904
60	8.85	3	.0036	111,678
100	7.97	2	.0027	74,452
150	5.31	2	.0027	74,452
200	7.97	1	.0028	37,226

Table 13. Costs of Manure Pump Driven by Tractor for Confinement Buildings with Deep Pit

No. of Head	Days per Year	Hrs per Day	No.	Pump Cost per An. Day	Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost
200	20	.41	1	.0005	.0004	.0009	1,559
300	20	.61	1	.0005	.0004	.0009	1,622
400	20	.81	1	.0005	.0004	.0009	1,685
500	20	1.01	1	.0005	.0004	.0009	1,748
750	20	1.52	1	.0005	.0004	.0009	1,906
1,000	20	2.03	1	.0005	.0004	.0009	2,064
2,000	20	4.06	1	.0005	.0004	.0009	2,694
3,000	20	6.09	1	.0005	.0004	.0009	3,325
4,000	20	8.11	1	.0005	.0003	.0008	3,956
5,000	20	5.07	2	.0005	.0003	.0008	6,020
10,000	20	6.76	3	.0005	.0003	.0008	10,606
20,000	20	8.11	6	.0005	.0003	.0008	19,779

Table 14. Costs for Pull-Type Vacuum Liquid Spreader without Injector for Confinement Barns with Deep Pit

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader Hrs per Day	Tractor & Spreader No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
200	20	0.25	4.00	1	.0051	.0033	.0084	3,143
		1.0	5.13	1	.0064	.0043	.0107	3,495
		2.0	6.64	1	.0081	.0055	.0136	3,964
300	20	0.25	6.00	1	.0049	.0033	.0082	3,764
		1.0	7.70	1	.0061	.0043	.0104	4,292
		2.0	9.97	1	.0076	.0055	.0131	4,996
400	20	0.25	8.00	1	.0047	.0033	.0081	4,386
		1.0	5.13	2	.0064	.0043	.0107	6,989
		2.0	6.64	2	.0081	.0055	.0136	7,928
500	10	0.25	6.67	3	.0052	.0033	.0085	8,806
		1.0	8.57	3	.0065	.0043	.0108	9,686
		2.0	8.30	4	.0084	.0055	.0140	12,758

Table 14. Continued

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader Hrs per Day	Tractor & Spreader No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
500	20	0.25	5.00	2	.0050	.0033	.0083	6,907
		1.0	6.42	2	.0063	.0043	.0105	7,787
		2.0	8.30	2	.0078	.0055	.0134	8,960
	30	0.25	6.67	1	.0046	.0033	.0079	5,008
		1.0	8.56	1	.0056	.0043	.0099	5,888
		2.0	5.54	2	.0078	.0055	.0134	8,960
750	20	0.25	7.50	2	.0048	.0033	.0081	8,461
		1.0	9.63	2	.0059	.0043	.0101	9,781
		2.0	8.30	3	.0078	.0055	.0134	13,440
1000	20	0.25	6.67	3	.0049	.0033	.0082	11,915
		1.0	8.56	3	.0060	.0043	.0103	13,675
		2.0	8.30	4	.0078	.0055	.0134	17,920

Table 15. Cost for Pull-Type Liquid Spreader without Injector for Confinement Barns with Deep Pit, Pump and Tractor

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader Hrs per Day	Tractor & Spreader No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Pump & Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
200	20	0.25	2.79	1	.0035	.0023	.0009	.0067	4,167
		1.0	3.93	1	.0048	.0033	.0009	.0090	4,559
		2.0	5.44	1	.0065	.0045	.0009	.0119	4,988
300	20	0.25	4.19	1	.0034	.0023	.0009	.0066	4,664
		1.0	5.89	1	.0047	.0033	.0009	.0088	5,192
		2.0	8.15	1	.0062	.0045	.0009	.0116	5,896
400	20	0.25	5.59	1	.0033	.0023	.0009	.0066	5,161
		1.0	7.85	1	.0045	.0033	.0009	.0087	5,865
		2.0	5.44	2	.0065	.0045	.0009	.0119	8,544
500	10	0.25	6.98	2	.0035	.0023	.0009	.0067	7,398
	20	0.25	6.98	1	.0033	.0023	.0009	.0065	9,560
	30	0.25	4.66	1	.0033	.0023	.0009	.0065	9,560

Table 15. Continued

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader Hrs per Day	Tractor & Spreader No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Pump & Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
500	10	1.0	9.81	2	.0047	.0033	.0009	.0089	9,278
	20	1.0	8.91	1	.0044	.0033	.0009	.0085	6,538
	30	1.0	6.54	1	.0044	.0033	.0009	.0085	6,538
	10	2.0	9.06	3	.0066	.0045	.0009	.0120	11,188
	20	2.0	6.79	2	.0063	.0045	.0009	.0118	9,452
	30	2.0	9.06	1	.0057	.0045	.0009	.0111	7,712
750	20	0.25	5.24	2	.0033	.0023	.0009	.0066	8,642
		1.0	7.36	2	.0045	.0033	.0009	.0087	9,962
		2.0	6.79	3	.0063	.0045	.0009	.0118	13,461
1000	20	0.25	6.98	2	.0033	.0023	.0009	.0065	9,885
		1.0	9.81	2	.0044	.0033	.0009	.0085	11,645
		2.0	9.06	3	.0061	.0045	.0009	.0115	15,731

Table 16. Costs for Pull-Type Liquid Spreader with Injector for Confinement Barns with Deep Pit, Pump and Tractor

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader Hrs per Day	Tractor & Spreader No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Pump & Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
200	20	0.25	3.17	1	.0058	.0027	.0009	.0093	5,438
		1.0	4.46	1	.0079	.0037	.0009	.0125	5,838
		2.0	6.17	1	.0106	.0051	.0009	.0167	6,371
300	20	0.25	4.75	1	.0056	.0026	.0009	.0091	5,994
		1.0	6.68	1	.0076	.0037	.0009	.0122	6,593
		2.0	9.26	1	.0101	.0051	.0009	.0162	7,393
400	20	0.25	6.34	1	.0055	.0026	.0009	.0090	6,550
		1.0	8.91	1	.0074	.0037	.0009	.0120	7,349
		2.0	6.17	2	.0106	.0051	.0009	.0167	11,308
500	10	0.25	7.93	2	.0057	.0026	.0009	.0092	10,000
		1.0	7.43	3	.0080	.0037	.0009	.0126	13,892
		2.0	7.71	4	.0111	.0051	.0009	.0171	18,118

Table 16. Continued

No. of Head	Days per Year	Hauling Distance	Tractor & Spreader: Hrs per Day	Tractor & Spreader: No.	Spreader Cost per An. Day	Tractor Cost per An. Day	Pump & Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost per An. Day
500	20	0.25	7.93	1	.0053	.0026	.0009	.0089	7,106
		1.0	5.57	2	.0077	.0037	.0009	.0124	10,998
		2.0	7.71	2	.0104	.0051	.0009	.0164	12,330
	30	0.25	5.28	1	.0053	.0026	.0009	.0089	7,106
		1.0	7.43	1	.0071	.0037	.0009	.0117	8,105
		2.0	5.14	2	.0104	.0051	.0009	.0164	12,330
750	20	0.25	5.95	2	.0055	.0027	.0009	.0090	11,390
		1.0	8.36	2	.0074	.0037	.0009	.0120	12,887
		2.0	7.71	3	.0104	.0051	.0009	.0164	17,779
1000	20	0.25	7.93	2	.0053	.0026	.0009	.0089	12,779
		1.0	7.43	3	.0075	.0037	.0009	.0121	17,671
		2.0	7.71	4	.0104	.0051	.0009	.0164	23,229

Table 17. Costs for Transporting Slurry Waste with Tank Truck, .25 to 2.0 Miles, 10, 20, 30 Days per Year

No. of Head	Days per Year	Hauling Distance	Hours per Day	No.	Cost per An. Day	Total Investment Cost
200	20	0.25	1.89	1	.0088	9,300
		1.0	2.11	1	.0098	9,300
		2.0	2.39	1	.0110	9,300
300	20	0.25	2.83	1	.0085	9,300
		1.0	3.16	1	.0093	9,300
		2.0	3.59	1	.0104	9,300
400	20	0.25	3.78	1	.0082	9,300
		1.0	4.21	1	.0090	9,300
		2.0	4.78	1	.0100	9,300
500	10	0.25	9.46	1	.0079	9,300
		1.0	5.26	2	.0096	18,600
		2.0	5.98	2	.0107	18,600
		10.0	7.78	3	.0201	27,900

Table 17. Continued

No. of Head	Days per Year	Hauling Distance	Hours per Day	No.	Cost per An. Day	Total Investment Cost
500	20	0.25	4.73	1	.0079	9,300
		1.0	5.27	1	.0086	9,300
		2.0	7.49	1	.0113	9,300
		10.0	7.31	2	.0222	18,600
	30	0.25	3.15	1	.0079	9,300
		1.0	3.51	1	.0086	9,300
		2.0	4.99	1	.0113	9,300
		10.0	7.78	1	.0153	9,300
1,000	20	0.25	9.46	1	.0067	9,300
		1.0	5.26	2	.0086	18,600
		2.0	5.98	2	.0095	18,600
		10.0	9.74	3	.0204	27,900
	300	0.25	0.63	1	.0067	9,300
		1.0	0.70	1	.0072	9,300
		2.0	0.80	1	.0078	9,300
		10.0	1.56	1	.0119	9,300

Table 17. Continued

No. of Head	Days per Year	Hauling Distance	Hours per Day	No.	Cost per An. Day	Total Investment Cost
5,000	20	0.25	9.46	5	.0067	46,500
		1.0	8.78	6	.0076	55,800
		2.0	9.96	6	.0083	55,800
		10.0	9.73	12	.0163	111,600
	200	0.25	3.15	1	.0044	9,300
		1.0	3.51	1	.0048	9,300
		2.0	3.98	1	.0054	9,300
10,000	20	0.25	9.46	10	.0067	93,000
		1.0	9.57	11	.0074	102,300
		2.0	9.96	12	.0083	111,600
		10.0	9.75	30	.0204	279,000
	300	0.25	6.30	1	.0045	9,300
		1.0	7.02	1	.0069	9,300
		2.0	7.97	1	.0149	9,300
		10.0	7.78	2	.0254	18,600

Table 17. Continued

No. of Head	Days per Year	Hauling Distance	Hours per Day	No.	Cost per An. Day	Total Investment Cost
20,000	20	0.25	9.96	19	.0066	176,700
		1.0	9.57	22	.0074	204,600
		2.0	9.96	24	.0083	223,200
		10.0	9.93	47	.0162	437,100
	300	0.25	6.31	2	.0045	18,600
		1.0	7.02	2	.0069	18,600
		2.0	7.97	2	.0149	18,600
		10.0	7.78	4	.0254	37,200

Table 18. Total Operating Cost per Animal Day for Various Systems for Removing and Hauling Wastes from 200 to 1,000 Head Confinement Buildings, .25 Mile Hauling Distance, 20 Days per Year

	Solid Waste Handling Systems			Slurry Handling Systems			
No. of Head	Tractor Front-End Loader & Pull-Type Spreader	Tractor Front-End Loader & Dump Truck	Tractor Front-end Loader & Spreader Truck	Pull-Type Vacuum Spreader without Injector	Pull-Type Spreader without Injector, Pump	Pull-Type Spreader with Injector, Pump	Tank Truck with Spreader, Pump
200	.0066	.0092	.0079	.0084	.0067	.0093	.0097
300	.0064	.0090	.0078	.0082	.0066	.0091	.0094
400	.0063	.0088	.0076	.0081	.0066	.0090	.0091
500	.0062	.0086	.0075	.0083	.0065	.0089	.0088
750	.0059	.0082	.0072	.0081	.0066	.0090	.0081
1000	.0058	.0078	.0069	.0082	.0065	.0089	.0075

Table 19. Total Investment Costs for Various Systems for Removing and Hauling Wastes from 200 to 1,000 Head Confinement Buildings, .25 Mile Hauling Distance, 20 Days per Year

No. of Head	Solid Waste Handling Systems: Tractor Front-End Loader + Pull-Type Spreader	Tractor Front-End Loader + Dump Truck	Tractor Front-End Loader + Spreader Truck	Liquid Waste Handling Systems: Pull-Type Vacuum Spreader without Injector	Pull-Type Spreader without Injector + Pump	Pull-Type Spreader with Injector + Pump	Tank Truck with Spreader + Pump
200	3,230	11,140	14,240	4,702	5,726	6,997	10,859
300	3,560	11,300	14,400	5,386	6,286	7,616	10,922
400	3,890	11,460	14,560	6,071	6,846	8,235	10,985
500	4,220	11,610	14,710	7,655	9,146	11,748	11,048
750	5,040	12,000	15,100	10,367	10,548	13,296	------
1000	5,860	12,390	15,590	13,979	11,949	14,843	11,364

Table 20. Total Operating Cost per Animal Day for Various Systems of Removing and Hauling Wastes from a 20,000 Head Confinement Building, .25 Mile Hauling Distance, 20 to 300 Days per Year

	Solid Waste Handling Systems				Slurry Handling Systems			
Days per Year	Commercial Loader + Dump Truck	Commercial Loader + Spreader Truck	Tractor with Front-End Loader + Pull-Type Spreader	Tractor with Front-End Loader + Dump Truck	Pull-Type Vacuum Spreader without Injector	Pull-Type Spreader without Injector + Pump	Pull-Type Spreader with Injector + Pump	Tank Truck + Pump
20	.0057	.0047	.0052	.0067	.0079	.0063	.0086	.0074
30	.0050	.0040	.0046	.0057	.0075	.0060	.0083	.0065
40	.0046	.0038	.0044	.0051	.0073	.0059	.0081	.0060
50	.0038	.0032	.0042	.0048	.0071	.0057	.0079	.0056
100	.0036	.0030	.0036	.0042	.0060	.0050	.0087	.0051
200	.0036	.0028	.0035	.0044	.0056	.0045	.0094	.0053
300	.0036	.0028	.0037	.0050	.0077	.0042*	.0098	.0053

*Spreaders need to be replaced before 300 days of use per year at 10 hours per day

Table 21. Total Investment Cost for Various Waste Handling Systems for 20,000 Head Confinement Building, .25 Mile Hauling Distance, 20 to 300 Days per Year

	Solid Waste Handling Systems				Slurry Handling Systems			
Days per Year	Commercial Loader + Dump Truck	Commercial Loader + Spreader Truck	Tractor with Front-End Loader + Pull-Type Spreader	Tractor with Front-End Loader + Dump Truck	Pull-Type Vacuum Spreader without Injector	Pull-Type Spreader without Injector	Pull-Type Spreader with Injector	Tank Truck
20	190,300	170,100	149,900	194,900	221,500	155,100	210,600	199,300
30	130,100	113,400	108,500	130,200	193,750	137,900	175,500	138,800
40	110,700	100,600	96,700	101,900	-------	127,900	161,500	114,900
50	69,900	69,500	86,300	83,300	166,800	117,800	154,200	92,000
100	50,500	56,700	54,400	46,100	88,500	66,300	83,900	54,200
200	40,800	43,900	36,200	27,500	49,800	37,700	44,100	35,600
300	40,800	43,900	18,100	18,600	30,400	28,200	33,400	35,600

Table 22. Effect of Moisture Content of Slurry on Costs of Evaporation Lagoon 500 Head, 20 Inches of Annual Precipitation, 50 Inches of Annual Evaporation

Lagoon Depth	Moisture Content	Lagoon Area (ft^2)	Investment Cost	Cost per An. Day
3 ft	.85	83,600	2,490	.0025
	.88	108,200	3,190	.0032
	.90	132,800	3,890	.0039
	.92	169,700	4,950	.0050
	.94	231,200	6,690	.0068
	.96	354,200	10,170	.0103
	.98	723,100	20,560	.0208
5 ft	.85	83,600	4,340	.0044
	.88	108,200	5,540	.0056
	.90	132,800	6,730	.0068
	.92	169,700	8,510	.0086
	.94	231,200	11,460	.0116
	.96	354,200	17,330	.0176
	.98	723,100	34,800	.0352

Table 23. Effect of Depth on Cost of Evaporation Lagoon for 500 Head, 30 Inches of Precipitation, 50 Inches of Evaporation, 90% Moisture Content Slurry

Depth	Lagoon Area (ft^2)	Investment Cost	Cost per Animal Day
1	132,800	1,250	.0013
2	132,800	2,550	.0026
3	132,800	3,890	.0039
4	132,800	5,280	.0054
5	132,800	6,730	.0068
6	132,800	8,220	.0083
7	132,800	9,760	.0099
8	132,800	11,360	.0115
9	132,800	13,010	.0132
10	132,800	14,720	.0149

Table 24. Effect of Feedlot Capacity on Cost of Evaporation Lagoon, 5 Feet Depth, 30 Inches Precipitation, 50 Inches Evaporation, 90% Moisture Content Slurry

Number of Animals	Lagoon Area (ft^2)	Investment Cost	Cost per Animal Day
200	53,100	2,840	.0072
300	79,700	4,140	.0070
400	106,300	5,440	.0069
500	132,800	6,730	.0068
750	199,200	9,930	.0067
1,000	265,600	13,100	.0066
2,000	531,300	25,700	.0065
5,000	1,328,200	63,270	.0064
10,000	2,656,300	125,480	.0064
20,000	5,312,600	249,990	.0063
30,000	7,968,900	373,250	.0063
40,000	10,625,200	496,900	.0063
50,000	13,281,500	620,500	.0063

Table 25. Costs for Evaporation Lagoon, 500 Head, 90% Moisture Content Slurry

	10 Inches Annual Precipitation			20 Inches Annual Precipitation			30 Inches Annual Precipitation		
Annual Evapo-ration (in.)	Lagoon Area (ft^2)	Invest-ment Cost	Cost per An. Day	Lagoon Area (ft^2)	Invest-ment Cost	Cost per An. Day	Lagoon Area (ft^2)	Invest-ment Cost	Cost per An. Day
3 ft depth									
20	265,600	7,670	.0078	-------	-----	-----	-------	-----	-----
30	132,800	3,890	.0039	265,600	7,670	.0078	-------	-----	-----
40	88,500	2,630	.0027	132,800	3,890	.0039	265,600	7,670	.0078
50	66,400	1,990	.0020	88,500	2,630	.0027	132,800	3,890	.0039
60	53,100	1,610	.0016	66,400	1,990	.0020	88,500	2,630	.0027
70	44,300	1,350	.0014	53,100	1,610	.0016	66,400	1,990	.0020
80	37,900	1,170	.0012	44,300	1,350	.0014	53,100	1,610	.0016

Table 25. Continued

Annual Evapo- ration (in.)	10 Inches Annual Precipitation Lagoon Area (ft^2)	Invest- ment Cost	Cost per An. Day	20 Inches Annual Precipitation Lagoon Area (ft^2)	Invest- ment Cost	Cost per An. Day	30 Inches Annual Precipitation Lagoon Area (ft^2)	Invest- ment Cost	Cost per An. Day
5 ft depth									
20	265,600	13,100	.0133	-------	------	-----	-------	------	-----
30	132,800	6,730	.0068	265,600	13,100	.0133	-------	------	-----
40	88,500	4,580	.0046	132,800	6,700	.0068	265,600	13,100	.0133
50	66,400	3,490	.0035	88,500	4,580	.0046	132,800	6,730	.0068
60	53,100	2,840	.0029	66,400	3,490	.0035	88,500	4,580	.0046
70	44,300	2,390	.0024	53,100	2,840	.0029	66,400	3,490	.0035
80	37,900	2,080	.0021	44,300	2,390	.0024	53,100	2,840	.0029

Table 26. Costs for Cable Scraper, Pump and Tractor, and Pull-Type Liquid Spreader for Removing and Hauling Wastes from 500 Head Confinement Building, .25 Mile Hauling Distance, 200 to 350 Days per Year

Days per Year	Cable Scraper Cost per An. Day	Pump and Tractor Cost per An. Day	Pull-Type Liquid Spreader: Hrs per Day	Pull-Type Liquid Spreader: No.	Pull-Type Liquid Spreader: Cost per An. Day	Tractor Costs per An. Day	Total Costs per An. Day	Total Investment Costs
200	.0037*	.0005	0.70	1	.0033	.0027	.0102	12,074
250	.0037	.0005	0.56	1	.0032	.0027	.0102	12,074
300	.0037	.0005	0.47	1	.0033	.0027	.0102	12,074
350	.0037	.0005	0.40	1	.0033	.0027	.0102	12,074

*Two cable scrapers operate 0.2625 hours per day each time used

Table 27. Costs for Tractor Front-End Loader and Pull-Type Spreader for Removing Wastes from Solid Floor Confinement Buildings, .25 Mile Hauling Distance, 20 Days per Year, 20 to 20,000 Head

	Tractor Front-End Loader			Pull-Type Spreader					
Capacity	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Tractor Cost per An. Day	Total Cost per An. Day	Total Investment Cost
200	1.02	1	.0043	1.11	1	.0013	.0009	.0066	3,230
300	1.53	1	.0042	1.67	1	.0013	.0009	.0064	3,560
400	2.04	1	.0041	2.22	1	.0013	.0009	.0063	3,890
500	2.56	1	.0040	2.78	1	.0013	.0009	.0062	4,220
750	3.83	1	.0037	4.17	1	.0013	.0009	.0059	5,040
1,000	5.11	1	.0036	5.59	1	.0012	.0009	.0058	5,860
2,000	5.11	2	.0036	5.56	2	.0012	.0009	.0058	11,720
5,000	8.52	3	.0032	9.26	3	.0012	.0009	.0053	13,000
10,000	8.52	6	.0032	9.26	6	.0012	.0009	.0053	26,000
20,000	9.29	11	.0031	9.26	12	.0012	.0009	.0052	52,000

Table 28. Costs for Tractor Front-End Loader and Pull-Type Spreader for Removing Wastes from Solid Floor Confinement Buildings, .25 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

	Tractor Front-End Loader			Pull-Type Spreader			Tractor	Total	
Days per Year	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Cost per An. Day	Cost per An. Day	Total Invest-ment Cost
20	9.29	11	.0031	9.26	12	.0012	.0009	.0052	149,902
30	9.73	7	.0026	9.26	8	.0011	.0009	.0046	108,486
40	8.52	6	.0024	9.26	6	.0010	.0009	.0044	96,678
50	8.18	5	.0022	8.89	5	.0010	.0009	.0042	86,324
100	6.81	3	.0019	7.41	3	.0009	.0008	.0036	54,372
200	5.11	2	.0018	5.56	2	.0009	.0007	.0035	36,248
300	6.81	1	.0025	7.41	1	.0006	.0006	.0037	18,124

Table 29. Costs for Tractor Front-End Loader and Pull-Type Spreader for Removing Wastes from Solid Floor Confinement Buildings, 1.0 Mile Hauling Distance,

Days per Year	Tractor Front-End Loader Hrs per Day	No.	Cost per An. Day	Pull-Type Spreader Hrs per Day	No.	Cost per An. Day	Tractor Cost per An. Day	Total Cost per An. Day	Total Invest-ment Cost
20	9.29	11	.0031	9.64	15	.0015	.0012	.0058	164,630
30	9.73	7	.0026	9.64	10	.0014	.0012	.0052	121,760
40	8.52	6	.0024	9.03	8	.0014	.0012	.0050	109,952
50	8.18	5	.0022	9.64	6	.0013	.0012	.0047	98,144
100	6.81	3	.0019	9.64	3	.0012	.0010	.0041	54,372
200	5.11	2	.0018	7.23	2	.0012	.0009	.0039	36,248
300	6.81	1	.0025	9.64	1	.0012	.0009	.0046	25,894

T 30. Costs for Tractor Front-End Loader and PUll-Type Spreader for Removing Wastes from Open-Lot Solid Manure Handling Systems, 2.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

D. p. Ye	Tractor Front-End Loader			Pull-Type Spreader			Tractor	Total	
	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Cost per An. Day	Cost per An. Day	Total Invest-ment Cost
2	9.29	11	.0031	9.94	19	.0020	.0016	.0066	184,267
	9.73	7	.0026	9.69	13	.0018	.0016	.0060	139,943
4	8.52	6	.0024	9.45	10	.0018	.0016	.0058	126,681
5	8.18	5	.0022	9.45	8	.0017	.0016	.0055	114,873
10	6.81	3	.0019	9.45	4	.0016	.0013	.0048	63,596
20	5.11	2	.0018	9.45	2	.0014	.0011	.0044	36,248
30	6.81	1	.0025	6.30	2	.0014	.0011	.0050	27,348

Table 31. Costs for Tractor Front-End Loader + Dump Truck for Removing Wastes from Solid Floor Confinement Building, .25 Mile Hauling Distance, 20 Days per Year, 200 to 20,000 Head

	Tractor Front-End Loader			Dump Truck				
Capacity	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
200	1.02	1	.0043	0.99	1	.0049	.0092	11,140
300	1.53	1	.0042	1.48	1	.0048	.0090	11,300
400	2.04	1	.0041	1.98	1	.0047	.0088	11,460
500	2.55	1	.0040	2.47	1	.0046	.0086	11,610
750	3.83	1	.0038	3.71	1	.0044	.0082	12,000
1,000	5.11	1	.0036	4.94	1	.0042	.0078	12,390
2,000	5.11	2	.0036	9.89	1	.0036	.0071	27,500
3,000	7.67	2	.0033	7.42	2	.0039	.0071	37,200
4,000	6.81	3	.0033	9.89	2	.0036	.0069	46,100
5,000	8.52	3	.0032	8.24	3	.0038	.0069	55,800
10,000	8.52	6	.0031	9.89	5	.0036	.0067	101,900
20,000	9.29	11	.0031	9.89	10	.0036	.0067	194,900

Table 32. Costs for Tractor Front-End Loader + Dump Truck for Removing Wastes from Solid Floor Confinement Building, .25 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

	Tractor Front-End Loader			Dump Truck				
Days per Year	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	9.29	11	.0031	9.89	10	.0036	.0067	194,900
30	9.73	7	.0025	9.42	7	.0031	.0057	130,200
40	8.52	6	.0024	9.89	5	.0028	.0051	101,900
50	8.18	5	.0022	9.89	4	.0026	.0048	83,300
100	6.81	3	.0019	9.89	2	.0023	.0042	46,100
200	5.11	2	.0018	9.89	1	.0026	.0044	27,500
300	6.81	1	.0025	6.59	1	.0026	.0050	18,600

Table 33. Costs for Tractor Front-End Loader + Dump Truck for Removing Wastes from Solid Floor (Open Lot) Waste Systems, 1.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

	Tractor Front-End Loader			Dump Truck				
Days per Year	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	9.29	11	.0031	9.77	11	.0039	.0070	204,600
30	9.73	7	.0025	8.96	8	.0035	.0061	139,900
40	8.52	6	.0024	8.96	6	.0031	.0056	111,600
50	8.18	5	.0022	8.60	5	.0029	.0052	93,000
100	6.81	3	.0019	7.17	3	.0026	.0045	55,800
200	5.11	2	.0018	5.37	2	.0025	.0043	37,200
300	6.81	1	.0025	7.16	1	.0037	.0061	18,600

Table 34. Costs for Tractor Front-End Loader + Dump Truck for Removing Wastes from Solid Floor (Open Lot) Wastes Systems, 2.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

Days per Year	Tractor Front-End Loader			Dump Truck			Total Cost per An. Day	Total Investment Cost
	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day		
20	9.29	11	.0031	9.92	12	.0043	.0074	214,300
30	9.73	7	.0025	9.92	8	.0037	.0063	139,900
40	8.53	6	.0024	9.92	6	.0033	.0058	111,600
50	8.18	5	.0022	9.52	5	.0031	.0054	93,000
100	6.81	3	.0019	7.94	3	.0028	.0047	55,800
200	5.11	2	.0018	5.95	2	.0027	.0046	37,200
300	6.81	1	.0025	7.94	1	.0066	.0091	18,600

Table 35. Costs for Commercial Loader and Dump Truck for Removing Wastes from Open-Lot Solid Manure Handling Systems, .25 Mile Hauling Distance, 1,000-20,000 Head, 20 Days per Year

No. of Head	Commercial Loader			Dump Truck			Total Cost per An. Day	Total Investment Cost
	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day		
1,000	1.13	1	.0029	4.94	1	.0042	.0071	40,800
2,000	2.26	1	.0027	9.89	1	.0036	.0063	40,800
3,000	3.39	1	.0026	7.42	2	.0039	.0064	50,500
4,000	4.53	1	.0024	9.89	2	.0036	.0060	50,500
5,000	5.65	1	.0023	8.24	3	.0038	.0060	60,200
10,000	5.65	2	.0023	9.89	5	.0036	.0059	110,700
20,000	7.54	3	.0021	9.89	10	.0036	.0057	190,300

Table 36. Costs for Commercial Loader and Dump Truck for Removing Wastes from Open-Lot Solid Manure Handling Systems, .25 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

Days per Year	Commercial Loader			Dump Truck			Total Cost per An. Day	Total Investment Cost
	Hrs per Day	No.	Cost per An. Day	Hrs per Day	No.	Cost per An. Day		
20	7.54	3	.0021	9.89	10	.0036	.0057	190,300
30	7.54	2	.0018	9.42	7	.0032	.0050	130,100
40	5.65	2	.0018	9.89	5	.0028	.0046	110,700
50	9.05	1	.0012	9.89	4	.0026	.0038	69,900
100	4.53	1	.0012	9.89	2	.0023	.0036	50,500
200	2.26	1	.0012	9.89	1	.0026	.0036	40,800
300	1.51	1	.0012	6.59	1	.0026	.0038	40,800

Table 37. Costs for Commercial Loader and Dump Truck for Removing Waste from Open-Lot Solid Manure Handling Systems, 1.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

Days per Year	Commercial Loader Hrs per Day	Commercial Loader No.	Commercial Loader Cost per An. Day	Dump Truck Hrs per Day	Dump Truck No.	Dump Truck Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	7.54	3	.0021	9.77	11	.0039	.0060	200,000
30	7.54	2	.0018	8.96	8	.0035	.0053	139,800
40	5.65	2	.0018	8.36	6	.0031	.0049	120,400
50	9.05	1	.0012	8.60	5	.0029	.0042	79,600
100	4.53	1	.0012	7.17	3	.0026	.0038	60,200
200	2.26	1	.0012	5.38	2	.0025	.0038	50,500
300	1.51	1	.0012	7.17	1	.0037	.0049	40,800

Table 38. Costs for Commercial Loader and Dump Truck for Removing Wastes from Open-Lot Solid Manure Handling Systems, 2.0 Mile Hauling Distance, 20,000 Head, 20 to 300 Days per Year

Days per Year	Commercial Loader Hrs per Day	No.	Cost per An. Day	Dump Truck Hrs per Day	No.	Cost per An. Day	Total Cost per An. Day	Total Investment Cost
20	7.54	3	.0021	9.92	12	.0043	.0064	209,700
30	7.54	2	.0018	9.92	8	.0037	.0055	139,800
40	5.65	2	.0018	9.92	6	.0033	.0051	120,400
50	9.05	1	.0012	9.52	5	.0031	.0044	79,600
100	4.53	1	.0012	7.93	3	.0028	.0041	60,200
200	2.26	1	.0012	5.95	2	.0027	.0040	50,500
300	1.51	1	.0012	7.94	1	.0066	.0078	40,800

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Beef Waste Management

27 *Abstract*

Alternative beef waste management systems were examined to determine minimum cost systems for effective waste disposal. Design and cost information was obtained from feedlot visits and the literature. A computer program was developed for use with a Conversational Programming System (CPS) for calculating the sizes of equipment and facilities and for estimating the facility and machinery operating and investment costs.

For a 20,000 head capacity open feedlot, the total system investment cost for pens, roads, and waste handling was $420,000 with an operating cost of $0.133 per animal day. The pen facilities were about 65% of the total costs, the runoff control system about 10%, and the solids handling about 25%.

Confinement building waste management systems were also examined. Various treatment and ultimate disposal methods were evaluated. A manure irrigation system was one of the least costly methods of conveying and disposing of the waste.

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