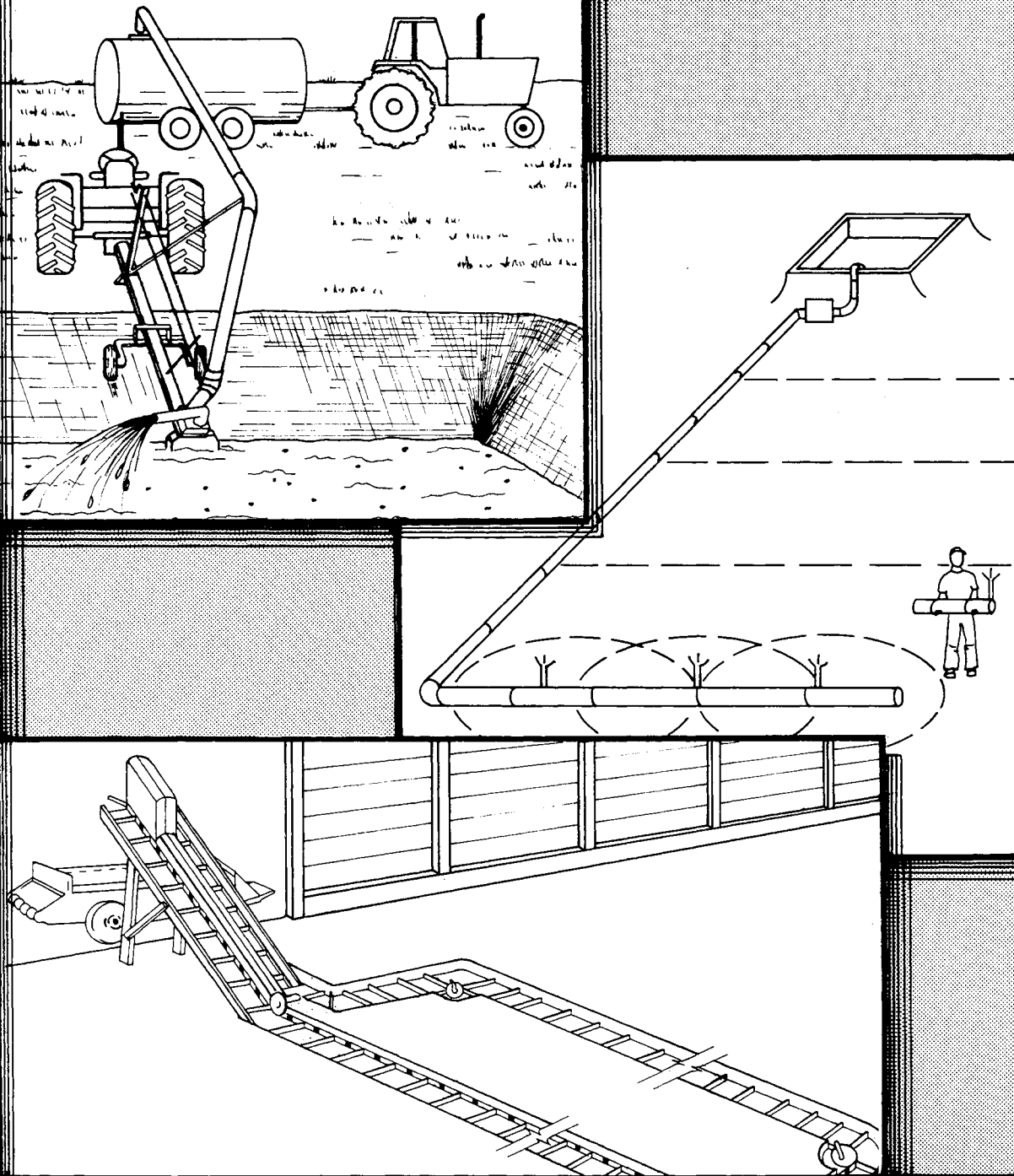


Livestock Waste Facilities Handbook



Third Edition, 1993

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1. WASTE DISPOSAL OVERVIEW

This book deals with technology that is subject to local, state, and federal regulation; influenced by factors such as soil type, topography, climate, and livestock management; and influenced by local changes in population and land use. Therefore, adapt recommendations and data to local conditions and recent developments.

This handbook is for:

- Livestock producers.
- Those who plan, evaluate, or select waste handling systems.
- Those who work with farmers and their livestock problems, and who need some knowledge of waste handling systems.
- Those who teach about waste handling, utilization, and disposal, and who need a resource on typical facilities.
- Students.

The handbook includes:

- Data on agricultural livestock wastes—manure, bedding, feedlot runoff, milking center wastewater, and other materials in livestock wastes.
- Typical facilities and equipment (components), their purpose or function, and their selection and use.
- Design criteria and data.
- No information on laboratory analyses and related sciences.

Waste problems and many solutions are not new.

- Mythical Greek gods had animal housing. Hercules solved manure problems with perhaps the first "flushing" system by diverting a river to flow through the Aegean stables.
- Field spreading of human and animal wastes is accomplished naturally under nomadic and pasture social systems. Intentional manure conservation and reuse was practiced by early Chinese.
- Slotted floors go back at least 200 years in Iceland.
- Dairy barns with wastes from scores of animals in one building date from at least the 19th century. Huge poultry centers with wastes concentrated in a small area are decades old, as are some very large swine and beef units.

The size of man's problem and its effects on nature's solutions are relatively new.

- Trends in agriculture have led to fewer producers, larger average herd or flock size, and much greater concentrations of agricultural animals in relatively small lots or buildings.
- The growth of problems in livestock waste management has not been nearly as rapid as the growth of public concern about air, water, and land pollution.

System Selection

Base system selection on economics, engineering, public reaction and regulation, and numerous factors related to agriculture and your operation. Although this handbook emphasizes physical facilities—construction and equipment—do not ignore the other factors.

Costs are not discussed, because of wide variations in different areas and rapid changes in the relative costs of labor, materials, equipment, energy, and borrowed money. In general, try to avoid special equipment that has only limited use. Leave as many options open as possible to allow for equipment breakdown, vacations, sickness, and future changes in technology or farm management. Count all costs, including costs shared with other operations (e.g. the large tractor needed only part time to haul manure).

System Principles

- Any system starts with the source of wastes: an animal, the milkhouse, or lot runoff.
- Ultimately all systems end in the soil; no pollutant is intentionally released to a stream, sub-surface tile, or ditch. Only a few systems currently have other end uses, such as refeeding, selling fertilizer, or specialized treatment.
- All systems are compromises between investment, labor, convenience, aesthetics, and regulations.
- No system is "best." Each component, facility, or process has advantages and disadvantages. The "best" for you depends on personal preferences, available capital and labor, waste sources, soil type, cropping practices, and a number of other factors.

How to Decide

- Stand back. Look objectively at where you are, where you want to be, and some likely ways to get there.
- Identify waste sources. A large source (200 cows, 300 feeder cattle, 2,000 pigs) may suggest large equipment and some automation. A small source may suggest staying with low investment and a little more labor. One enterprise may have several sources: free stall barn, milking parlor, milkhouse, outdoor lot.
- Consider all alternatives. If you are changing your operation—expanding, remodeling, rebuilding—look at all the options for waste handling. Consider major management options, different kinds of housing, various types of waste handling equipment, and disposal alternatives.

Exhibit 1100

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Can you move the source—livestock center—away from the farmstead to a site that is better drained and farther from your neighbors and a creek? Is now the time to go to liquid handling? Automate the work done each day or week rather than work done once a year.

- Look at outside influences. Are your neighbors fairly close? Is a stream or watercourse near your livestock center? Is your area frozen and snowed-in part of the year? Is your area arid or wet? Consider prevailing winds, underground water pollution, and snow drifting patterns that can hamper manure collection, hauling, and spreading.

For guidelines on locating a farmstead and on locating activities within the farmstead, see MWPS-2, *Farmstead Planning Handbook*. It is available at the addresses listed on the inside front cover.

Table 1-1. Factors affecting manure and waste management.

Operation	Climate
Size and type	Precipitation
Capital	Amount
Mechanization level	Distribution
Owner preferences	Evaporation
	Temperature norms
Farm	Prevailing winds
Size	
Soil type	Animal
Topography	Species
Crops	Ration
	Housing
Regulations	Management
	Manure characteristics
Proximity to neighbors	

Table 1-1 lists several factors to consider in designing a waste management system. Expand this list to reflect local considerations and to include more details for your operation.

Regulations

Federal, state, and local regulations attempt to minimize or eliminate pollution. A well designed system can achieve these goals and also have advantages for the livestock operation.

Federal regulations apply to all states. Federal regulations apply to operations over a certain size or operations that discharge wastes into surface or ground water.

Many states and local governments have imposed additional or more stringent requirements, such as facilities with specific runoff holding capacities, specific land application times, and procedures for ground water protection. Other regulations, such as zoning laws and public health laws relating to milk production facilities and water supply sources, can affect your livestock facility's design, construction, and operation and its manure management program. Some agencies attempt odor control by regulating the distance between public housing and waste control or livestock facilities.

Seek out the regulations that apply to your facilities. Your local county extension agent or the extension agricultural engineer at your state's agricultural college can help, as can a state pollution or water quality control agency, a state board of health, and agencies responsible for specific products such as milk, meat, or eggs.

2. ANIMAL WASTE CHARACTERISTICS

The quantity and composition of wastes produced influence livestock waste facility design. The properties of manure depend on several factors: animal species; ration digestibility, protein, and fiber content; and animal age, environment, and productivity. The waste system also handles added bedding, soil, water, hair, etc.

Waste with 20%-25% solids content (75%-80% moisture content) can usually be handled as a solid, i.e. it can be stacked and can be picked up with a fork loader. Liquids need to be drained and the waste dried or bedding added to get solid waste. In the 10%-20% solids content range, handling characteristics vary depending on the type of solids present. In this range,

the percent solids content does not necessarily define handling characteristics.

Waste with 4%-10% solids content can usually be handled as a liquid, but may need special pumps. Waste with 0%-4% solids content is handled as a liquid with irrigation or flushing consistency. Liquids which have had the larger solids settled or filtered out or wastes with dilution water added may have 4% or less solids.

Manure

Table 2-1 lists manure properties. Because of the variations in animal manure properties, the values

Table 2-1. Manure production and characteristics as produced.

Values are approximate. The actual characteristics of a manure can easily have values 30% or more above or below the table values. The volumes of waste that a waste handling system has to handle can be much larger than the table values due to the addition of water, bedding, etc. For example, liquid waste systems for swine farrowing and gestation units may have to handle twice as much waste volume as indicated; swine nurseries 3-4 times as much, because of large amounts of wash and wasted water.

Animal	Size, lb	Total manure production			Water, %	Density lb/ft ³	TS lb/day	VS lb/day	BOD ₅ lb/day	Nutrient content, lb/day		
		lb/day	ft ³ /day	gal/day						N	P ₂ O ₅	K ₂ O
Dairy cattle	150	13	0.21	1.6	87.3	62	1.8	1.5	0.24	0.064	0.03	0.05
	250	22	0.35	2.6	87.3	62	3.0	2.5	0.40	0.106	0.04	0.09
	500	43	0.69	5.2	87.3	62	6.0	5.0	0.80	0.213	0.09	0.17
	1,000	86	1.39	10.4	87.3	62	12.0	10.0	1.60	0.425	0.17	0.34
	1,400	120	1.94	14.5	87.3	62	16.8	14.0	2.24	0.595	0.24	0.48
Beef cattle	500	30	0.48	3.6	88.4	63	4.3	3.6	0.8	0.17	0.13	0.15
	750	45	0.71	5.3	88.4	63	6.4	5.4	1.2	0.26	0.19	0.22
	1,000	60	0.95	7.1	88.4	63	8.5	7.2	1.6	0.34	0.25	0.30
	1,250	75	1.19	8.9	88.4	63	10.6	9.0	2.0	0.43	0.31	0.38
Cow ^a		63	1.00	7.5	88.4	63	7.3	6.2	1.7	0.36	0.273	0.313
Swine												
Nursery pig	35	2.3	0.04	0.3	90.8	62	0.39	0.30	0.11	0.02	0.012	0.012
Growing pig	65	4.2	0.07	0.5	90.8	62	0.72	0.55	0.20	0.03	0.022	0.023
Finishing pig	150	9.8	0.16	1.2	90.8	62	1.65	1.28	0.47	0.07	0.050	0.054
	200	13.1	0.21	1.6	90.8	62	2.20	1.71	0.63	0.09	0.067	0.072
Gestating sow	275	9.0	0.15	1.1	90.8	62	0.82	0.66	0.27	0.07	0.050	0.050
Sow and litter	375	22.5	0.36	2.7	90.8	62	2.05	1.64	0.68	0.10	0.055	0.055
Boar	350	11.5	0.19	1.4	90.8	62	1.04	0.84	0.34	0.09	0.064	0.064
Sheep	100	4	0.06	0.4	75.0	64	1.10	0.92	0.12	0.042	0.020	0.039
Poultry												
Layers	4	0.21	0.0035	0.026	74.8	60	0.064	0.048	0.013	0.0029	0.0025	0.0014
Broilers	2	0.14	0.0022	0.016	74.8	63	0.044	0.034	0.0024	0.0017	0.0009	—
Horse	1,000	51	0.81	6.06	79.5	63	15	10	1.7	0.30	0.161	0.301

Source: American Society of Agricultural Engineers, data adapted from 1992 ASAE standard D384.1

Swine data based on Purdue University findings

^aNot ASAE data

TS = Total solids (taken from 1992 ASAE data)

VS = Volatile solids (taken from 1992 ASAE data)

BOD₅ = The oxygen used in the biochemical oxidation of organic matter in 5 days at 68 F. A standard test to assess wastewater strength.(taken from 1992 ASAE data)

N = Total nitrogen

Elemental P (Phosphorus) = 0.44 x P₂O₅

Elemental K (potassium) = 0.83 x K₂O

Densities are from 1992 ASAE Standards

Nutrient contents taken from Purdue University data

Cow = 1.05 ft³/day

in Table 2-1 are estimates rather than accurate data for your farm.

Nutrient losses during storage and treatment are discussed in the animal waste utilization section.

Estimate livestock weights from Fig 11-1.

Table 2-2. Nutrients in livestock manure as produced.
Nutrients produced per animal per year.

Animal	Size, lb	N, lb/yr ^a	P ₂ O ₅ , lb/yr ^a	K ₂ O, lb/yr ^a
Dairy cattle	150	23	11	18
	250	39	15	33
	500	78	33	62
	1,000	155	62	124
	1,400	217	88	175
Beef cattle	500	62	47	55
	750	95	69	80
	1,000	124	91	110
	1,250	157	113	139
Cow		131	100	114
Swine				
Nursery pig	35	7.3	4.4	4.4
Growing pig	65	11	8.0	8.4
Finishing pig	150	26	18	20
	200	33	24	26
Gestating sow	275	26	18	18
Sow and litter	375	37	20	20
Boar	350	33	23	23
Sheep	100	15	7	14
Poultry				
Layers	4	1.06	0.91	0.51
Broilers	2	0.88	0.62	0.33
Horse	1,000	110	59	110

^alb/yr = lb/day × 365 × animal weight + 1,000

Bedding

Some wastes include bedding. Table 2-3 lists density and water-absorbing capacity of common beddings. To estimate the amount of bedding used, weigh the bedding added to each pen per week and multiply by the number of pens and weeks between cleaning.

To estimate the total **weight** of bedding and manure, add the amount of manure produced per animal from Table 2-1 (solids and liquids) to the amount of bedding; subtract any liquids to be drained off that are not absorbed by the bedding. If well bedded, neglect drained liquids.

Total weight = manure weight + bedding weight

To estimate the **volume** of manure and bedding, add the manure production volume, Table 2-1, to ½ of the bedding volume. Bedding volume is halved during use.

Total volume = manure volume + ½ bedding volume

Example 2-1:

Calculate storage requirements for manure with bedding for a 100-milking cow herd in free stall housing using chopped straw bedding.

Table 2-3. Bedding materials.

Approximate water absorption and density of dry bedding (typically 10% moisture).

2-3a. Water absorption of bedding.

Material	lb water absorbed per lb bedding
Wood	
Tanning bark	4.0
Fine bark	2.5
Pine	
Chips	3.0
Sawdust	2.5
Shavings	2.0
Needles	1.0
Hardwood chips, shavings or sawdust	1.5
Corn	
Shredded stover	2.5
Ground cobs	2.1
Straw	
Flax	2.6
Oats	
Combined	2.5
Chopped	2.4
Wheat	
Combined	2.2
Chopped	2.1
Hay, chopped mature	3.0
Shells, hulls	
Cocoa	2.7
Peanut, cottonseed	2.5
Oats	2.0

2-3b. Bedding material density.

Form	Material	Density lb/ft ³
Loose	Alfalfa	4-4.4
	Nonlegume hay	3.3-4.4
	Straw	2-3
	Shavings	9
	Sawdust	12
Baled	Alfalfa	6-10
	Nonlegume hay	6-8
	Straw	4-5
	Shavings	20
Chopped	Alfalfa	5.5-7
	Nonlegume hay	5-6.7
	Straw	5.7-8

Table 2-4. Bedding requirements for dairy cattle.

Housing system	Type of bedding		
	Long straw	Chopped straw	Shavings
	lb/day per 1,000 lb weight		
Stanchion barn	5.4	5.7	
Free stall housing		2.7	3.1
Loose housing bedding area	9.3	11.0	

Solution:

1. Determine the manure produced per day for each group of animals (typical Holstein dairy herd size distribution):

No. of head	Age group	Housing type	Animal weight, lb	Manure production, ft ³	Bedding lb	Bedding ft ³
80	Milking cows	Free stall	1,400	155 ^a	302 ^b	22 ^b
20	Dry cows	Free stall	1,400	39	76	5
51	Heifers, 10 mo. to freshening	Free stall 1½	900	64	124	9
25	Calves to 10 mo.	Free stall	400	14	27	2
13	Calves, birth to 1½ mo.	Individual stalls	110	2		
Total				273	529	38

^aFrom Table 2-1, 1,000 lb dairy cows produce 1.39 ft³ total manure/day.

Manure calculation example:

For the 900 lb heifers:

$(1.39 \text{ ft}^3 + 1,000 \text{ lb}) \times 900 \text{ lb} \times 51 \text{ animals} = 64 \text{ ft}^3$

^bThe bedding calculation is based on 2.7 lb chopped straw used/1,000 lb animal/day for free stalls, Table 2-4, and 7 lb/ft³ density of chopped straw, Table 2-3b.

Volume of bedding is reduced to ½ for storage.

For the milking cows:

$80 \times 2.7 \times (1,400 \div 1,000) = 302 \text{ lb straw/day}$

$302 \times \frac{1}{2} \div 7 = 22 \text{ ft}^3 \text{ straw/day}$

2. Determine total storage required for a 180-day storage period. The cattle have free access to an outside loafing area, so ½ of the manure is deposited on the ground and is not stored as solid manure.

For stall barn housing, all solids, liquids and bedding are typically stored together. In some barns and some storages, the liquids are drained off and handled separately. For this example, assume about half of the manure is not included in storage.

For 100 cow dairy herd in free stall housing	Storage capacity, ft ³
½ of manure = ½ × 274 × 180	24,660
Bedding = 38 × 180	6,840
Total	31,500

Increase storage volume for rain and snow.

Adding Bedding to Manure

Some manure systems require that the manure be solid—a consistency that does not flow but stays in a pile. Add bedding material such as straw or wood-chips to manure to produce a solid waste. See Table 2-5.

Bedding moisture content determines the weight of bedding needed. Only ⅓ as much dry sawdust or ⅓ as much as dry baled straw is needed compared with wet green sawdust. Storing sawdust under cover reduces the amount needed by 25%, so consider covered storage.

Table 2-5. Bedding required for solid manure.

For dairy cows.

Bedding type	Approximate moisture content, %	Bedding required lb/cow-day
Green sawdust		
Stored uncovered	75	27.5
Stored covered	25	19.0
Dried sawdust	10	9.0
Baled straw	10	4.0

Estimate the amount of bedding to add to raise manure solids content (or lower its moisture content) from Fig 2-1.

Example 2-2:

Numbers in parentheses refer to example points on the chart in Fig 2-1.

(1) To increase solids content from 6% to

(2) 15%, add

(3) 12 lb of bedding per 100 lb manure.

Or:

(3) Adding 12 lb bedding to 100 lb manure raises solids content from

(1) 6% to

(2) 15%.

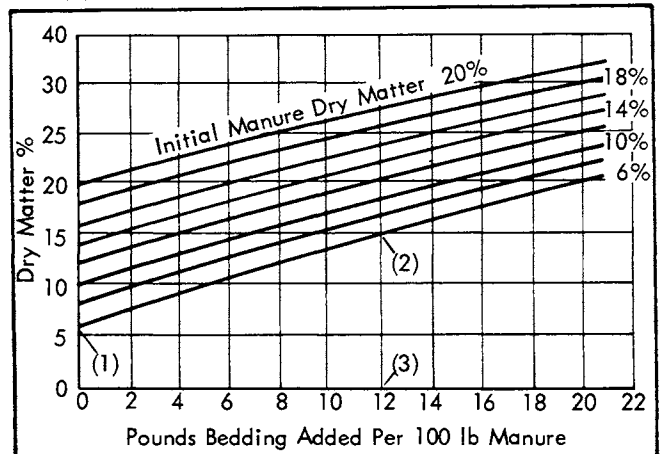


Fig 2-1. Changing manure dry matter by adding bedding.

For bedding with 10% moisture content. Procedure: Find the sloped line that corresponds to the manure's initial dry matter content (1). Follow the line until it meets the horizontal line that corresponds to the desired dry matter (solids) content (2). Then go down to read the pounds of bedding to be added per 100 lb manure (3) to reach the desired solids content.

Diluting Manure

In liquid manure systems, dilution water often enters the manure from cleaning water and waterer overflow. To measure cleaning water used, determine the time required to fill a container of a known size with the hose and nozzle used.

Cleaning water discharge rate, gpm = (gallons filled × 60) ÷ (seconds to fill)

Waterer overflow is difficult to predict or measure. Prompt waterer valve maintenance keeps overflow at a minimum.

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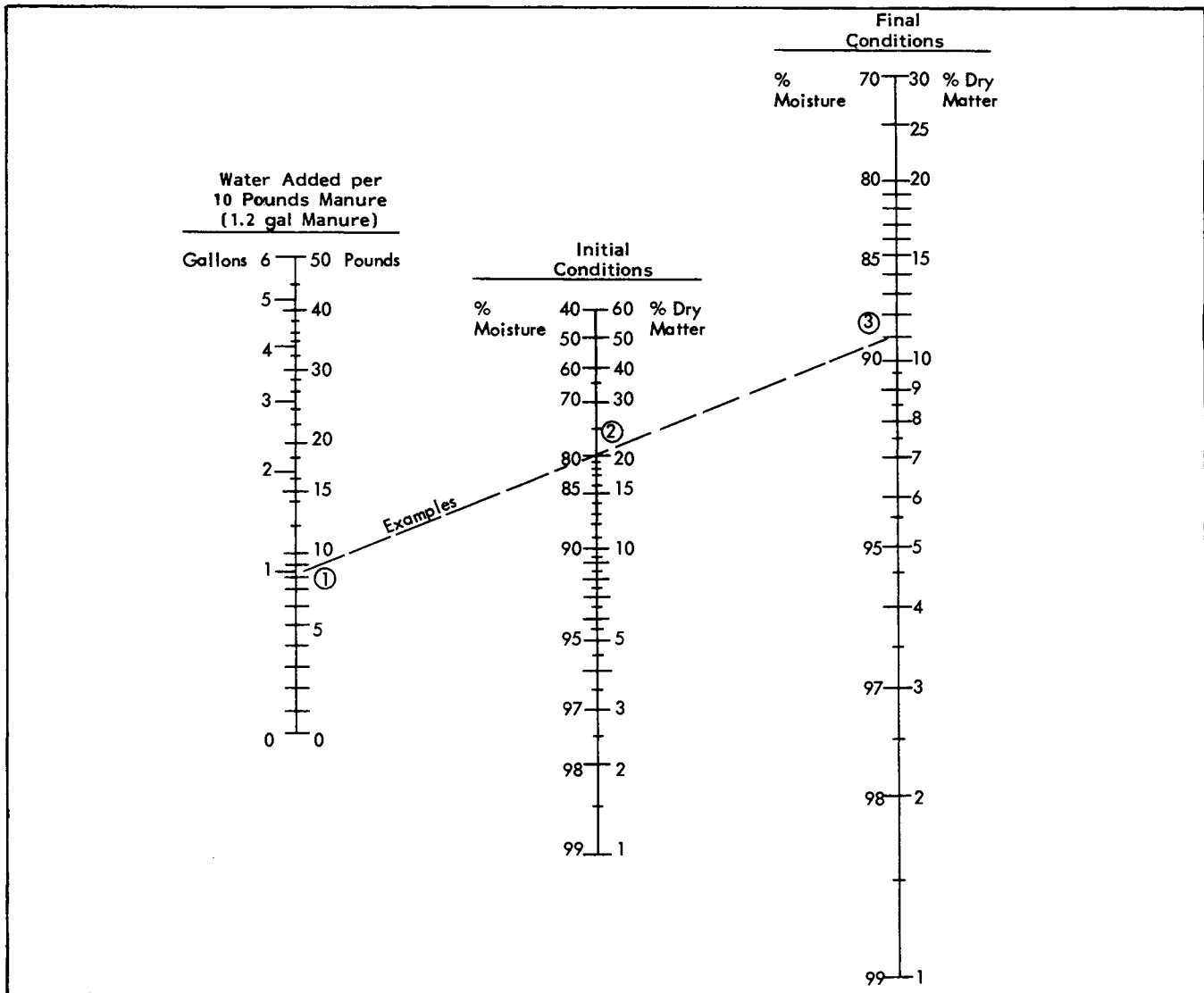


Fig 2-2. Moisture content of diluted manure.

If any two of these conditions are known, the third can be found by drawing a straight line through the two known points and intersecting the column with the unknown condition.

Determine the manure solids content after dilution, or the amount of water needed to dilute manure to a desired solids content from Fig 2-2.

Example 2-3:

Numbers in parentheses refer to example points on the chart in Fig 2-2.

- (1) 8 lb water (nearly 1 gal) added to 10 lb manure at
- (2) 20% dry matter content (80% moisture) dilutes the manure to
- (3) 11% dry matter (89% moisture).

Or:

- (2) To dilute manure at 20% solids to
- (3) 11% solids, add
- (1) 1 gal water per 1.2 gal manure.

Milkhouse and Parlor Wastes

Management and equipment greatly affect the volume of wastes from milking and cleaning operations. If cow udders are washed with paper towels and

disinfectant, there is little waste; with an automatic prep stall, water use can be about 9 gal/day for each cow washed. Floors can be washed with relatively little water and a stiff-bristle broom, or hosed down with a lot of water.

Table 2-6 includes data summarized from manufacturer's recommendations and field observations in several states. Small units tend to use less cleaning water overall, but require more per cow/day. A 100-cow unit with automatic washing equipment can use over 800 gal/day, requiring over 3,200 ft³/month additional storage volume.

Milking center wastewater can resemble:

- Dilute liquid manure—when it contains large amounts of feed, bedding, and hoof dirt. Some of the solids settle; others float.
- Dilute milk plant wastes—during equipment washing. The suspended milk solids do not settle easily. The residual cleaning chemicals are usually concentrated enough to affect subsequent treatment and disposal.

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- Concentrated milk processing wastes—if it contains colostrum or medicated or spilled milk.
- Plain water—when from final pipeline rinses and water-cooled equipment.

Milking Center Wastewater Disposal

Do not dispose of milkhous and parlor wastewater into field tile, streams, lakes, or groundwater. Septic tank, soil absorption systems are also **not** recommended for milking center wastewater. Milk solids do not settle in septic tanks so they carry over into the soil absorption system and plug the soil so absorption stops. Milking center wastewater can be disposed of in one of the following:

- Liquid manure system
- Runoff holding pond
- Separate lagoon
- Grassed infiltration area
- Sand filtration

A separate septic system is required for human wastes from toilet facilities. Check with your local health department. Refer to MWPS-24, *Onsite Domestic Sewage Disposal Handbook*, for more information.

Lagoons receiving only milking center wastewater and precipitation falling directly on the lagoon generally remain partially aerobic and reasonably odor free. Lagoons designed to store milking center wastewater for 6 to 8 months usually require pumping only about once per year due to evaporation and infiltration. A surface area of 50-60 ft²/cow and a 5' design depth is recommended if wastewater production rates are not known. See the information on lagoons in the biological treatment section.

Table 2-6. Volume of milkhous and parlor wastes.

All but toilet water may be reused as flush water for free stall alley flushing. Use the larger values of the range for smaller herds (less than 150 cows) and the smaller values for larger herds.

Washing operation	Water volume
Bulk tank	
Automatic	50 to 60 gal/wash
Manual	30 to 40 gal/wash
Pipeline	
In parlor*	75 to 125 gal/wash
Pail milkers	30 to 40 gal/wash
Misc. equipment	30 gal/day
Cow prep	
Automatic	1 to 4½ gal/wash per cow
Estimated average	2 gal/wash per cow
Manual	¼ to ½ gal/wash per cow
Milkhous floor	10 to 20 gal/day
Toilet	5 gal/flush
Parlor floor without flushing	40 to 75 gal/day
Parlor and holding area with flushing	
Parlor only	20-30 gal/cow-day
Parlor and holding area	25-40 gal/cow-day
Holding area only	10-20 gal/cow-day

*Volume increases for long lines in a large stanchion barn.

Gases and Odors

Consider the air quality in the vicinity of your operation as well as inside the livestock buildings. Wastes stored under slotted floors may be in the buildings long enough for bacterial action to produce gases and strong odors. Odors can be a nuisance to producers and cause complaints and even lawsuits by neighbors. Noxious gases can irritate both livestock and operators, and can be harmful and even lethal. Pit ventilation may be necessary in extreme cases.

Atmospheric air is 78% nitrogen, 21% oxygen, 0.9% argon, 0.03% carbon dioxide, and smaller amounts of inert gases. Air composition is changed in livestock buildings. Breathing uses oxygen and releases carbon dioxide. An oxygen content in the air of less than 10% is dangerous. Odors are given off from animals' skins, urine, and manure. Anaerobic decomposition of manure in a pit releases additional noxious gases. If ventilation is not adequate, concentrations of certain toxic gases within enclosed buildings can harm animals and operators.

Noxious Gases

Most gas generated in an enclosed animal building is carbon dioxide, ammonia, hydrogen sulfide, and methane, all of which are colorless, Table 2-7. Organic compounds from uncontrolled decomposition of wastes include odorous gases such as amines, amides, mercaptans, sulfides, and disulfides.

In an environmentally controlled building, noxious gases usually do not reach lethal or even harmful concentrations except with ventilation failure or vigorous manure pit agitation.

Carbon dioxide (CO₂)

General description. Carbon dioxide is highly soluble in water. It is released from manure decomposition and animal respiration. Most of the gas bubbling up from liquid manure lagoons is CO₂.

Human responses. Carbon dioxide is not highly toxic in itself, but it contributes to oxygen deficiency or asphyxiation. Small increases above normal seem harmless, but a 10% concentration (by volume) causes violent panting, and above this is narcotic even if there is adequate oxygen. At a 25% concentration, death occurs after a few hours.

Animal responses. At a 4% concentration, CO₂ increases the depth and rate of respiration; a 7%-9% concentration can be tolerated, but with considerable discomfort. Concentrations above 10% may produce dizziness and even unconsciousness.

The average CO₂ concentration in a normally ventilated hog confinement unit may be 0.06%-0.07%, about twice the normal atmospheric level. Without ventilation, the level can rise to over 0.4% in 6 hr.

Ammonia (NH₃)

General description. Ammonia is also highly soluble in water. It does not burn readily, but mixtures of over 16% with air are explosive.

Ammonia is released from fresh manure and during anaerobic decomposition. Its solubility in water is

Exhibit 1100

Table 2-7. Properties and effects of noxious gases.

This table is based on adult humans.

Gas	Odor	Odor threshold, ppm	Threshold limit value		Concentration effects		
			Time-weighted average (8-10 hr) ppm	Short term exposure (15 min) ppm	Level ppm	Exposure period, min	Physiological effects
		(a)	(b)	(c)	(d)	(e)	
Carbon dioxide (CO ₂)	None	—	5,000	30,000	20,000	—	Asphyxiant
					30,000	—	Safe
					40,000	—	Increased breathing
					60,000	30	Drowsiness, headaches
					300,000	30	Heavy, asphyxiating breathing Could be fatal
Ammonia (NH ₃)	Sharp, pungent	5	25	35	400	—	Irritant
					700	—	Throat irritant
					1,700	—	Eye irritant
					3,000	30	Coughing and frothing
					5,000	40	Asphyxiating Could be fatal
Hydrogen sulfide (H ₂ S)	Rotten egg smell, nauseating	0.7	10	15	100	Several hours	Poison
					200	60	Eye and nose irritant
					500	30	Headaches, dizziness
					1,000	—	Nausea, excitement, insomnia Unconsciousness, death
Methane (CH ₄)	None	—	—	30,000 ^f	500,000	—	Asphyxiant Headache, nontoxic
Carbon monoxide (CO)	None	—	50	200	500	60	Poison
					1,000	60	No effect
					2,000	60	Unpleasant, but not dangerous
					4,000	60+	Dangerous Fatal

^aA mixture of gas and air in this range can explode with a spark.^bAbout the lowest concentration at which odor is detected.^cMaximum allowable concentration allowed by health agencies for workers in 8 to 10 hr periods.^dParts of pure gas per million parts of atmospheric air. Divide by 10,000 for % by volume: 20,000 ppm / 10,000 = 2% by volume.^eThe time for the effects of the gas to be felt.

lowered when the pH is raised, as by the addition of lime. Ammonia can be controlled somewhat in liquid manure systems, because much of it dissolves in the water. High water solubility explains the greater ammonia odors in units with litter or solid floors (such as in scraper systems) than in liquid manure units. Heated floors also promote ammonia production and release.

Odor from as little as 1 ppm (0.0001%) can be detected and identified. Dimethylamine has the characteristic pungent odor of ammonia and irritates mucous membrane and respiratory tract.

Human responses. Low concentrations irritate eyes and the respiratory tract; more may cause suffocation; a 0.5% concentration is a dangerous level. Ammonia begins to burn eyes at 25 to 30 ppm (0.0025%-0.0030%).

Animal responses. Ammonia is an irritant, and at concentrations up to 0.02%, induces sneezing, salivation, and appetite loss, but no loss of feed efficiency. Above 50 ppm (0.005%), eye inflammation develops in chickens. Prolonged exposure may increase respiratory diseases and pneumonia.

Ammonia can condense and subsequently oxidize to nitrite or nitrate. These compounds may accumulate on the floor and cause poisoning if ingested.

Hydrogen sulfide (H₂S)

General description. Hydrogen sulfide is the most toxic gas associated with liquid manure storage. It is soluble in water, so it can be controlled somewhat by high dilution of manure. The gas burns with a bluish flame and, in a mixture with oxygen, can explode violently. It smells like rotten eggs.

Hydrogen sulfide is produced by anaerobic decomposition of organic wastes. High concentrations can be released by agitation and pumping of liquid wastes.

Paper impregnated with lead acetate solution turns black in hydrogen sulfide and indicates its presence. Hydrogen sulfide forms black copper sulfide on copper, white zinc sulfide on galvanized steel, and black discoloration of lead-pigmented white paint.

Human responses. It is both an irritant and an asphyxiant. Low concentrations severely irritate eyes

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and respiratory tract in an hour. Concentrations of 0.1% cause immediate unconsciousness, and death through respiratory paralysis occurs unless artificial respiration is immediate.

The sense of smell can be rapidly fatigued by H_2S . Higher concentrations do not proportionately increase odor, so odor is not always an adequate warning.

Animal responses. High concentrations during agitation can cause death. Hydrogen sulfide concentrations as high as 0.08% have been reported in confinement hog houses during agitation and for several minutes thereafter.

Animals living continuously at levels of about 20 ppm (0.002%) develop fear of light, nervousness, and appetite loss that decreases daily gain. Symptoms at 50 to 200 ppm (0.005%-0.02%) include vomiting, nausea, and diarrhea. With normal ventilation, the levels of hydrogen sulfide can be maintained well below 20 ppm (0.002%) except, perhaps, during pit agitation.

Methane (CH_4)

General description. Methane is not very soluble in water, is highly flammable, and burns with a blue flame. It is most hazardous in a highly explosive mixture with air in concentrations as low as 5%.

Ruminant animals exhale a minute amount of methane, but most comes from manure decomposition.

Being lighter than air, methane tends to rise and accumulate near the top of stagnant corners or tightly enclosed manure storage pits. Methane dissipates fairly rapidly with some ventilation.

Human and animal response. Methane normally is not considered a toxic gas. Accumulations in stagnant areas of buildings or manure storage pits can be asphyxiating, but explosions are a more serious concern.

Carbon monoxide (CO)

CO is a colorless and odorless gas about the same weight as air. It is exhausted from gas engines and from gas, oil, and coal heaters. Vent engines to the outside to prevent toxic carbon monoxide accumulations. Provide adequate ventilation with unvented heaters to prevent toxic concentrations.

Potentially Lethal Situations

Ventilation breakdown, with no natural drafts to replenish the air, can cause death by asphyxiation from lack of oxygen and increased carbon dioxide, by heat prostration, by poisoning from other gases, or some combination.

Agitation of liquid manure releases large quantities of noxious gases and creates dangerous and possible lethal conditions, even with maximum ventilation. If manure under slotted floors must be agitated with animals in the building, choose a mild day so you can ventilate at the maximum capacity and watch for signs of ill effects. For naturally ventilated buildings, you want a windy day. If possible, remove animals before agitation.

Entering a storage pit is extremely dangerous. Death can result from hydrogen sulfide or lack of oxygen. If an animal falls into a pit, do not follow it. Enter a manure storage only after it has been well ventilated; wear self-contained breathing tanks; and have an attached safety rope with at least two people standing by who are able to pull you out at the first sign of dizziness.

Methane accumulates in unvented covered pits creating explosive conditions. Do not introduce a flame or spark unless the pit has first been ventilated.

Livestock Area Odor, Gas Control

Prevent their production and accumulation:

- Clean solid floors daily by flushing or scraping. Locate quick connect water lines along the length of buildings so high pressure washers can easily be used.
- Keep bedding dry. Ventilate to dry wet areas quickly, or add new bedding.
- If manure is stored or collected beneath a slotted floor, exhaust at least some ventilating air from under the slats. This is especially important for long storage periods, for flush or scrape under slat systems, and for slats with little open area (e.g. concrete slats).
- Do not overfill a pit under slotted floors—have at least 12" of clearance between bottom of slat supports and top of manure.
- Add enough water to manure storages to keep manure solids submerged.
- Provide a standby electrical generator for emergency ventilation of a large building.
- Install a ventilation power failure alarm.
- Dust collects and carries odors—reduce dust levels by periodic washing of pen partitions, walls, ceilings, and floors. Cover feeders and adjust to minimize feed spillage.
- Avoid manure storage periods longer than 6 months. The shorter the storage period, the lower the odor levels in the building. While little odor is produced within the first 3 days or so, there is a peak in ammonia production at 3 days and again at 21 days of storage time. Therefore, frequent manure removal will maintain low odor levels.
- Heat exchangers, solar collectors, and other methods of tempering ventilating air allow higher ventilating rates for odor control.

Control of Odors and Gases Leaving the Livestock Area

Odor quality is a comparison with a known odor (rotten eggs, roses, decaying animals, etc.). **Strength** is the amount of fresh air needed to dilute odorous air to the threshold odor level. **Occurrence** includes frequency and total length of time the odor persists.

First, select a site where odors will create the fewest problems. Locate at least $\frac{1}{2}$ mile away from neighboring houses and at least 500' away from the

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farm residence; locate large operations even farther away. Then if necessary, counter the cause, treat the emissions, or both.

Some odorous gases are water soluble—keep manure **diluted** and/or **covered** with water to decrease odor.

High ventilating rates dilute odors around the building to less objectionable strength.

Cover wastes to prevent the release of odors to the atmosphere. Covered storage may be a floating crust on cattle manure, a plastic cover, or a concrete lid on a tank. Immediate plowdown or chisel injection of wastes decreases odors from field spreading and also decreases nitrogen loss by ammonia volatilization. See animal waste utilization section.

Some chemical treatments reduce odors but not all of them are effective. Hydrated lime reduces hydrogen sulfide and carbon dioxide production but increases ammonia liberation, which decreases fertilizer value. Chlorine stops bacterial action, reducing odors, but is expensive and dangerous. Both

treatments require relatively large amounts of chemicals, may require special equipment, have some detrimental results, and are at best temporary cures to odor problems. Beware of pills or potions claiming to eliminate odors. Purchase odor control products on a limited basis or on a "pay if satisfied" basis. Controlled university tests have failed to produce convincing evidence of their effectiveness.

It is usually impractical to eliminate odors from animal buildings. Schedule cleaning and manure hauling at times least offensive to those living nearby. Let your neighbors know that you recognize odor problems and are trying to minimize them.

Put your best foot forward in the community. Do not be a recluse. Join and be active in civic organizations. Get to know your neighbors well. Keep your operation clean, painted, and attractive. Construct lagoon banks above eye level and do not make side-slopes too steep to mow. Operations in disrepair, overgrown with weeds, and with exposed dead animals often end up facing nuisance lawsuits.

3. COLLECTION AND TRANSPORT TO STORAGE

Several collection methods are possible. Some systems combine collection and storage functions, such as a built-up manure pack or slotted floors over a liquid tank. In selecting a collection system, consider:

- Type of facility.
- Labor requirements.
- Investment.
- Total waste handling system.

Flooring Systems

Slotted Flooring

In this book, slotted flooring refers to slats and perforated or mesh flooring. Slotted flooring rapidly separates an animal from its manure. Slotted flooring materials, spacing, and width depend on the manure properties and experience with slipping, foot injury, and other animal response, Table 3-1.

When selecting slotted flooring, consider initial cost, predicted life, intensity of use (wear rate), strength, corrosion, fire, noise, and replacement cost. Tapered slats (greater top than bottom width) tend to pass wastes better than uniform-width slats, especially for depths greater than 1".

Concrete slats are the most common and durable but are the heaviest and require the strongest supports. Wood wears, warps, and is chewed by hogs, leaving irregular slat spacing. Manufactured slotted floor systems of steel, aluminum, and plastic are more uniform than wood or concrete. They may be easier to handle, install, and replace than concrete, but are more expensive and may not last as long. Slat life varies considerably with installation and management practices.

Install slotted flooring securely because twisting, flexing, or shifting may damage the flooring or pinch animals. For ease of installing commercial slats, make the opening $\frac{1}{2}$ "-1" longer than the slat length to allow for variation. In buildings where slats are parallel to a wall or partition, leave $1\frac{1}{2}$ "-3" space to avoid solids buildup, Fig 3-1.

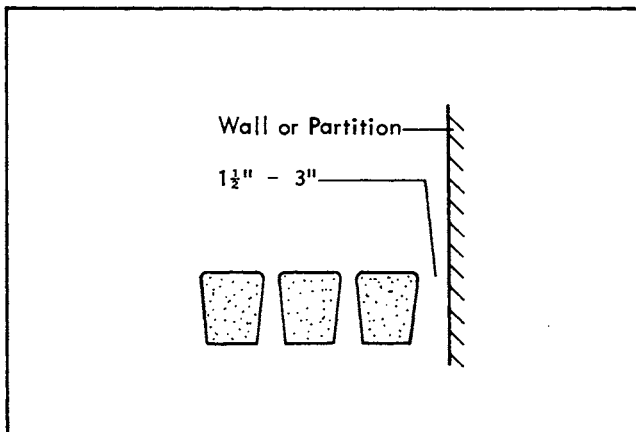


Fig 3-1. Space slats from wall.

Table 3-1. Slat size and spacing.

Dashed lines refer to Example 3-1.

Animal	Spacing between slats	
	Narrow slats (1 $\frac{1}{4}$ "-3")	Wide slats (4"-8")
Beef	Not recommended	$1\frac{1}{2}$ "-1 $\frac{3}{4}$ "
Dairy		
Cows	Not recommended	1 $\frac{1}{2}$ "-1 $\frac{3}{4}$ "
Calves	$\frac{3}{4}$ " between lumber 1x2s on edge, elevated calf stall	1 $\frac{1}{4}$ "
Sheep		
Ewes	1"	1"
Lambs	Slats not recommended; use unflattened expanded metal	
Feeders		
Swine		

Avoid slots between $\frac{3}{8}$ " and $\frac{3}{4}$ " wide. Wire mesh, metal, or plastic slats are preferred for farrowing and pre nursery.

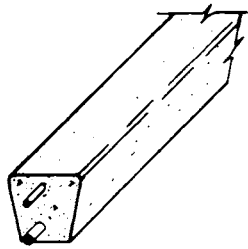
Use 1" slots behind sow, but cover them during farrowing.

Provide solid floor and firm footing for breeding.

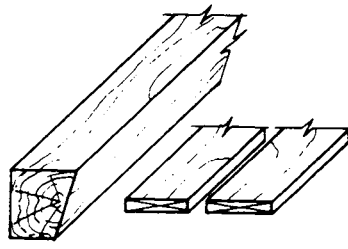
	Slot width in.	Concrete slat width, in.
Sow and litter	$\frac{3}{8}$	4
Pre nursery pig	$\frac{3}{8}$	Not recommended
Nursery pig	1	4
Growing-finishing pig	1	6-8
Gestating sow or boar		
Pens	1	6-8
Stalls	1	4

Experience shows that the following guidelines help maintain clean floors in **partly slotted swine** buildings.

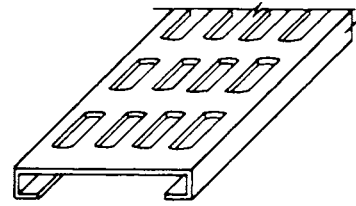
- Slat at least 67% of the floor area for pigs under 30 lb; at least 40% for pigs 30 to 75 lb; and at least 30% for pigs over 75 lb.
- Use a long, narrow pen shape (length 2 to 4 times the width). Minimum pen width is 4' for pigs under 30 lb and 5' for pigs 30 to 75 lb.
- Use solid partitions over solid floors and open partitions over slotted areas. Pigs tend to dung where it is damp and cooler, and sleep in drier areas away from drafts.
- Place feeders on solid floors and waterers over slats.
- Provide a 1"-2" step between slotted and solid floors to separate dunging and sleeping areas and to keep manure off the solid floor.
- Provide supplemental zone heat in solid floor areas for small pigs in cold weather.
- Keep the pens full. Sparsely filled pens are more apt to have dirty floors.
- Use hinged or removable hovers over the sleeping areas to reduce drafts and retain heat.
- Wet down the slotted area just before putting pigs in the pen.
- Feed on the solid floor for the first few days.
- Adjust the ventilating system so the cold incoming winter air falls first to the slotted area, not into the resting area.



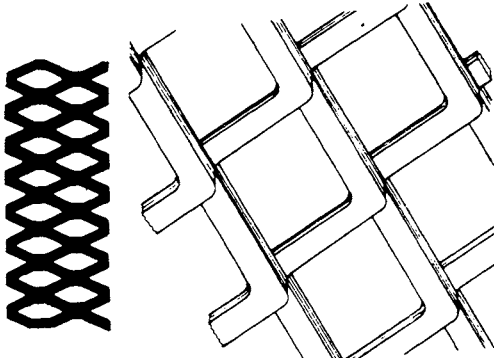
3-2a. Reinforced concrete.



3-2b. Wood.

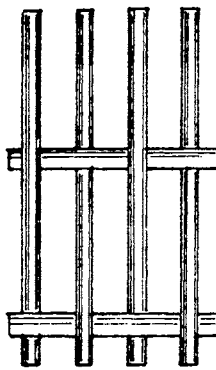


3-2c. Punched or perforated plastic or steel.

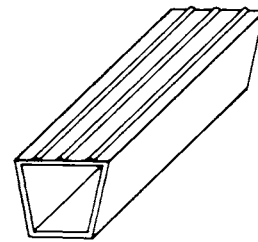


Flattened

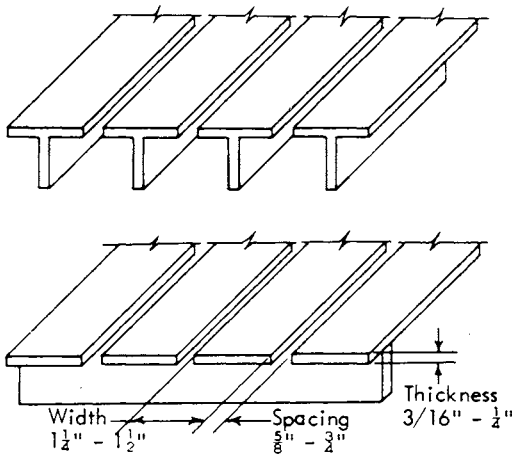
3-2d. Expanded metal.



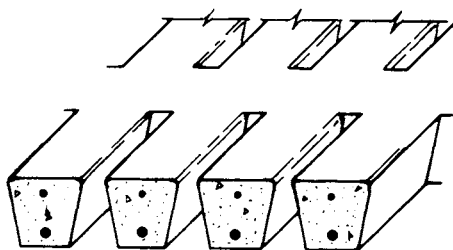
3-2e. Woven wire.



3-2f. Extruded aluminum, fiberglass, or plastic.



3-2g. Steel or aluminum bars, straps, or Ts.



3-2h. Reinforced concrete gang slats.

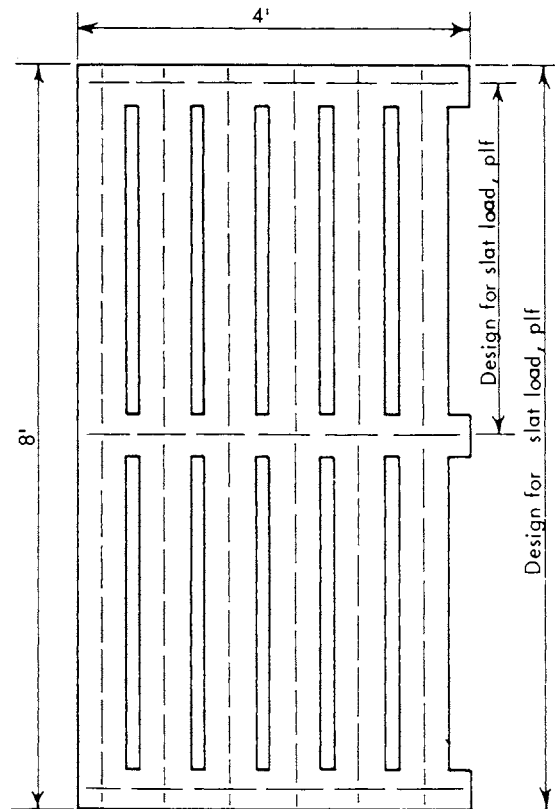


Fig 3-2. Slotted flooring examples.

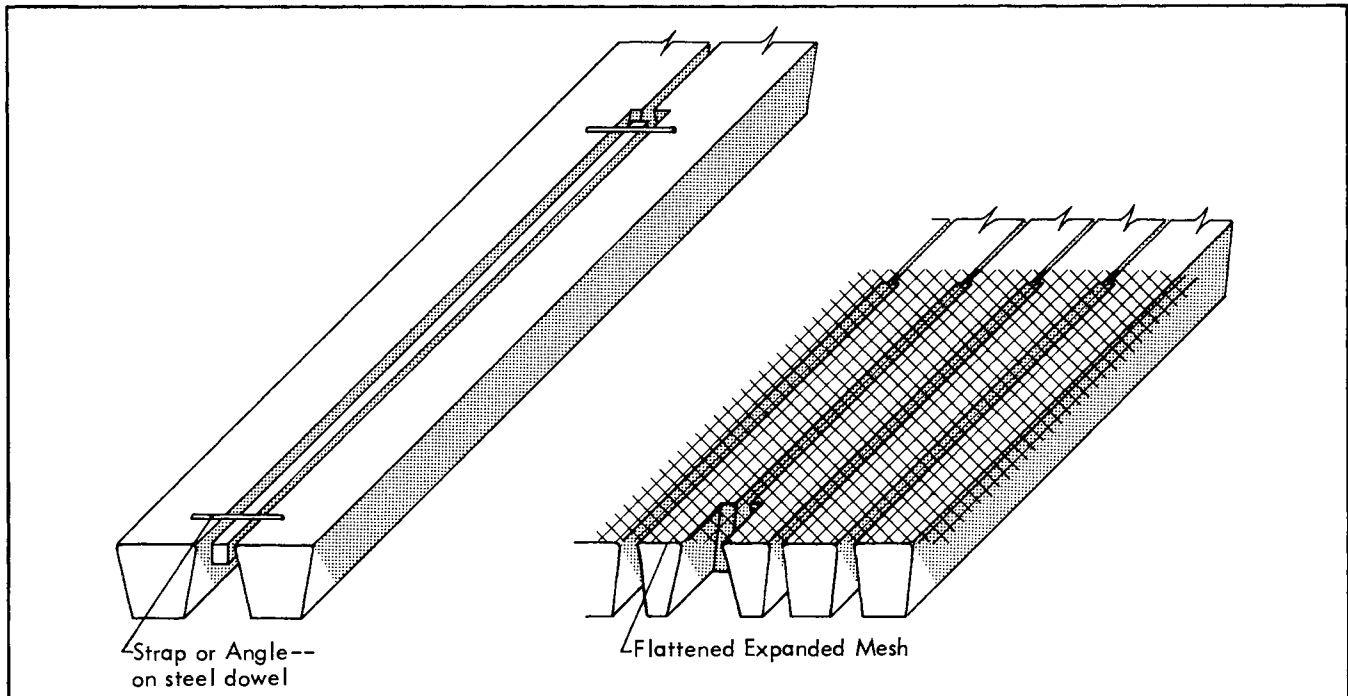


Fig 3-3. Covers for wide slots in farrowing stalls.

Plywood or other panel material can be used, but a material that drains is preferred.

Slat Direction

In partly slotted buildings, place slats parallel to the long dimension of rectangular pens. In swine farrowing and gestation stalls, place slats parallel to the sow.

Slat direction in totally slotted buildings is influenced by other factors, such as construction costs. However, try to place slats parallel to natural traffic flow, so animals walk along rather than across slats. Slats parallel to feeders or farrowing sows aid pigs in feeding.

Slotted Floor Materials

Wood slats

Wood slats are primarily for smaller animals—swine, calves, and sheep, Fig 3-2b. They have the lowest initial cost and the shortest life. Their life expectancy is 2 to 4 years and even less in areas of intensive use, such as around feeders and waterers. Wood slats can be slick. Install them so individual slats or small sections can be replaced as needed.

Oak is best, but other hardwoods such as hickory and maple can be used. Animal performance can be reduced by variable spacing due to warping (particularly with slats less than 3" wide), wear, careless installation, insecure fastening, and uneven slat heights. See Table 3-3 for wood slat designs.

Wood slats are useful in minor remodeling, portable pasture units, and sometimes for repairs. Consider a more permanent material for major new construction.

Concrete slats

Concrete slats are the most durable and work especially well for larger animals, such as swine over

75 lb and cattle. They can be purchased precast, precast at the building site, or cast-in-place, Figs 3-2a, 3-2h, and 3-5. Precast slats may have higher quality material and construction. Consider buying gang slats (two or more slats connected into one section) to reduce installation labor.

When casting slats, use 4,000 psi concrete, Table 3-8. Correctly position reinforcing steel. Locate the load-bearing steel (the bottom bar) in the center, near the bottom of the slat. The small bar near the top is needed for handling the slats and can be omitted from cast-in-place slats.

Slat surface finish varies with animal type and application, Table 3-8. Do not crown slats for cattle or for animals in stalls. Edging slats with a $\frac{1}{4}$ " sidewalk edger prevents chipping, improves cleaning, and reduces foot injuries.

Cure slats for 5 days by covering with plastic, a curing compound, or wet straw.

Plastic water pipe sometimes is placed in the top half of the slat, Fig 3-5d. Set the pipe connections between slats in sand or plastic insulation to permit movement during expansion and contraction. If the plastic pipe does not fit into the zone shown in Fig 3-5d, have the slat design checked by an engineer.

Steel slotted flooring

Steel slotted flooring is for small animals, e.g. hogs, calves, and sheep. Most steel slotted flooring needs to be supported 1'-2' o.c. See Table 3-7 for designs of wood beam supports. Many early steel slats failed after 2 to 4 years because the steel corroded from the underside. Epoxy paint on the underside of steel slats helps. Porcelain-coated steel slats resist corrosion, providing they are not chipped. Plastic-coated slats work well in swine farrowing creep

Exhibit 1400

but some are short-lived under the sows. Stainless steel lasts considerably longer than plain or galvanized steel. See Figs 3-2c to 3-2e and 3-2g.

Woven wire and steel rod mesh work well for swine farrowing and nursery facilities. If foot injuries are a problem in the pig creep, cover the mesh with plywood the first few days after farrowing.

Flattened expanded metal ($\frac{3}{4}$ ", 9 to 11 gauge) works for pigs under 30 lb, but does not last as long as concrete when subjected to concentrated traffic by heavier pigs. Avoid expanded metal with sharp edges. In farrowing stalls, lay expanded metal so the long openings are parallel to the sow.

Unflattened expanded metal ($\frac{3}{4}$ ", 9 gauge) provides a skid-resistant rough surface for sheep to keep their hoofs worn down and to eliminate trimming. Do not use for swine.

Stainless steel slotted planks work well for swine farrowing and nursery units. They are 8"-12" wide and span 4'-10' depending on flange depth.

Grates

Grates of steel straps 1"-1 $\frac{1}{2}$ " wide and $\frac{3}{16}$ "- $\frac{1}{4}$ " thick are used for farrowing, nursery pigs, and other small animals. They are spaced $\frac{3}{8}$ "- $\frac{3}{4}$ " depending on the size of animal.

Removable steel grates of smooth round rods are best for covering the gutter behind dairy cows in stalls, Fig 3-4.

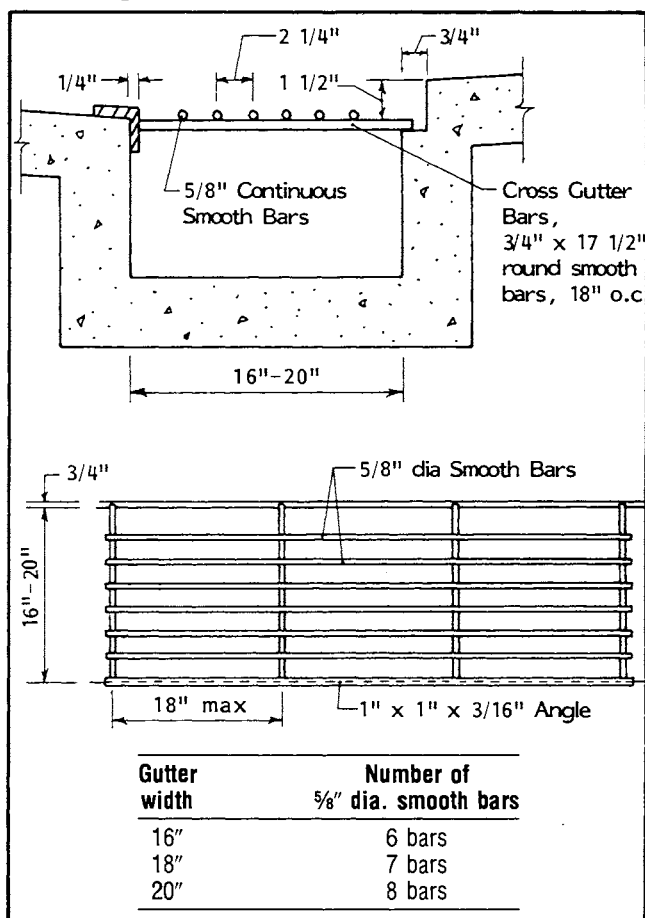


Fig 3-4. Grates for dairy barns.

Use steel angles on both sides if stall platform is not higher than service alley.

Aluminum slats

Aluminum slats are uniform for accurate spacing, lightweight for ease of handling and transporting, and smooth for easy cleaning and to help reduce abrasions of animals' feet and knees. They can be slick for heavier animals. See Figs 3-2f and 3-2g. Aluminum slats can be noisy, if not well supported. This can be a problem with animals that "spook" easily.

Corrosion and deterioration of aluminum slats has been a major problem in many livestock buildings. Insulate steel waterers, feeders, and fencing from the aluminum to prevent electrolytic corrosion—place plastic or rubber insulators between steel and aluminum. Insulate aluminum slats from concrete.

Aluminum slats are available in several shapes, from narrow "T"s to 8" wide punched planks. Follow the manufacturer's recommendations for slat size, spacing, and supports.

Plastic slats

Plastic slotted flooring tends to be slick unless coated with a rough surface or fabricated with a textured surface. Fiberglass reinforced plastic slats are popular for swine farrowing and nursery units. The fiber strands make them more durable. See Figs 3-2c, 3-2f, and 3-2g.

Slat Design

Recommended design live loads for concrete and wood slats are listed in Table 3-2. Three exceptions are:

- An alternate requirement for slats and slat supports under pigs up to 50 lb is one concentrated load of 220 lb (man and pig) located first for maximum moment, then maximum shear.
- Design slats and slat supports in farrowing areas for one concentrated load of 250 lb located first for maximum moment, then maximum shear.
- Where slats are interconnected between supports so that three or more slats must deflect together, Fig 3-2h, design each span of slat between support and interconnection, and between two interconnections, for the recommended load

Table 3-2. Slotted floor design loads.

Dashed lines refer to Example 3-1.

plf = pounds per linear foot = lb per foot of length;

psf = pounds per square foot.

Animal	Live loads for slat design, plf slat	Live distributed loads for girder and column design, psf floor area
Swine		
to 50 lb	50	35
to 200 lb	100	50
to 500 lb	170	70
Sheep	120	50
Calves		
to 400 lb	150	50
Beef, dairy cattle	[250]	[100]

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per unit length of slat. Design the full span of each slat for $\frac{1}{2}$ the recommended load per unit length (an arbitrary recommendation).

Selected slat designs are in Tables 3-3 and 3-4. Some girder designs are in Table 3-5. Table 3-6 has some unreinforced concrete footing and masonry col-

umn designs. For additional information, order TR-3, *Concrete Manure Tank Design*, from one of the addresses on the inside front cover. Table 3-7 gives designs for grid systems to support metal mesh or plastic floors—use only if product literature is not available.

Table 3-3. Native oak dimensions.

Slat application	Slat dimensions BxA	Maximum span	
		Laid flat	On edge
Swine			
Up to 200 lb (Design load = 100 plf)	$1\frac{1}{2}" \times 3\frac{1}{2}"$ $1\frac{1}{2}" \times 5\frac{1}{2}"$	3' 4'	$4\frac{1}{2}'$ 7'
Up to 400 lb (Design load = 150 plf)	$1\frac{1}{2}" \times 3\frac{1}{2}"$ $1\frac{1}{2}" \times 5\frac{1}{2}"$	2' 3'	$3\frac{1}{2}'$ $5\frac{1}{2}'$
Calves			
Dairy replacement up to 300 lb (Design load = 150 plf)	$1\frac{1}{2}" \times 3\frac{1}{2}"$	Laid flat as shown	
Veal up to 450 lb (Design load = 225 plf)	$1\frac{1}{2}" \times 3\frac{1}{2}"$	On edge as shown	

Table 3-4. Selected reinforced concrete slat designs.

BxD = top width x depth, in.; bar size = reinforcing steel size, #3 = $\frac{3}{8}"$, #4 = $\frac{1}{2}"$, etc., and wt, lb/ft = slat weight. Minimum concrete compressive strength is 3,500 psi; minimum steel yield point is 40,000 psi.

Dashed lines refer to Example 3-1.

Slat span ft		Load, lb/ft slat length							
		50	100	120	150	170	250		
4	BxD, in.	4x4	4x4	4x4	4x4	4x4	4x4	4x4	
	Bar size	#3	#3	#3	#3	#3	#3	#4	
	Wt, lb/ft	16.7	16.7	16.7	16.7	16.7	16.7	16.7	
6	BxD	4x4	4x4	4x4	5x5	4x4½	5x5	4x5	5x5
	Bar size	#3	#4	#4	#4	#4	#4	#4	#5
	Wt, lb/ft	16.7	16.7	16.7	26.1	18.7	26.1	20.8	26.1
8	BxD	4x4	5x5	4x5	5x5	4x5	5x5	4x5½	5x5½
	Bar size	#4	#4	#4	#5	#5	#5	#5	#5
	Wt, lb/ft	16.7	26.1	20.8	26.1	22.9	28.6	22.9	28.6
								<u>29.2</u>	31.3

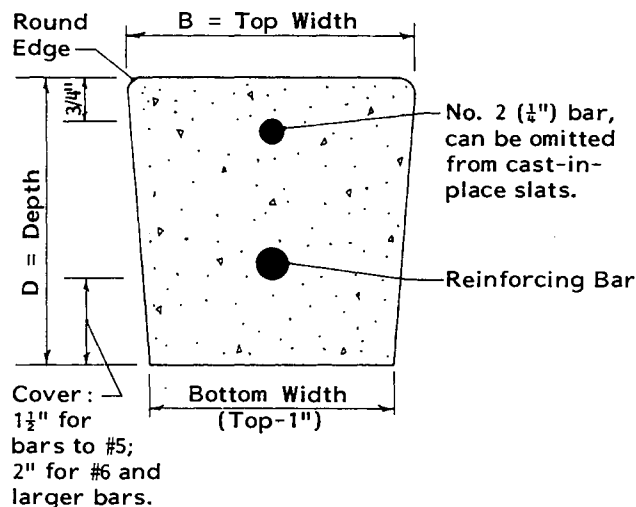
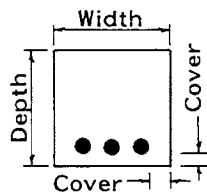
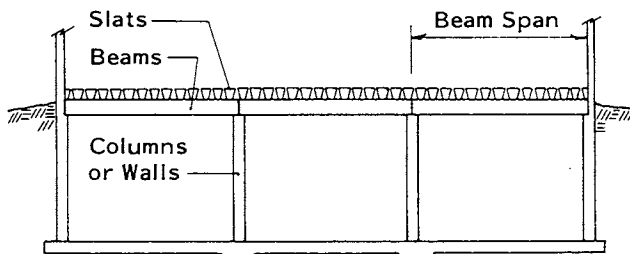


Table 3-5. Reinforced concrete girders to support slotted floors.

Clear distance between bars must not be less than the bar diameter, 1", or 1½ times the size of coarse aggregate.
Dashed lines refer to Example 3-1.

Load lb/ft of girder		Beam span, ft			
		6	8	10	12
500	BxD	6"x6"	6"x7"	7"x8"	7"x9"
	Bars	2#4	2#5	2#6	2#7
600	BxD	6x6	6x8	7x8	7x10
	Bars	2#5	2#5	2#7	2#8
700	BxD	6x6	6x9	7x9	7x10
	Bars	2#5	2#5	2#7	2#8
800	BxD	6x7	7x8	8x8	8x10
	Bars	2#5	2#6	2#8	2#8
900	BxD	6x7	7x9	7x9	9x10
	Bars	2#5	2#6	2#8	3#7
1,000	BxD	6"x8"	8"x8"	8"x9"	9"x10"
	Bars	2#5	2#7	2#8	3#8
1,200	BxD	7x9	9x9	9x10	9x11
	Bars	2#5	2#7	2#8	3#8
1,400	BxD	7x9	9x10	10x11	10x12
	Bars	2#5	2#7	2#8	3#8
1,600	BxD	7x10	9x11	10x12	11x13
	Bars	2#5	2#7	2#8	3#8
1,800	BxD	7x11	10x11	10x13	12x14
	Bars	2#6	3#6	3#7	3#8
2,000	BxD	8"x11"	10"x12"	12"x12"	13"x14"
	Bars	2#6	3#6	3#8	3#8
2,200	BxD	9x11	11x12	12x13	13x14
	Bars	2#6	3#6	3#8	3#8
2,400	BxD	9x11	11x13	12x14	14x15
	Bars	3#5	3#6	3#8	4#8

W = width, in.
D = depth, in.
bars = number of bars and size of bars in bottom of beam
cover = 1½" for sizes through #5; 2" for #6 and larger

**Example 3-1:**

Design a concrete slat floor system for beef cattle.
Slats are 8' long and columns are 8' o.c.

Solution:

From Table 3-2, slats must support 250 plf.

From Table 3-4, use 4"x7" slats with 1-#5 bar. The slats weigh 29.2 lb/ft.

From Table 3-1, space slats 1.5" apart.

$$\begin{aligned}\text{Weight of slats/ft}^2 &= \text{weight/ft} \times [12 \text{ in/ft} \div \\ &(\text{width, in.} + \text{spacing, in.})] \\ &= 29.2 \times [12 \div (4" + 1.5")] \\ &= 63.7 \text{ psf}\end{aligned}$$

Girders must support 100 psf live load, Table 3-2, + 63.7 psf slat weight.

Girders support 8' x (100 + 63.7) = 1,309.6 plf.
From Table 3-5, select a 9"x10" girder with 2-#7 bars.

Table 3-6. Unreinforced concrete footings and masonry columns.

Design load: 125 psf; includes swine up to 200 lb plus slat dead load. Block cores are filled. All footings are square. Soil bearing pressure = 3,000 psf.

Slat length between beams ft	Column height ft	Beam span, ft			
		6	8	10	12
----- Column size -----					
6	4	8"x8"	8"x8"	8"x8"	8"x8"
	8	8"x8"	8"x8"	8"x8"	8"x16"
8	4	8"x8"	8"x8"	8"x8"	8"x8"
	8	8"x8"	8"x8"	8"x16"	8"x16"
10	4	8"x8"	8"x16"	8"x16"	8"x16"
	8	8"x8"	8"x16"	8"x16"	8"x16"
----- Footing, width x depth -----					
6		18"x6"	20"x6"	22"x6"	24"x6"
8		20"x6"	22"x6"	24"x6"	28"x8"
10		22"x6"	24"x6"	28"x8"	30"x9"

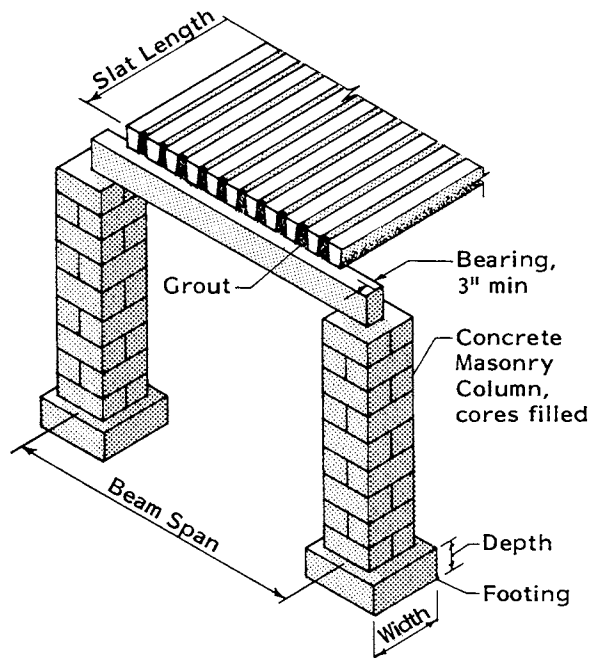


Table 3-7. Wood beams.

For supporting wood, metal, or plastic slotted flooring. **Design load: 60 psf**; includes swine up to 75 lb plus dead load. Bending strength is 1,200 psi for 2x and 800 psi for 4x and 6x lumber. Mesh materials require blocking (or stringers) between the beams 12" o.c. in swine farrowing and 16" o.c. in a swine nursery. All beams are set on edge.

Beam span ft	Beam size					Beam span ft	Beam size				
	2x4	2x6	2x8	2x10	2x12		4x4	4x6	6x6	6x8	4x12
	----- Max. beam spacing, ft -----						----- Max. beam spacing, ft -----				
4	2.55	6.3				4	3.97	9.8			
6	1.13	2.8	4.87	7.92	11.7	6		4.36	6.85		
8	0.64	1.57	2.74	4.46	6.59	8		2.45	3.85	7.16	10.25
10	0.41	1.01	1.75	2.85	4.22	10		1.57	2.46	4.58	6.56

Table 3-8. Floor and slat concrete specifications.

All concrete slats require rounded edges.

Area type	Surface *	Slope		Concrete strength psi	Water-cement ratio lb/lb
		Along length	Across length		
Beef and sheep					
Solid (sleeping area)	Textured	1/4"-1/2"/ft	Flat	3,500	0.53
Slotted (slats)	Grooved & textured	Flat	Flat	4,000	0.49
Gutters					
Open	Smooth	See gutter design	1/2"/ft crown	3,500	0.53
Underslat	Smooth	See gutter design	1/2"/ft crown	4,000	0.49
Pits	Smooth	Flat	Flat	4,000	0.49
Walk/feed alleys	Textured	1/4"/ft to a drain, if there is one	1/2"/ft crown	3,500	0.53
Dairy					
Milking facility					
Parlor platform	Textured	1/4"/ft to a drain, minimum		4,500	0.44
Parlor pit	Textured	1/4"/ft to a drain, minimum		4,500	0.44
Milk room	Textured	1/4"/ft to a drain, minimum		4,500	0.44
Holding area	Grooved	1/4"/ft	—	4,000	0.49
Free stall barn					
Scraped alley	Grooved	0"-1/4"/ft	Flat	4,000	0.49
Flushed alley	Grooved & textured	3/8"-5/8"/ft	1/2" crown	3,500	0.53
Drive alley	Textured	0"-1/4"/ft	Flat	3,500	0.53
Stall base	Textured	4"/7' stall	Flat	3,500	0.53
Feed manger	Smooth	0"-1/4"/ft	Flat	4,000	0.49
Stanchion barn					
Gutter with cleaner	Smooth	Flat or same as alley slope	Flat	4,000	0.49
Work alley	Textured	Flat or same as milkline slope	1/4"/ft crown	3,500	0.53
Feed manger	Smooth	Flat or same as milkline slope	Flat	4,000	0.49
Stall base	Textured	3"/6'	1/4"/ft crown	3,500	0.53
Slats	Grooved with rounded edges	Flat	Flat	4,000	0.49
Swine					
Solid (sleeping area)	Textured	1/4"-1/2"/ft	Flat	3,500	0.53
Slotted (slats)	Smooth	Flat	Flat	4,000	0.49
Gutters					
Open	Smooth	See gutter design	1/2"/ft crown	3,500	0.53
Underslat	Smooth	See gutter design	1/2"/ft crown	4,000	0.49
Gravity drain	Smooth	1"/20'	—	4,000	0.49
Pits	Smooth	Flat	Flat	4,000	0.49
Under stalls	Smooth	1/4"/ft	Flat	3,500	0.53
Breeding pens	Grooved & textured	0"-1/4"/ft	Flat	3,500	0.53
Walk/feed alleys	Textured	1/4"/ft to a drain if there is one	1/2"/ft crown	3,500	0.53
All livestock handling facilities					
	Textured	Flat or slight slope	1/2"/ft crown	3,500	0.53

*Smooth—troweled or vibrated against a smooth form. Use a smooth concrete surface **only** where specifically recommended.

Textured—broom finish, impregnated with grit, or rough float finish.

Grooved—grooves at least 1/8" deep either formed before the concrete sets or cut in cured concrete.

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Table 3-8. Floor and slab concrete specifications, continued.**Concrete mixes.**

Use air-entrained concrete.

Make a trial batch to check for slump and workability.

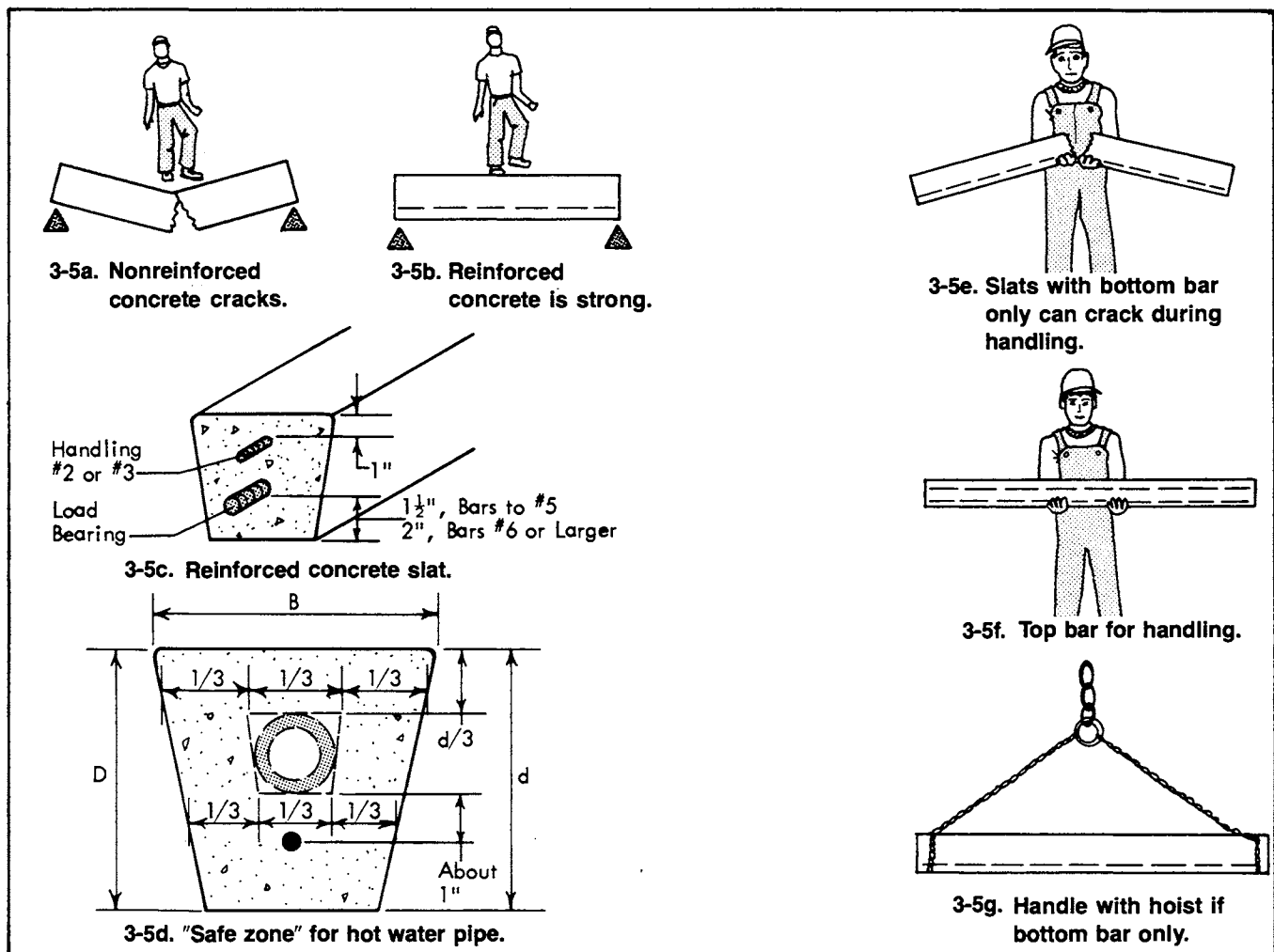
Wet sand occupies more volume than dry sand, so yield is not quite the same as in the example below.

Approximate strength	Mix	Max. size aggregate	^a Gallons of water for each sack of cement, using			^b Suggested mixture for 1-sack trial batches			Ready-mix sacks cement per yard ^c
			Damp ^c sand	Wet ^d	Very ^e	Cement, sacks ft ³	Aggregates		
				(average) sand	wet sand		Fine ft ³	Coarse ft ³	
4,500 psi	5-gallon	¾"	4½	4	3½	1	2	2¼	7¾
3,500 psi	6-gallon	1½"	5½	5	4½	1	2½	3½	6

^aIncreasing the proportion of water to cement reduces the strength and durability of concrete. Adjust the proportions of the batches without changing the water-cement ratio. Reduce gravel to improve smoothness; reduce both sand and gravel to reduce stiffness.^bProportions vary slightly depending on gradation of aggregates.^cDamp sand falls apart after being squeezed in the palm of the hand.^dWet sand balls in the hand when squeezed but leaves no moisture on the palm.^eVery wet sand has been recently rained on or pumped.^fMedium consistency (3" slump).**Air contents.**

For concrete subject to severe exposure conditions.

Maximum-size coarse aggregate, in.	Air content, % by volume
1½, 2, or 2½	5 ± 1
¾ or 1	6 ± 1
¾ or ½	7½ ± 1

**Fig 3-5. Reinforced concrete slats.**

Solid Floors

Sloped solid floors aid manure movement toward gutters or slotted areas. Animal traffic tends to work manure down slopes of about $\frac{1}{2}$ "/ft (4%) or more. Slopes over about 1"/ft (8½%) can cause footing problems.

Tractors and other wheeled vehicles cannot operate safely and efficiently on steep floors. Limit slopes of paved storages and drives to less than 1'/10' (10%); 1'/20' or less is recommended. Steeper slopes limit maneuvering and traction and can cause tractor over-turns.

Rough concrete floors result in more injury, lameness, and infection than smooth, clean floors. However, a floor can be too smooth. If the floor is kept dry, and the slope does not exceed $\frac{1}{2}$ "/ft, slipping problems are rare. An exception is swine breeding areas where footing is more critical. Refer to *Slip Resistant Concrete Floors*, AED-19, by Midwest Plan Service, for more information. See Table 3-8 for concrete floor and slat surface recommendations.

Latex, epoxy, or chlorinated rubber paints on the creep floor of swine farrowing stalls can reduce knee abrasions. Sawdust sprinkled on wet paint improves traction, but must be reapplied at least annually. Check paint labels for toxic materials, such as lead. Repaint annually and avoid washing the painted area with high pressure washers.

Concrete floors on a good base (4"-6" gravel or compacted fill) can usually be 4" thick. For heavy vehicle loads, increase floor thickness to 6". For floors that cover tanks, a complete structural design is essential. Refer to *Concrete Manure Tank Design*, TR-3, by Midwest Plan Service, for more information.

Welded wire mesh (usually 6x6, 10 gauge) is usually required to reinforce concrete floors especially where extra resistance to vertical displacement is needed. Wire does not make up for poor concrete or for poor placement, finishing, or curing practices.

Collection

Manual Scrape Gutter

For smaller operations, shallow manual gutters work well behind dairy stalls or under cantilever swine farrowing stalls, Fig 3-6. Hand scrape manure from the gutter directly outside or into a sump or deep narrow collection gutter at the end. Have the shovel or pusher made to fit the gutter. Scrape every day to control odors. The bottom of the gutter is level. In dairy stall barns, 16" wide gutters are adequate and save alley space.

Mechanical Scrapers

Scrapers can reduce manual labor depending on the storage method and the degree of cleanliness you want. The equipment is relatively simple to maintain, but poor quality equipment deteriorates rapidly due to the corrosive environment.

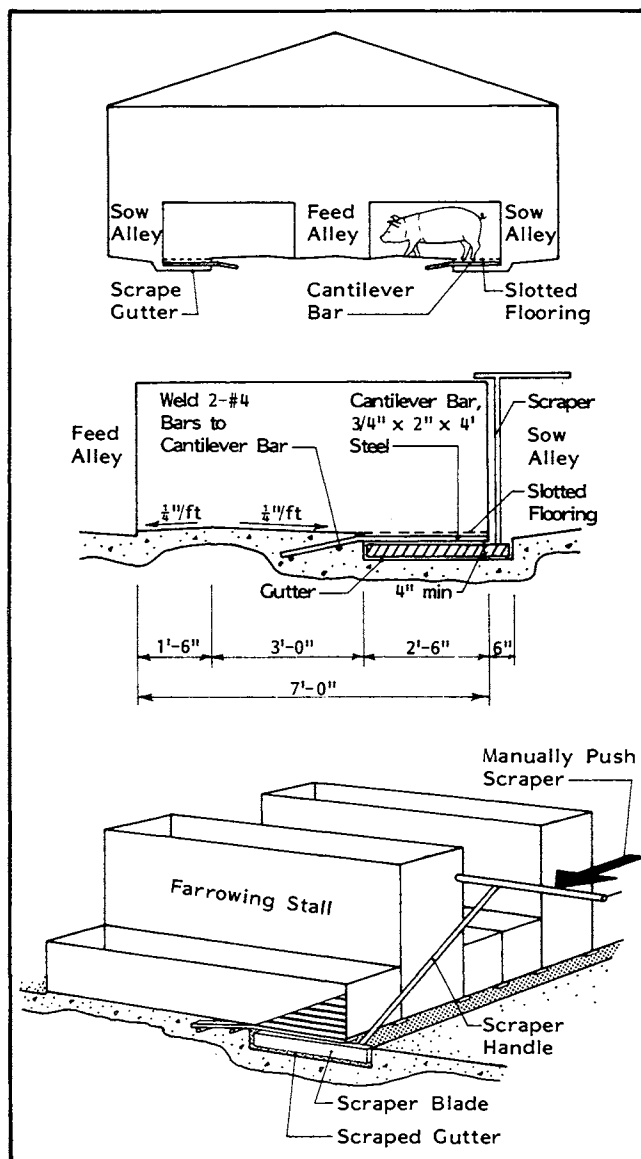


Fig 3-6. Manual scrape gutter.

Under cantilever farrowing stall.

Scrapers remove manure regularly, so building and livestock cleanliness are easier to maintain. These buildings have fewer odors than buildings with pits under slats because of frequent manure removal (at least once a day), but some ammonia is still released from the wet gutter surface. Consider exhausting some ventilating air from underslat gutters to reduce odors. Scrapers work with either solid or slurry manure.

Mechanical scrapers are also well suited for remodeled buildings, because their gutters are flat and have a minimum depth of 4" in open gutters and 12"-24" in underslat gutters.

Make the gutter surfaces uniform and level. Rough concrete can stop rigid steel blade scrapers; floating or rubber-edged blades can handle slight irregularities. Hang weighted flexible curtains in the gutter under all building walls to reduce airflow through the gutter and to prevent drafts and other ventilation problems.

Scraper Types

Tractor-mounted blades

The tractor moves manure to the end of the barn where it falls into a storage or transportation unit, Fig 3-7. A mechanical scraper does the same work automatically. Tractor scrapers are flexible, work better on frozen manure, and generally have fewer problems than automated systems. They are very useful for cleaning paved lots.

Barn cleaners

A barn cleaner is a scraper that operates in a narrow gutter (about 16") and has closely spaced flights on a chain drive, Fig 3-8. It is designed to handle waste with a high solids content.

Alley and open gutter scrapers

Alley scrapers, such as those in free stall barns, cover the entire width and length of the alley in one pass, Fig 3-10. The drive cable or chain is usually recessed into the alley floor. Recessing helps stabilize the blade and eliminates a tripping hazard, but places the cable or chain in a more corrosive environment.

Travel speeds of 4 to 7 ft/min (fpm) are practical. Alley scrapers do not interfere with cattle in the scraped alley or near the feedbunk. Consider equipping swine open gutter scrapers with a shocking mechanism to clear livestock from the path. Equip the drive with pressure switches so an excessive load on the scraper such as an animal or broken slat stops the scraper or reverses the direction of travel. Scrapers can be used in cold barns, but provide a way to tractor clean on coldest days.

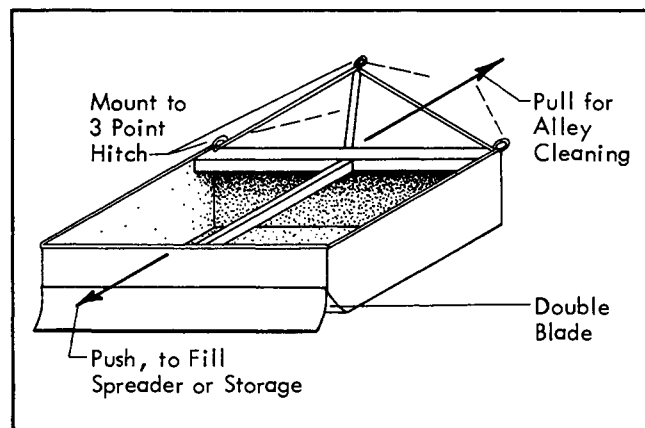


Fig 3-7. Tractor-mounted scraper.

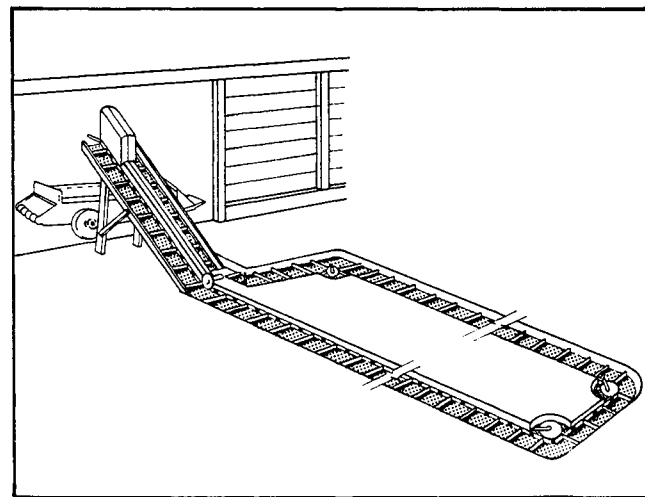


Fig 3-8. Barn cleaner.

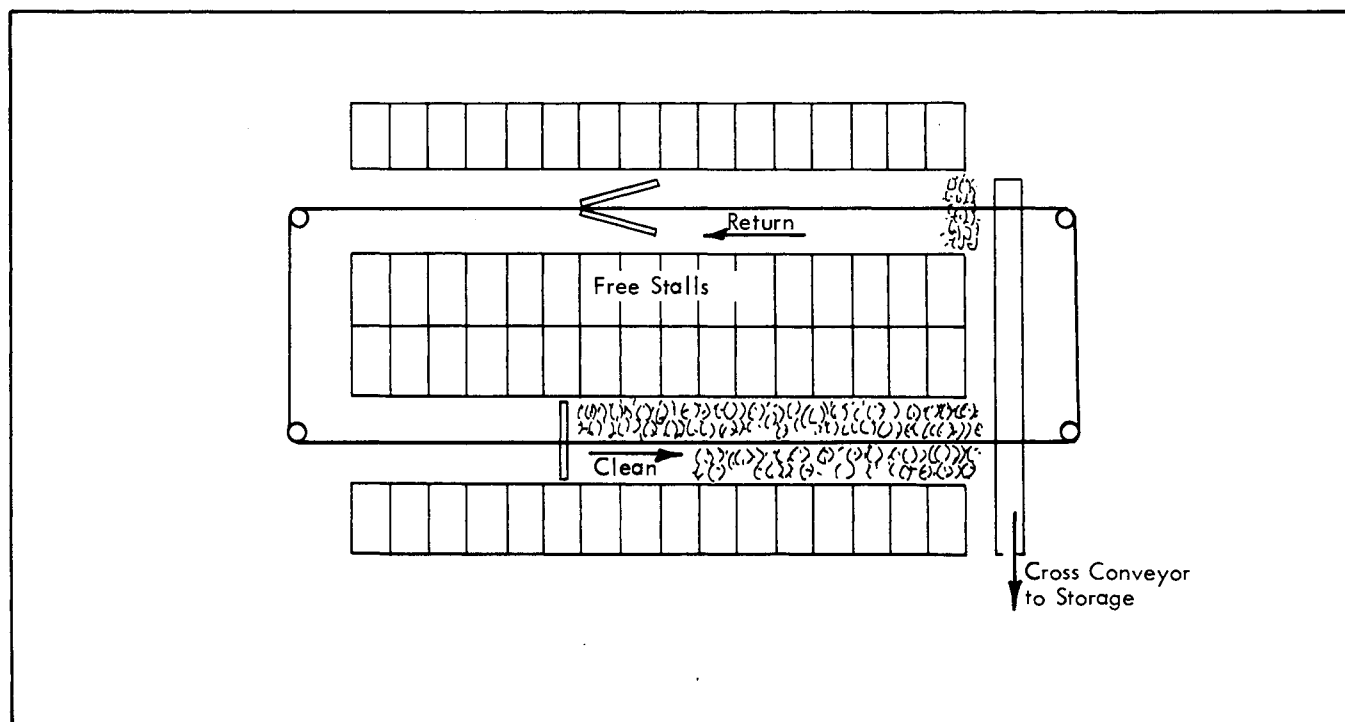
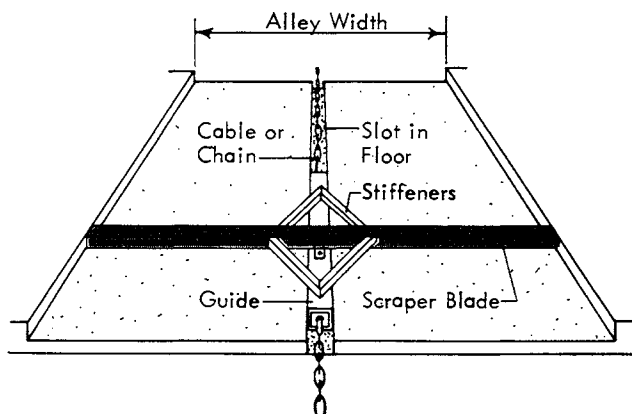
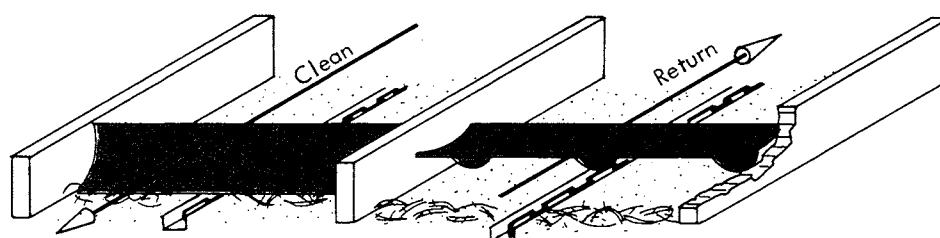


Fig 3-9. One-way folding alley scraper.

The drive automatically reverses—as one scraper dumps its load of manure, travel direction reverses.

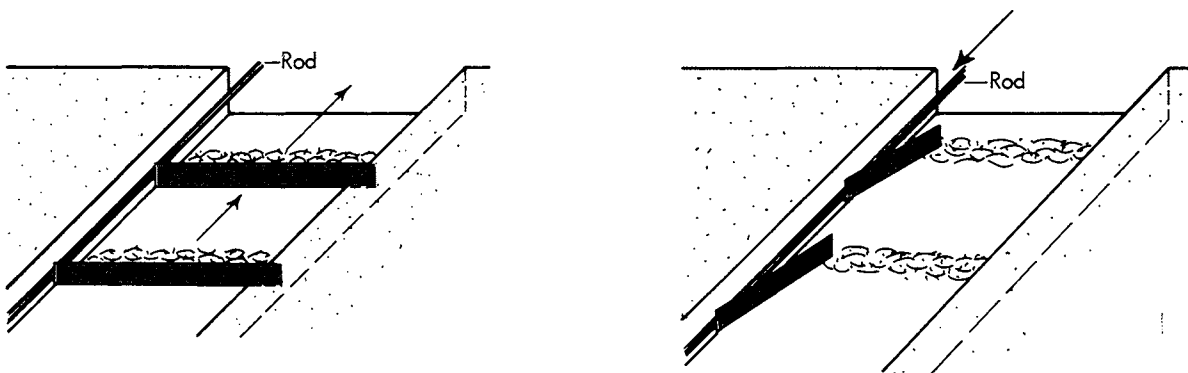


3-10a. Two-way rigid scraper.



3-10b. Push-pull alley scraper.

Many types are available, operated with rods, bars, cables, or chains.



3-10c. Shuttle-stroke open gutter cleaner.

Fig 3-10. Alley scrapers.

Underslat scrapers

Scrapers under slats operate in a shallow pit to combine the advantages of scrapers and slotted floors. The scraped area is usually less than 10' wide. Underslat scrapers travel much faster than alley scrapers because livestock safety is not a concern.

They have one or more scraping blades, a cable or chain to pull the scraper, and a drive unit with controls, Fig 3-11. Scraper blades are made of steel and may have a rubber facing. A rubber-faced blade cleans irregular floors better, but a steel blade is better for removing partially dried or frozen manure. Commercial scraper blades are 2'-12' wide. Blade height varies from 5"-12", depending on cleaning frequency and gutter length. Some cable tow blades have side plates to improve alignment and reduce spillage.

Scraper cables are usually stainless steel or plastic-coated galvanized steel to prevent corrosion. Chains are usually heavy duty, flat link, and forged eye links. Because cable failure is possible, design the system so you can readily restring the cable through the long shallow gutters. Consider stretching a looped, thin nylon rope (twice the gutter length) under the slotted floor but clear of the scraper. Also, make the corner wheels easily accessible for lubrication and repair. Use removable slats to make repairs and maintenance easier.

The drive unit has an electric motor, a speed reducing mechanism, and a cable or chain drive. Motors are ¼ hp or more depending on the number of scrapers, scraping area, speed, and run length. Locate drive units out of pits to reduce corrosion and to improve accessibility for maintenance and repair.

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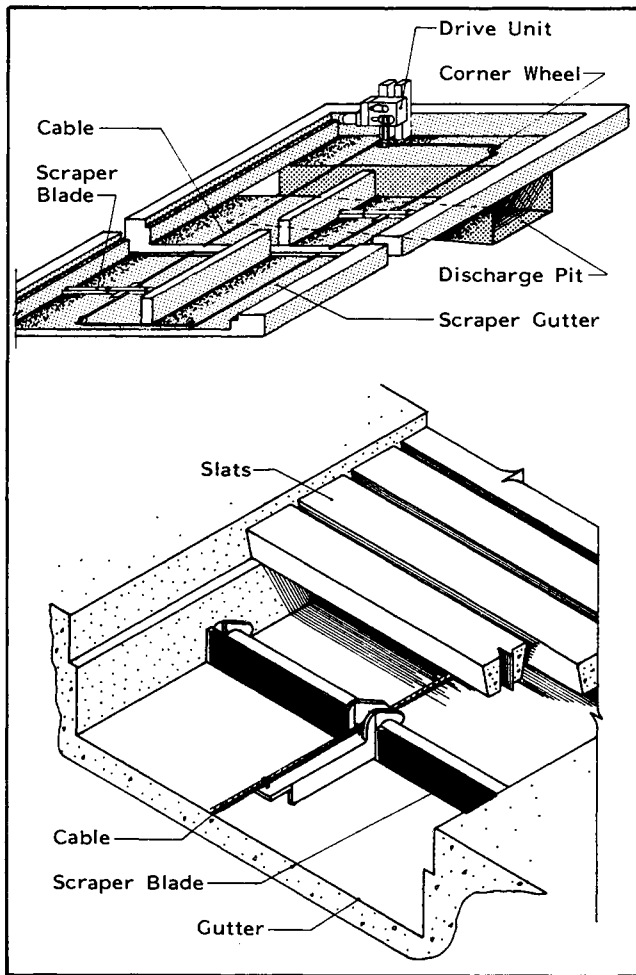


Fig 3-11. Typical underslat scraper system.

Operation

Control mechanical scrapers with a time clock. Operate as often as needed to control odors, keep the building clean, and to prevent equipment from freezing. Scraping frequency varies with animal type, gutter length and depth, and season. Swine buildings need to be scraped 2 to 4 times/day; cattle 3 to 6 times/day; and poultry every day or two. More frequent or continual operation may be necessary if the temperature is below freezing. In cold buildings, use floor heat where the scraper routinely stops.

Deposit scraped manure directly into a storage tank under the end of the building, or into a cross conveyor or pump hopper for conveying to storage. Because bedding and drying lower the manure's moisture content, water may have to be added during filling to ensure enough moisture when emptying semi-solid storages. The cross conveyor can also carry manure directly to a spreader.

If little or no bedding is present, it may be possible to gravity drain the manure from sump to storage. See the gravity flow transport section.

A scraper cleans well only if it is well maintained. Follow manufacturers' recommendations, and then adjust it for frequency of operation and livestock cleanliness.

Front-end Loaders

Front-end loaders remove solid manure from open lot surfaces, storages, or building floors. Typical farm tractor loader capacities are 1,000 to 4,000 lb. Their turning radius is relatively large, limiting their use to straight runs, or to larger areas where turning is minimal. A loaded bucket reduces rear wheel traction, limiting use to relatively flat areas. Wide front tractor wheel spacing is desirable for stability. Avoid building layouts requiring backing down long alleys or working in limited space.

Small loaders (skid-steer) can clean in cramped areas, greatly reducing hand labor. Most have a turning radius of their own length and a low height and can work easily in tight quarters. Some have relatively low load lifting capacity.

Self-propelled industrial loaders can clean large open feedlots and move stacked manure where traction is poor. Their large load capacities (over 5,000 lb) and short turning radii handle large manure volumes with low labor, but their initial cost is high.

Flushing Systems

In a flush system, a large volume of water flows down a sloped, shallow gutter or alley, Fig 3-12. The water carries manure to a lagoon for a swine operation or an earth storage basin for a dairy operation. There are three types:

- Underslat gutter, used in beef buildings and swine farrowing, nursery, gestation, and larger facilities where residue or disease transmission is a concern.
- Narrow open gutter (less than 4' wide), used primarily in hog finishing buildings. In open gutter swine units, the flushing attracts hogs to the channel and induces dunging, helping to "toilet train" them.
- Wide open gutter, used primarily for dairy free stall alleys, holding areas, and milking parlors.

Water may be recycled from a lagoon, earth basin, or holding pond for flushing. In a recycling flush system, a pump transports the water to a flush tank at the high end of the gutter in the building. The flush tank periodically dumps water into the gutter. Flush frequency is determined by the rate water is pumped into the tank. Size the tank to contain enough water to scour wastes from the gutter. Where irrigation is practiced, many producers use fresh water for flushing instead of recycled water.

Some systems use a large capacity pump operated by a time clock to supply flush water instead of a flush tank. Pump flushing uses much more water than tank flushing.

Locate a sump pit at the discharge (or runoff) end of the flushing gutter if waste must be pumped to the lagoon or earth basin. Make the sump volume at least as large as the flush volume for the total building.

Try to limit gutter length to 125'. For gutters 125' to 250' long, slope both ends of the gutter so they flush toward the middle of the building length. For

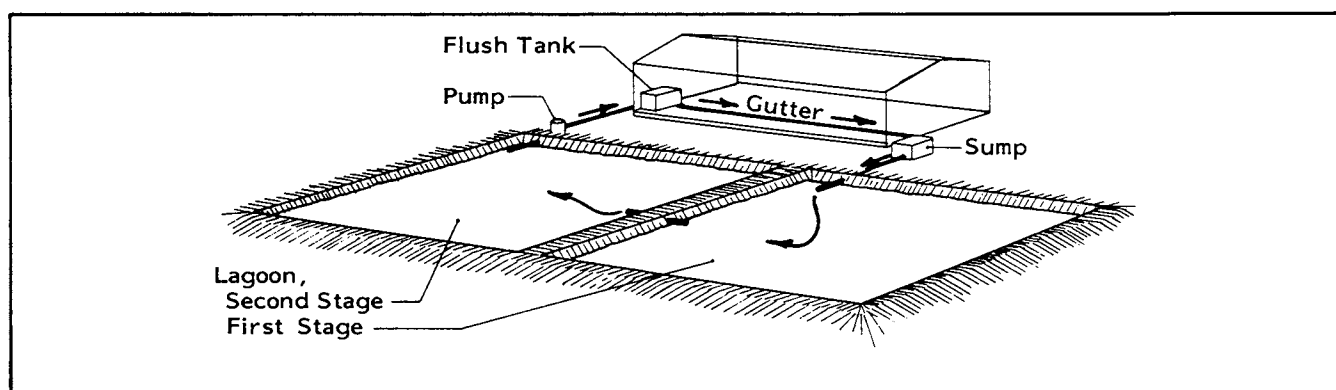


Fig 3-12. Flush system with two-stage lagoon.

gutters longer than 250', consult a knowledgeable building engineer.

Underslat Gutter Design

Gutter width is determined by the amount of slotted area; slot at least $\frac{1}{3}$ of the floor area. Subdivide underslat gutters into channels no more than 4' wide; 2'-2½' wide channels are preferred, Fig 3-13. These dividers keep flush water from channeling around waste deposits as it moves down the gutter. Use inverted concrete slats as channel dividers.

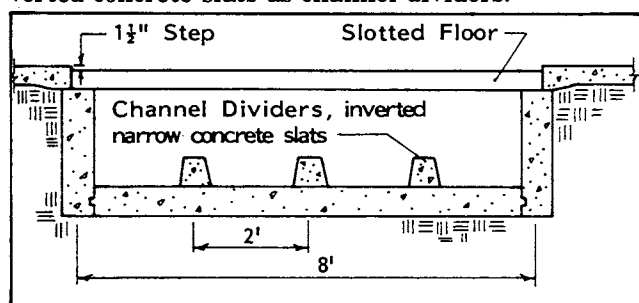


Fig 3-13. Underslat flush gutter.

Use channel dividers for all but the first 20' of gutter.

Slope underslat gutters at 1.25% to get the required 3" initial water flow depth, Table 3-9. Construct the gutter with no cross slope and no more than a very slight crown.

The required volume per flush (flush tank volume) depends on gutter width and desired initial flow depth. From Table 3-10, a 3" initial flow depth requires a tank volume of at least 55 gal/ft of gutter width. From Table 3-10, obtain a tank with a discharge rate of 255 gpm/ft of gutter width. Multiply these values by the gutter width to get the flush tank specifications.

Determine total daily flush volume from Table 3-11 and divide by the tank volume to determine the required number of flushes per day.

For large capacity pump flushing, size the pump for 110 gpm/ft of gutter width, Table 3-10. Pump flush for 3 to 5 min at least twice a day.

Table 3-9. Minimum slope for flush gutters.

	Underslat gutter	Narrow open gutter			Wide open gutter		
Initial flow depth, in.	3	1.5	2	2.5	4	5	6
Slope, %	1.25	2	1.5	1.25	5	4	3

Table 3-10. Tank volumes and discharge rates.

Values are per foot of gutter width to provide various flow depths.
gpm = gallons per minute.

Initial flow depth, in.	Tank volume gal/ft of gutter width	Tank discharge rate gpm/ft of gutter width	Pump discharge
1.5	30	112	55
2.0	40	150	75
2.5	45	195	95
3.0	55	255	110
4.0	75	615	150
5.0	100	985	175
6.0	120	1440	200

Table 3-11. Minimum total daily flush volume.

Animal type	Flush volume gal/hd
Swine	
Sow and litter	35
Prenursery pig	2
Nursery pig	4
Growing pig	10
Finishing pig	15
Gestating sow	25
Dairy cow	100
Beef feeder	100

Example 3-2:

Design an underslat flush gutter for a 12' wide by 100' long slotted area. Flush with a flush tank. The building holds 300 finishing pigs.

Solution:

- Subdivide the gutter into $12' \div 2' = 6$ channels (2' wide) with inverted concrete slats.
- From Table 3-9, slope gutter at 1.25% from the tank end down to the sump end and design for a 3" initial flow depth.
- From Table 3-10, size flush tank volume:

$$55 \text{ gal/ft of gutter width} \times 12' = 660 \text{ gal}$$

- Determine flush tank discharge rate:

$$255 \text{ gpm/ft of gutter width} \times 12' = 3,060 \text{ gpm}$$

The tank must release its entire volume within:

$$(660 \text{ gal} \div 3,060 \text{ gal/min}) \times 60 \text{ sec/min} = 13 \text{ sec}$$

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5. From Table 3-11, determine total daily flush volume:

$$300 \text{ pigs} \times 15 \text{ gal/pig-day} = 4,500 \text{ gal/day}$$

6. Divide total daily flush volume by tank volume to get flushes/day:

$$4,500 \text{ gal/day} \div 660 \text{ gal/flush} = 6.8 \text{ or } 7 \text{ flushes/day}$$

Narrow Open Gutter Design

Provide at least 1 ft² of gutter area per pig. If the gutters are wider than 4', subdivide them with inverted concrete slats. Gutter slope depends on the desired initial flow depth, Table 3-9. Provide no cross slope or a very slight crown.

Flush tank volume depends on gutter width and desired initial flow depth. Given an initial flow depth, the flush tank volume and discharge rate per foot of gutter width can be determined from Table 3-10. Multiply these values by the gutter width to get the flush tank specifications.

Determine total daily flush volume from Table 3-11 and divide by the tank volume to determine the required number of flushes per day.

For large capacity pump flushing, size the pump based on the desired initial flow depth, Table 3-10. Pump flush for 3 to 5 min at least twice a day.

Example 3-3:

Design a narrow open flush gutter for a 56' long building housing 160 finishing pigs. Design both a flush tank and a high capacity pump flush system. Design for a 2" initial flush water flow depth.

Solution:

1. Determine gutter width by dividing number of pigs by gutter length and multiplying by 1 ft² gutter area/pig.

$$(160 \text{ pigs} \div 56') \times 1 \text{ ft}^2 \text{ gutter area/pig} = 2.86' \text{ wide gutter. Consider a } 3' \text{ wide gutter.}$$

2. From Table 3-9, the gutter slope to achieve a 2" initial flow depth is 1.5%.

3. Size the tank flush volume for a 3' wide gutter: From Table 3-10, base tank volume on 40 gal/ft of gutter width.

$$40 \text{ gal/ft} \times 3' = 120 \text{ gal}$$

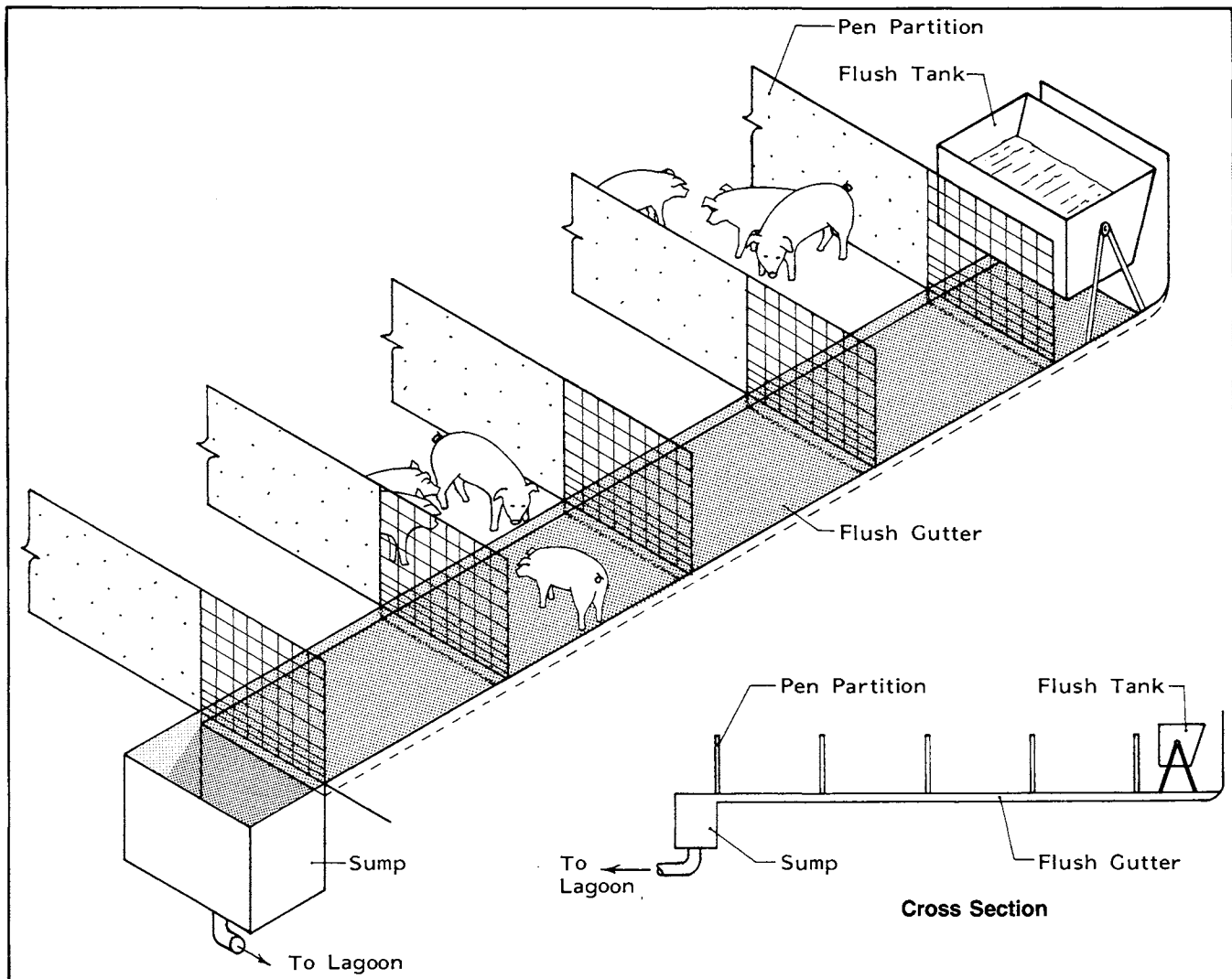


Fig 3-14. Narrow open gutter flush system.

4. Determine flush tank discharge rate for a 3' wide gutter.

From Table 3-10, base tank discharge rate on 150 gpm/ft of gutter width.

$$150 \text{ gpm/ft} \times 3' = 450 \text{ gpm}$$

The tank must release its entire volume within:

$$(120 \text{ gal} \div 450 \text{ gal/min}) \times 60 \text{ sec/min} = 16 \text{ sec}$$

5. From Table 3-11, determine total daily flush volume:

$$160 \text{ pigs} \times 15 \text{ gal/pig-day} = 2,400 \text{ gal/day}$$

6. Divide total daily flush volume by tank volume to get flushes/day:

$$2,400 \text{ gal/day} \div 120 \text{ gal/flush} = 20 \text{ flushes/day}$$

7. For a **large capacity pump flush system**, base pump size on 75 gpm/ft of gutter width (Table 3-10 at 2" initial flow depth). For a 3' wide gutter:

$$75 \text{ gpm/ft} \times 3' = 225 \text{ gpm}$$

Use at least a 225 gpm pump and flush 3 to 5 min at least twice a day.

Wide Open Gutter Design

For dairy free stalls, the flush alley is usually 10'-12' wide. Slope the alley 3%-5% to get initial flush water flow depths of 4"-6", Table 3-9. Make the alleys flat from curb to curb or form a $\frac{1}{2}$ "- $\frac{3}{4}$ " crown in the center to keep the flow forced toward the curbs. Make

sure the alley elevation is the same at both curbs at any given point along the alley length.

Flushing removes most of the manure from alleys, but it is difficult to remove manure deposited against curbs behind free stalls. Make the curbs along flushed alleys about 10" high. Elevate cross alleys so the flush alley curbs can be continuous. If the curbs are stopped for cross alleys, flush water spreads into the cross alley where it loses velocity and deposits manure.

The required flush tank volume depends on gutter width and desired initial flow depth. Given an initial flow depth, the flush tank volume, and discharge rate per foot of gutter width can be determined from Table 3-10. Multiply these values by the gutter width to get the flush tank specifications.

Determine total daily flush volume from Table 3-11 and divide by the tank volume to determine the required number of flushes per day.

Pickup channels receive the flushed material. Provide at least a 2% bottom slope. Minimum depth is 1' and minimum width is 2'. With larger flush tanks such as gated tanks, minimum width is 2½'. Fence cows away from pickup channels and leave them uncovered. If the barn layout requires that channels be crossed occasionally with equipment, use removable pipe rail sections or grates.

In cold climates, where either the flush tanks or the pickup channel or both are located outside, do not flush when outside temperatures stay below 20-25 F. Freezing occurs first around the tanks and the pickup

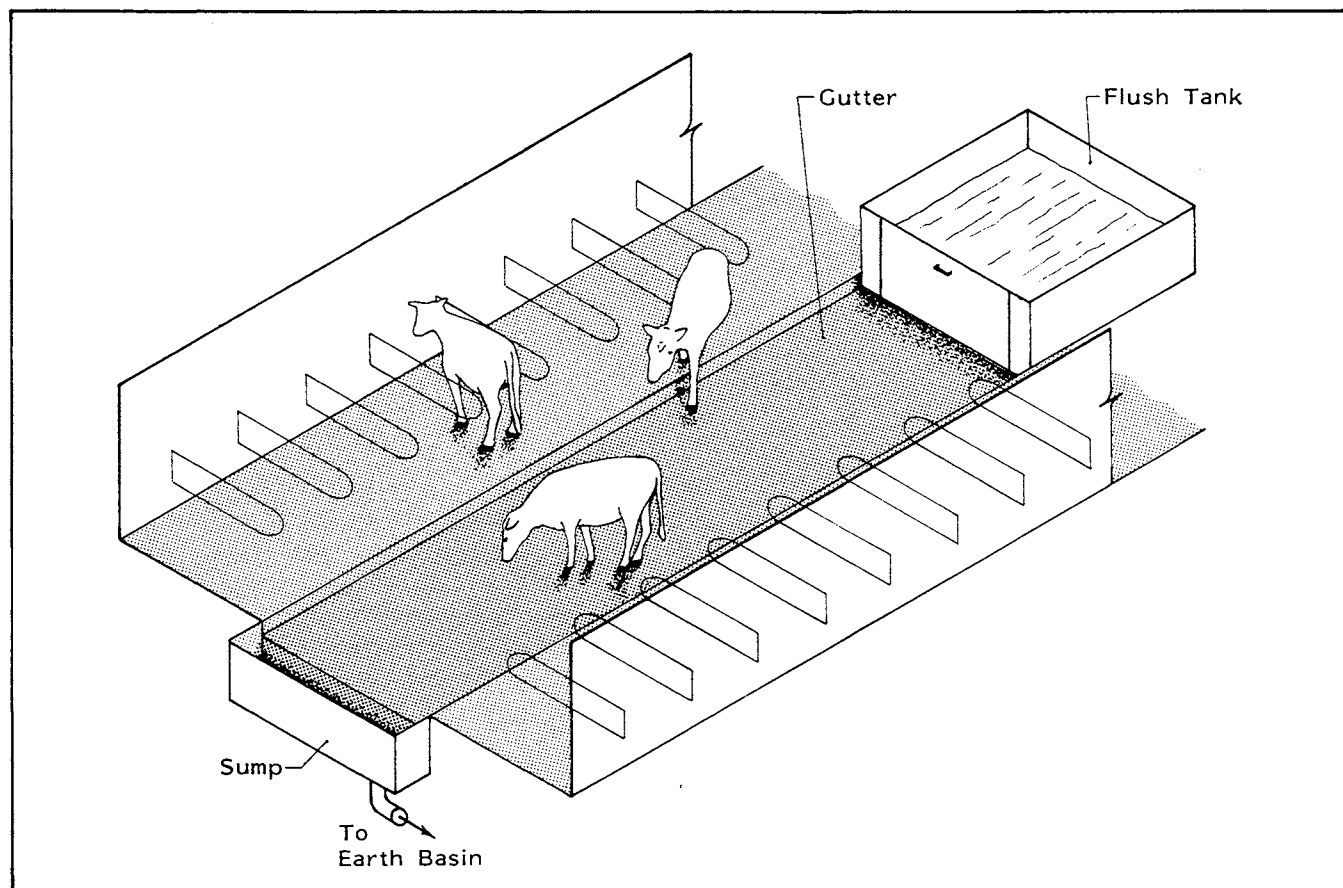


Fig 3-15. Wide open gutter flush system.

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channel where velocities are low. The alleys seem to drain and not freeze. If the flush tanks and pickup channels are located inside the barn, flushing may be possible all winter.

Cows have more foot problems with flushing. Protrusions remain sharp because floors are not scraped. Also, the protrusions are washed when flushed and no manure is left to decrease the roughness or cushion the sharpness. See Table 3-8.

Usually the flushed manure is stored in an earth storage basin and periodically pumped for irrigation. Solids settle out near the entry point and are difficult to agitate and resuspend. Consider using a liquid-solid separation device before the flushed manure goes to storage. See the section on liquid-solid separation. Basin water can be reused for flushing, but check with the milk inspector.

Example 3-4:

Design a flush system for an 80' long alley with 20 dairy cows along each side (40 cows total). The building layout has 10' wide alleys. Design for an initial flush water flow depth of 4".

Solution:

1. From Table 3-9, a 4" initial flow depth requires a 5% slope.
2. From Table 3-10, base the tank volume on 75 gal/ft of gutter width for a 4" initial flow depth.

$$75 \text{ gal/ft} \times 10' = 750 \text{ gal}$$

3. From Table 3-10, base the tank discharge rate on 615 gpm/ft of gutter width.

$$615 \text{ gpm/ft} \times 10' = 6,150 \text{ gpm}$$

The tank must release its entire volume within:

$$(750 \text{ gal} \div 6,150 \text{ gal/min}) \times 60 \text{ sec/min} = 7.3 \text{ sec}$$

4. From Table 3-11, determine total daily flush volume:

$$40 \text{ cows} \times 100 \text{ gal/cow-day} = 4,000 \text{ gal/day}$$

5. Divide total daily flush volume by tank volume to get flushes/day:

$$4,000 \text{ gal/day} \div 750 \text{ gal/flush} = 5.33 \text{ or } 6 \text{ flushes/day}$$

Flush Tanks

Automatic siphon tank, Fig 3-16. This tank has the advantage of no moving parts. As the tank slowly fills with water, an air bubble trapped under the bell is forced out the siphon pipe until it triggers the siphoning action. Place an automatic siphon tank above the pens so it does not use floor space. See AED-17, *3-Inch 150-Gal Siphon-Flush Tank*, for construction details.

An 8"-24" automatic siphon can handle very large volumes of water. This flush unit has a small 2" siphon to trigger the larger siphon and is well suited to flushing underslat gutters or wide open gutters.

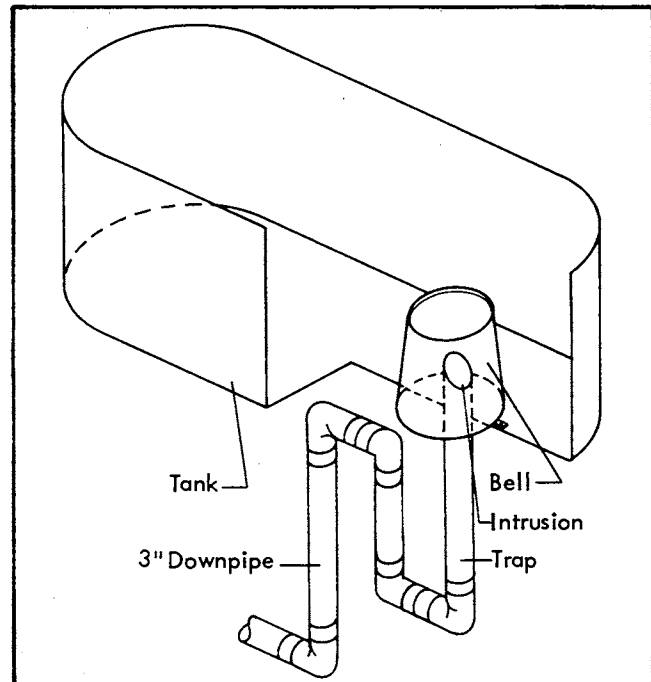


Fig 3-16. Automatic siphon tank.

Manual flush tank, Fig 3-17. The manual flush tank is best suited to twice-a-day flushing in underslat systems. Fig 3-17 shows a small but effective one for farrowing/nursery swine buildings. Another system has a dividing wall across an underslat pit to dam up several hundred gallons of water in the high end of the gutter. The gutter is flushed by opening a sluice gate or by pulling one or more large standpipe overflows located in the water storage pit.

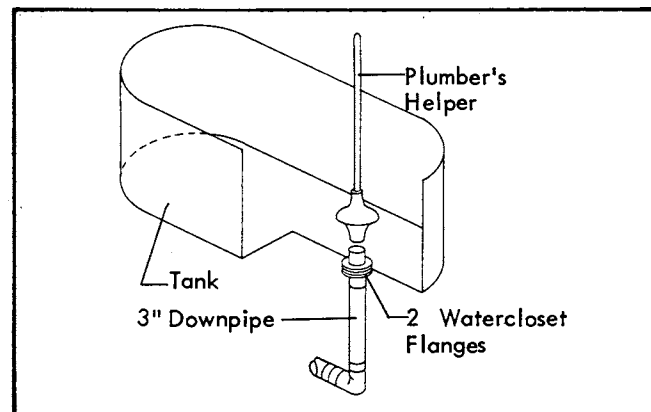


Fig 3-17. Manual flush tank.

Tipping tank, Fig 3-18. A tipping tank dumps when it fills to a depth where the center of gravity of the water volume overbalances the pivot point. Because the water discharges all at once, flushing velocity and depth are high and can cover an 8'-10' wide gutter.

Gated tank, Fig 3-19. Sealed, manually-operated gates are commercially available to be installed in tanks built on site, Fig 3-19. These gates include sealed front drop gates, lift or sluice gates that are raised to release the water, and circular gates closed by a tire seated against the circular opening.

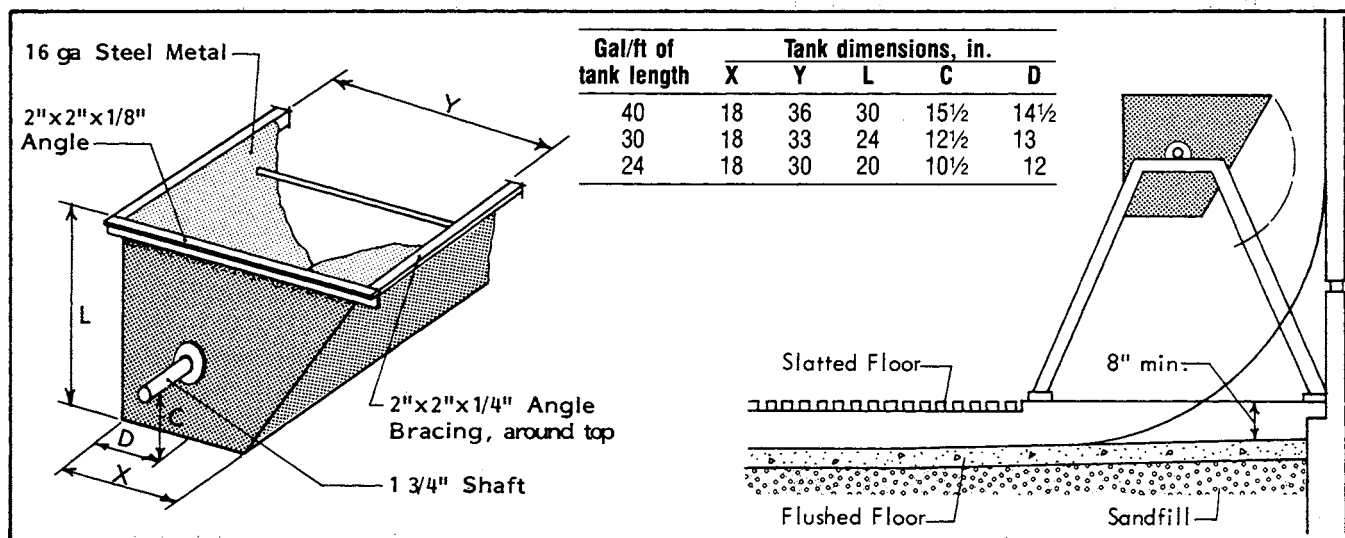


Fig 3-18. Tipping tank.

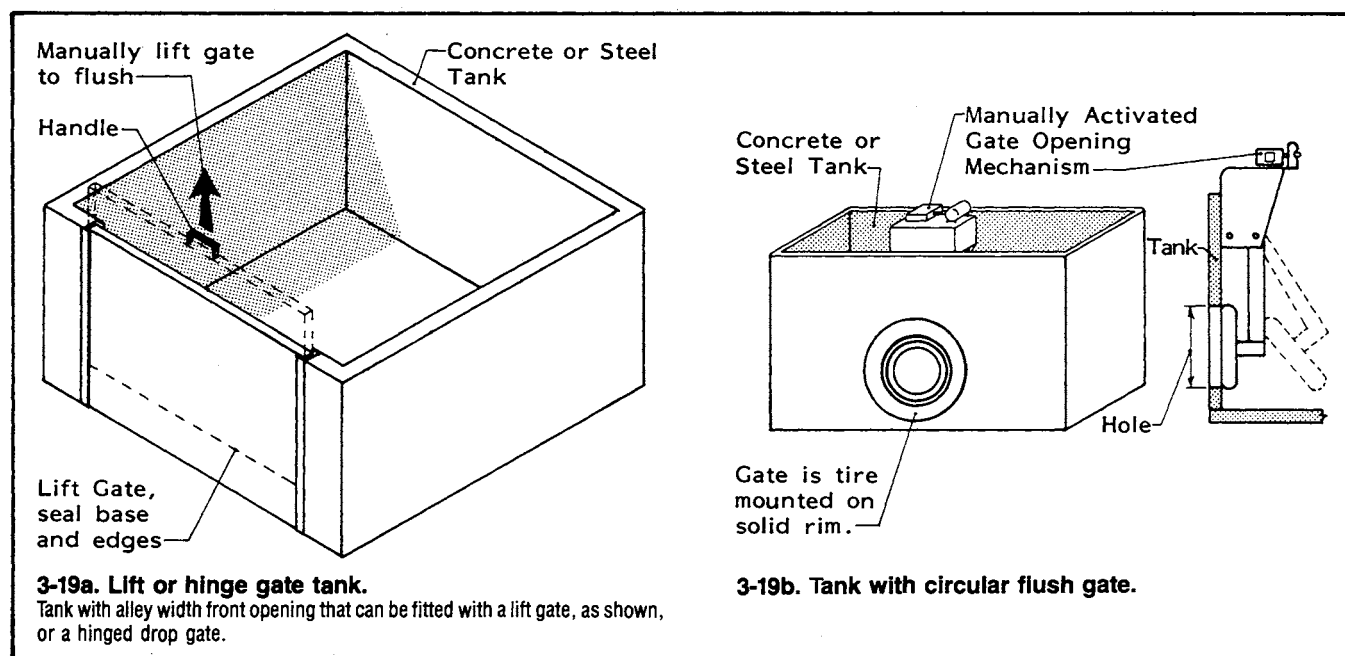


Fig 3-19. Gated flush tank.

Use for large volume applications.

Manure Gutters

Deep Narrow Gutter

Deep narrow gutters were popular in the 1960s before slatted floors were used. They are usually self-cleaning because the manure moves out rapidly when the plug is pulled. Odors are reduced because the manure is removed from the building before malodorous anaerobic bacteria have a chance to multiply.

Deep narrow gutters are located at the lower end of solid feeding floors of growing-finishing buildings, Fig 3-20. Locate the waterers near the gutter. Wash or scrape manure into gutters daily to keep the floors clean. Limit pen length to 20' to reduce scraping distance.

Fit the gutter with a watertight plug or gate that can open as often as once a day to drain the contents into a storage facility. An emergency overflow stand-pipe is often used, but this feature is not recommended unless the drain to storage is gas-trapped. Limit gutter lengths to about 50' with 6" drain pipe, 100' with 8" drain pipe, and 200' with 10" drain pipe. Slope gutter bottom toward the drain at 1"/20'.

Gravity Drain Gutters

Gravity drain gutters are commonly installed in swine buildings under raised farrowing stalls and nursery decks with totally slatted floors, Fig 3-21.

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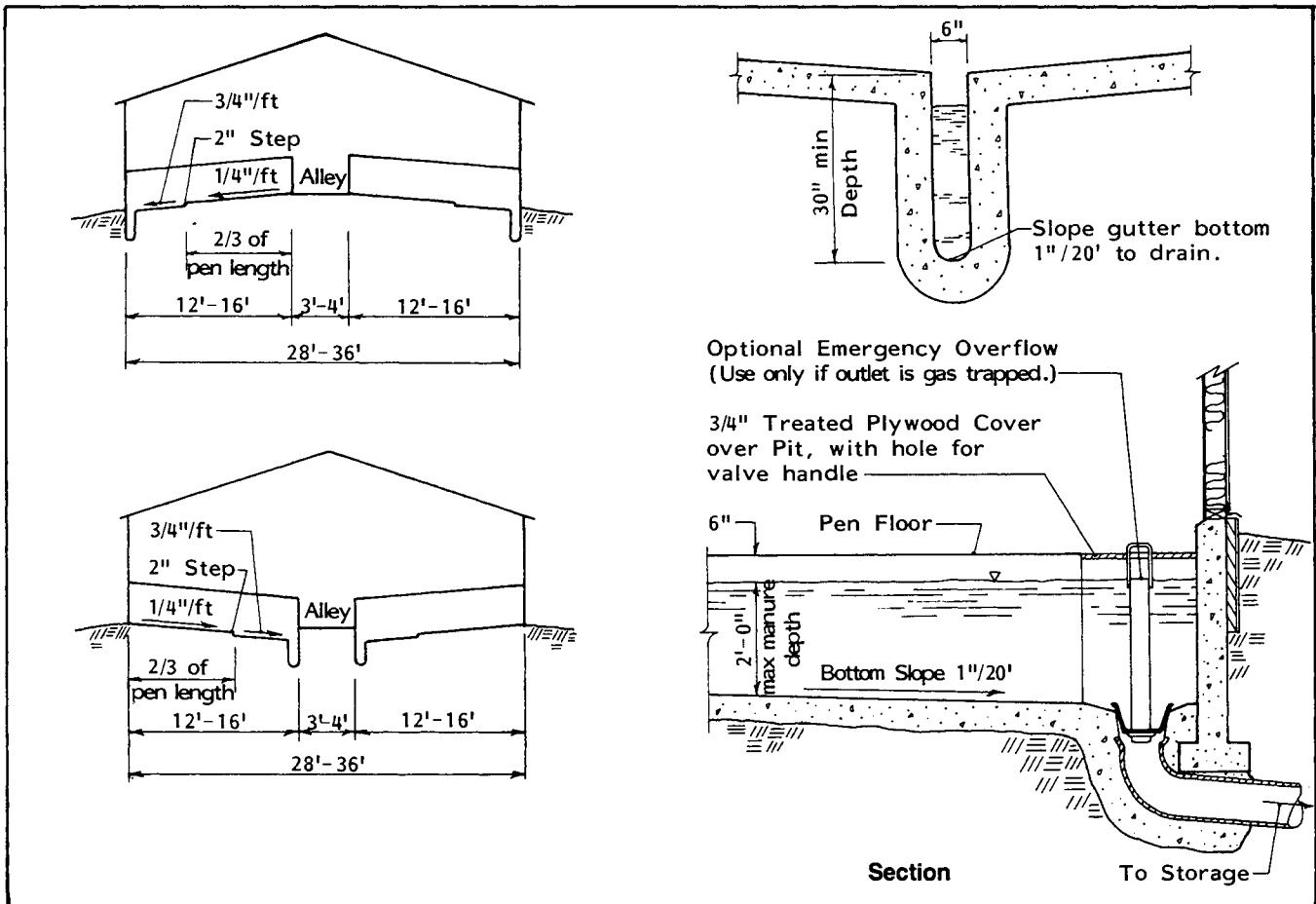
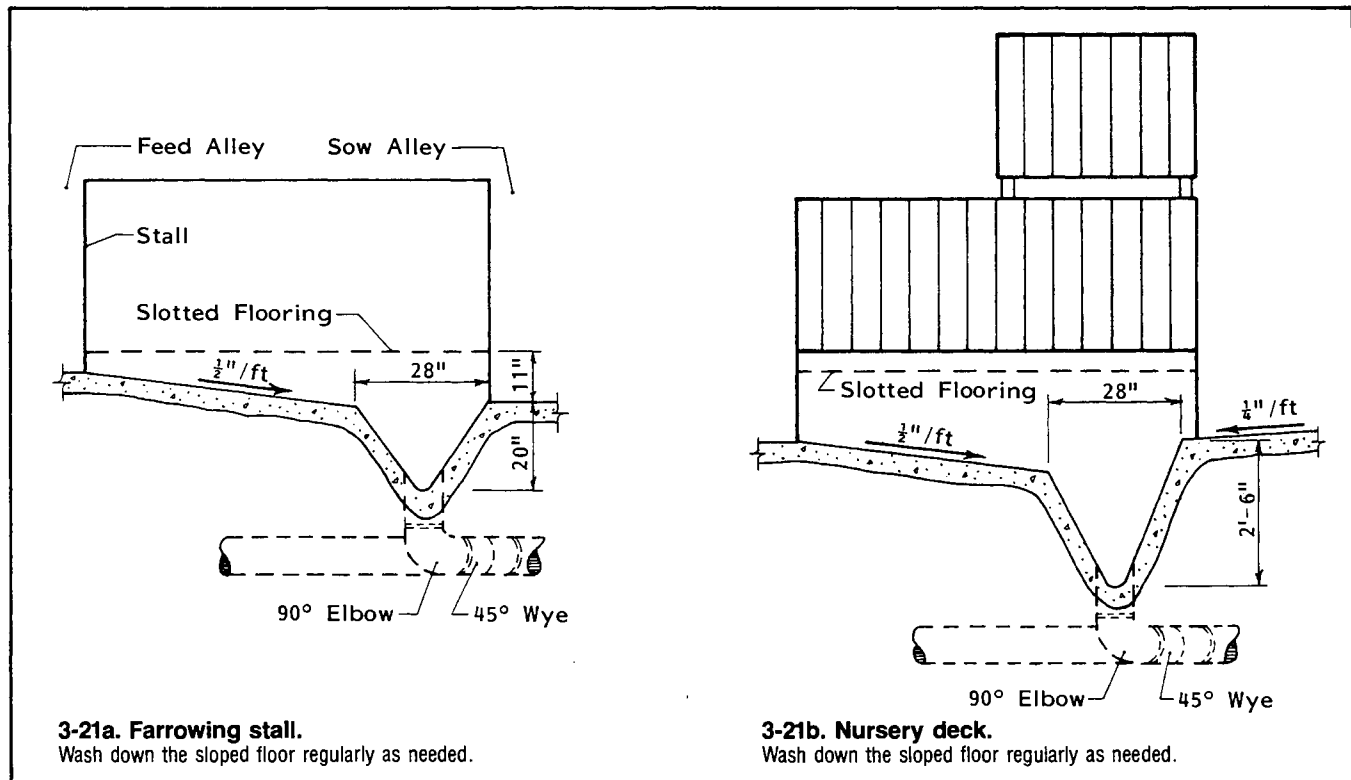


Fig 3-21. Gutters under raised farrowing stalls and nursery decks.

Some are also installed in farrowing and nursery units with partly slotted floors. Gravity drain gutters have Y, U, V, or rectangular shapes.

Raised stalls and decks are preferred but some farrowing units have a 30" wide gutter in the rear and a shallow, 12" wide gutter in front, Fig 3-22a. The front gutter catches waste from the waterer and reduces manure accumulation in the front corners, which is particularly important after the pigs are three weeks old. Consider having the front gutter drain into the rear gutter to add dilution water to the rear gutter. Another plan has a gutter only in the rear, Fig 3-22b. Slope the front portion of the stall floor forward into a small gutter so wastewater does not drain back through the stall area.

Fig 3-23 shows a nursery arrangement with slotted areas at both ends of the pen so all corners are slotted. A heated sleeping area in the center with slotted areas at both ends helps maintain clean floors and also provides a warm, solid rest area for the little pigs. A conventional partly slotted nursery has slotted flooring on only one end, and it is difficult to keep pens clean because some pigs always dung in the corners of the solid sleeping area. Locate waterers

over each gutter because the waste from the waterer provides the liquid necessary to make the manure flow out of the gutters. If gutters receive no wastage from waterers, add extra water to provide enough liquid. Slope the sides $\frac{3}{4}$:1 (rise:run) for adequate cleaning.

For raised flat nursery decks and cages, two or three gutters can be located adjacent to one another to provide a continuous, wider collection area, Fig 3-24. Again, it is important to locate waterers over each row of gutters, even though it is difficult to construct.

In gravity drain systems, liquid manure is allowed to build up in gutters. Periodically, a plug is pulled, and the manure drains out by gravity. It can be drained into a storage tank or lagoon, or it can be drained into a sump from where it is pumped into a storage tank or lagoon. Gravity drain gutters use much less water than flushing systems. Unlike flushing systems, these gutters usually do not require a lagoon or recycling of water back from the lagoon.

The gravity-drain system lends itself to producers who want to store the manure outside the building and haul it to the field for fertilizer. They do not want

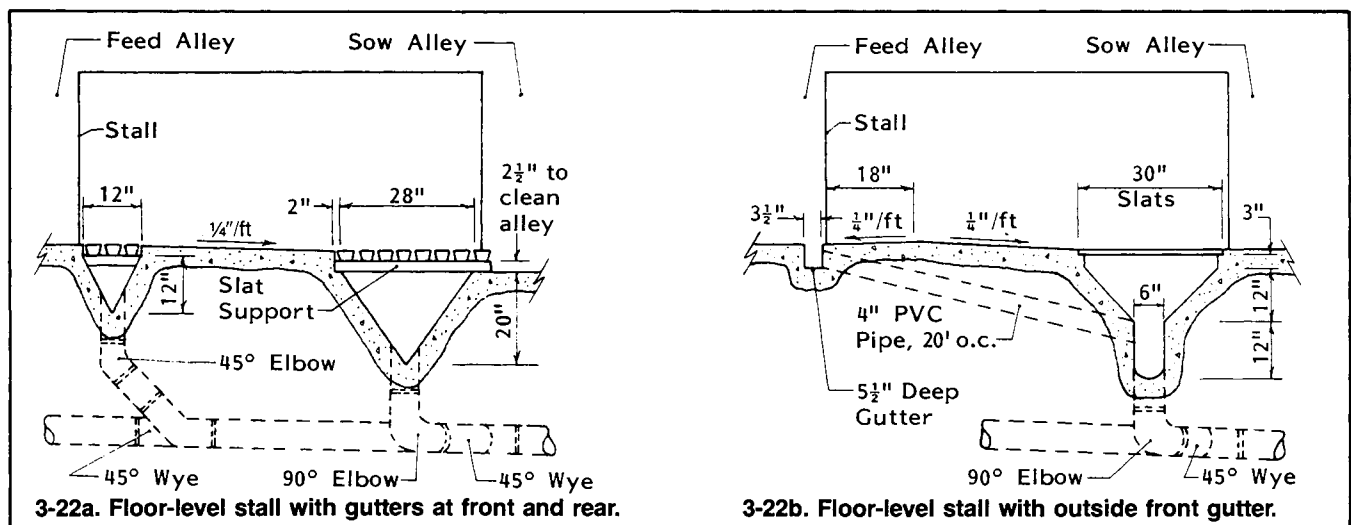


Fig 3-22. Gravity drain gutters under farrowing stalls.

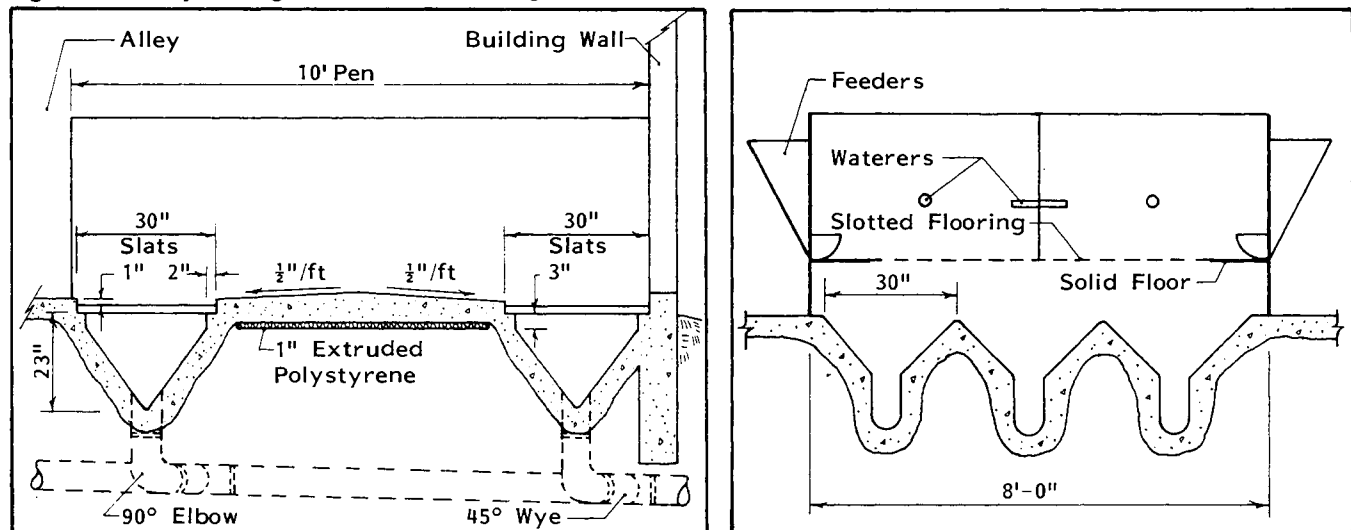


Fig 3-23. Nursery with two gravity drain gutters.

Fig 3-24. Raised nursery deck over multiple gutters.

to dilute it with water because dilution results in extra water to haul.

The gutters can be constructed of concrete or purchased as a complete unit made of fiberglass or plastic.

Y Gutter

The Y gutter is an adaptation of the deep narrow gutter. Its purpose is to provide the cleaning action of the narrow gutter with some slotted flooring above the gutter to provide cleaner floors. Construction is

more complicated than for a V or rectangular gutter. With the recommended side slopes on the upper part of the Y (1:1 for farrowing and $\frac{3}{4}$:1 for a nursery) the gutter's top width is usually $2\frac{1}{2}$ '-3'. Gutter lengths have usually been limited to 50'. Slope the gutter bottom $1\frac{1}{20}$ '-40' towards the drain. Fig 3-25 shows the construction details of a form to shape the gutter.

Paint the sloping sides of concrete gutters to make them slick for better cleaning. Cure new concrete 90 days before painting.

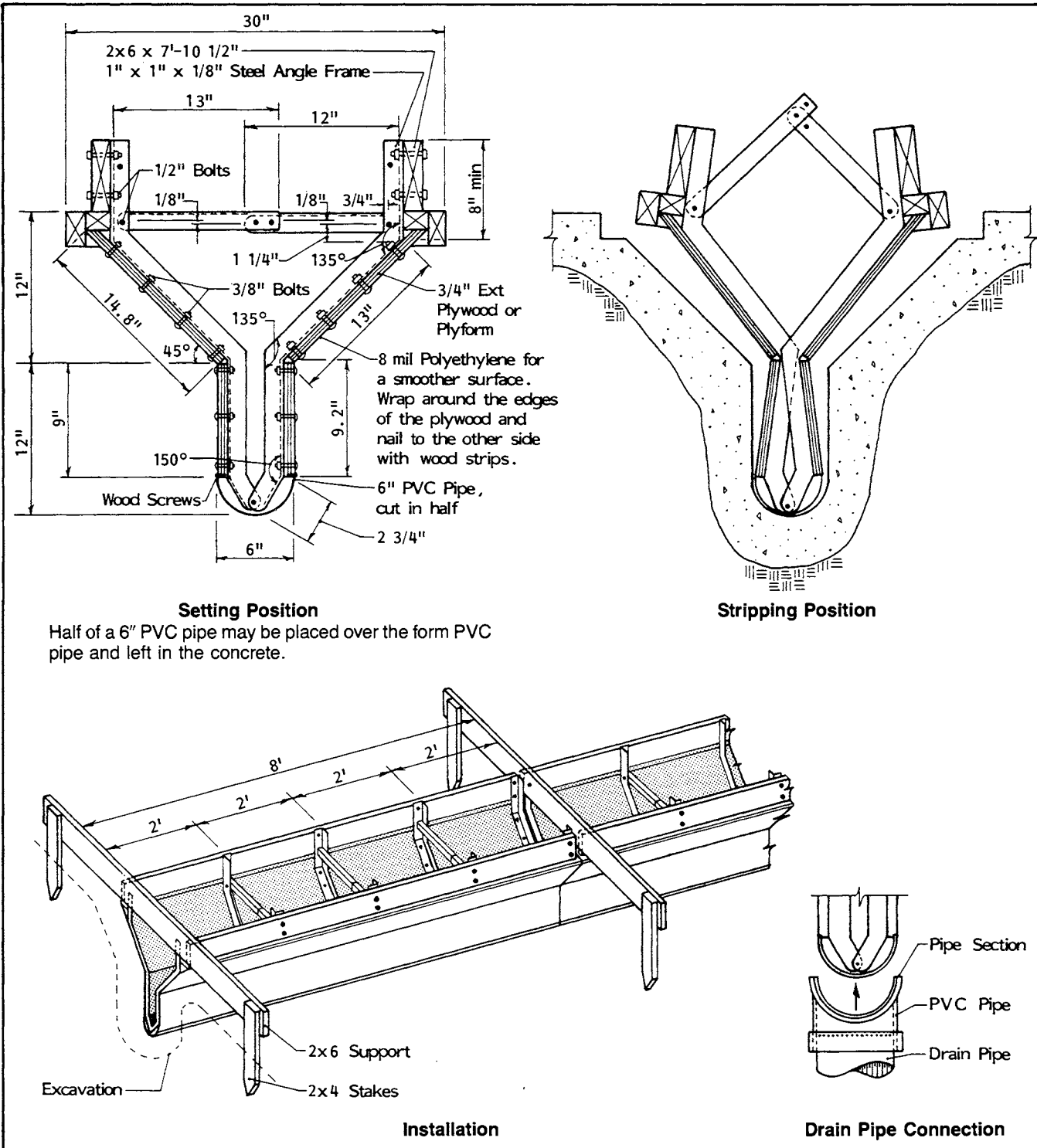


Fig 3-25. Gravity drain Y gutter construction form.

V Gutter

The V gutter resulted from attempts to simplify gutter construction over the more complicated Y gutter. The bottom of the V can be an 8" PVC pipe cut in half or flat 6"-8" concrete. The sides appear to clean better than the Y gutter sloped sides because the manure does not have as much time to dry on the upper slope. The cleaning action of the outflowing manure seems to be nearly as good as for a Y gutter.

Rectangular Gutter

These are easier to construct than either the Y or V gutters so they appeal to contractors and builders. They may not clean quite as well but many producers are satisfied with the results.

Make the bottom slope either very slight ($1''/40'$) or near 1% ($1''/8'$). The steeper slope requires baffles 10' o.c. at the upper half of the slope to help scour the solids out, Fig 3-26.

Some producers leave the gutter bottom flat from end to end and install a drain at each end. By alternating the end at which the gutter is drained, the solids clean out fairly well. One producer installed 5 drains equally spaced in a 180' long gutter. A different drain is pulled each time so the solids are cleaned out of the entire gutter fairly well.

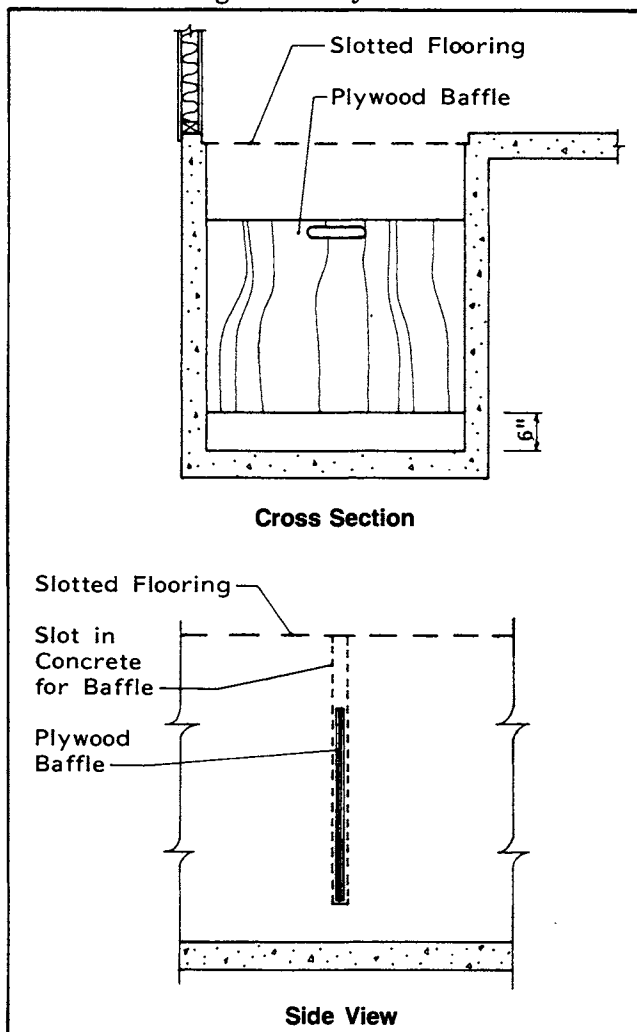


Fig 3-26. Rectangular gravity drain gutter with baffle.

Operation

How often to drain the gutter depends on the rate at which liquids accumulate. This rate is influenced by the amount of waste water. The drain plug is usually pulled every four to five days. Water can be added after each draining to the depth needed to wet the entire gutter bottom. Adding water is more critical in the nursery because baby pig manure is stickier. The gutter can be cleaned if needed by running water through it from a hose or by dumping a bucket of water into the top end of the gutter.

Watertight plugs can be of several different types, Fig 3-27.

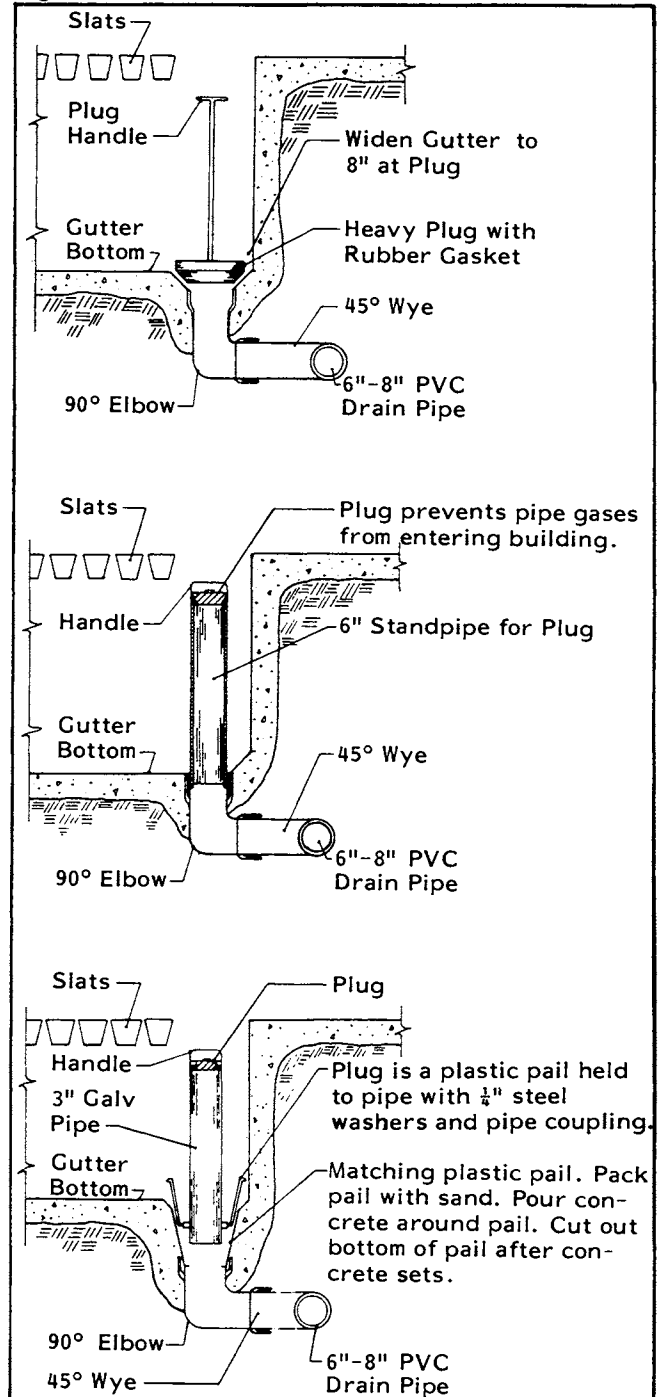


Fig 3-27. Drain plugs for narrow gutters.

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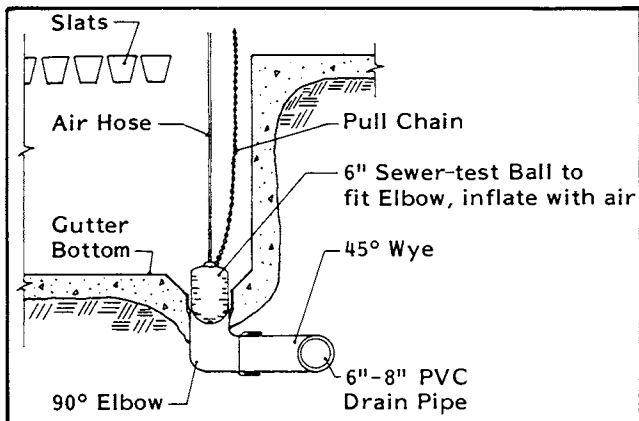


Fig 3-27. Drain plugs for narrow gutters, continued.

To drain the gutters, drain pipe is usually buried under the alley. The gutters from each room connect to the drain pipe with a T or Y joint, Fig 3-28. The plug for each gutter fits into a 90° elbow leading to the drain pipe.

Minimum drain pipe diameter is 6", with 8" preferred—use 10" for wide and long gutters. Slope 6" diameter pipes at 1%; 8" and 10" at ½%.

To transport manure from the building to storage via gravity, construct the building on fill or construct the storage at a lower elevation than the building. If this is not feasible, drain into a sump pit and pump the manure into storage.

Recirculation Flush Pits

Recirculation flush pits are a modification of the gutter flushing concept. Their design evolved to help alleviate pit odor problems in remodeled buildings, but they are also being installed in new swine, beef, and dairy buildings. They also solve some of the problems associated with flushing systems, such as mechanical failure of flush tanks, failure of small continuously running pumps, and salt precipitate forming in continuously used small diameter lagoon recycling pipes. While the design of these systems is rather vague at present, they have generally worked quite well. The following design is based solely on observation of successful farm operations. No rigorous engineering design has yet been made.

The pit is usually under a partly slotted floor and is relatively shallow—2'-4' deep on the high end and sloped from 1"/20' (for swine buildings) to 1½% toward the outlet end. The pit is flushed twice a week to a lagoon and refilled with cleaner lagoon water. Two stage lagoons are recommended to adequately settle solids before the liquids are recycled. The refill pump and pipes from the lagoon are sized to rapidly refill the pit to its design depth of 2½' of liquid at the high end. The pumps are generally designed to refill the pit in less than 4 hours. Add the lagoon water at the high end of the pit to aid cleaning during pit emptying. A pit overflow is typically located near the pit

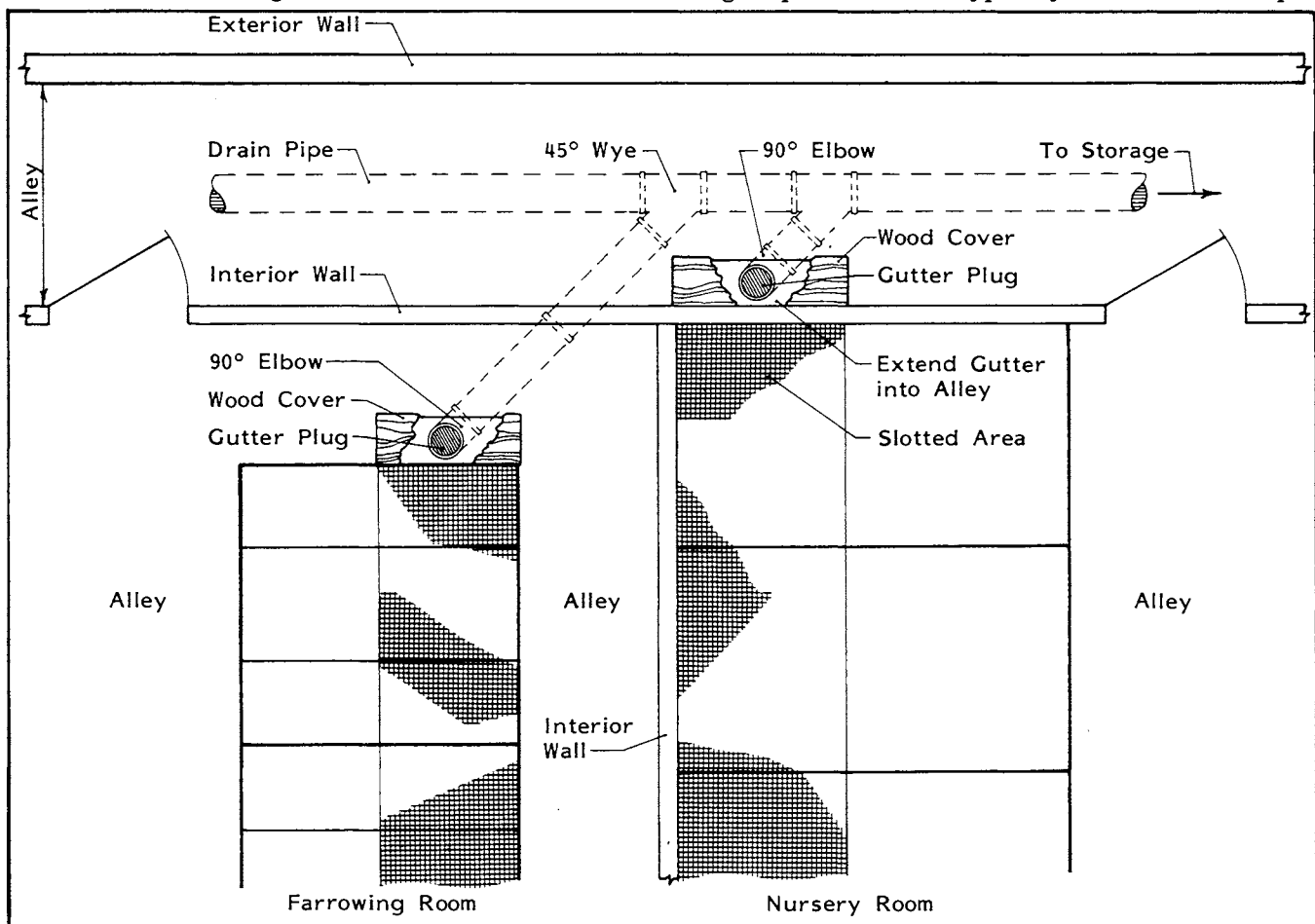


Fig 3-28. Main sewer lines.

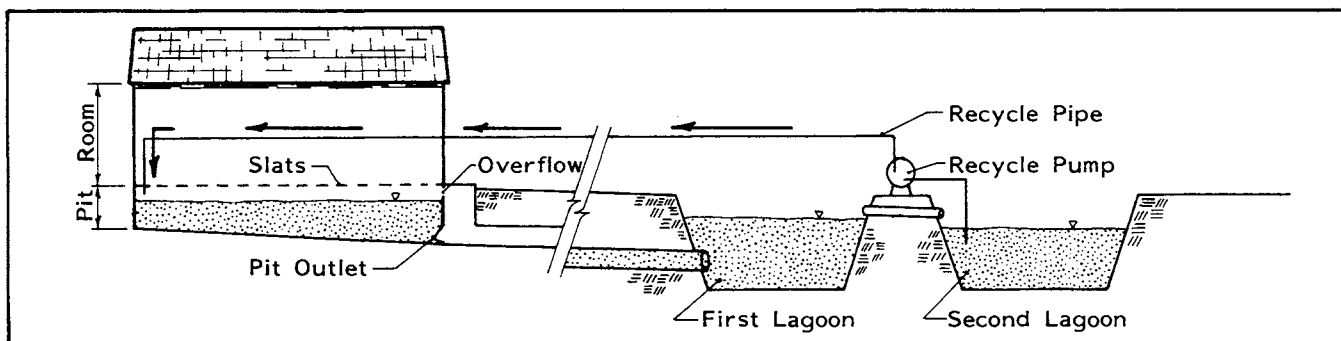


Fig 3-29. Recirculation flush pit.

outlet pipe to handle excess fill water and pit contents displaced by waste additions.

As a general rule, pit outlets are sized large enough (8"-24") to drain the pit in less than 15 minutes. Several types of homemade doors and gates have been used. Some of the large commercially available tank doors designed for flushing dairy freestall barns can be built into the end wall of the pit to provide a large sealable closure.

Initial cost is somewhat greater than for flush systems because of the large recycling pump and pipe (often 3"-6" diameter). However, the system can be shut down and drained after each use, which reduces contact with corrosive lagoon water.

Gravity Flow Channels

Gravity flow channels are rectangular shaped channels with a flat, level bottom and a 6"-8" high dam at the outflow end, Fig 3-30. The main application has been tie stall and free stall dairy barns. The

dam retains a lubricating layer under the manure, and the manure surface forms a 1%-3% incline. Manure flows by gravity down the inclined manure surface, so no mechanical pumps are needed. Biological activity helps liquefy the manure and promotes a constant oozing of material over the dam. The manure flowing over the dam falls into a cross channel or outlet pipe, Fig 3-31. These systems can freeze in cold barns.

Channel width does not affect the performance of these systems, so channels can be used under slotted floors. Channel depth depends on channel length and manure surface incline. The required depth below the grates or slotted flooring can be determined from Table 3-12 or calculated from:

Minimum depth, in. = (channel length, ft x 12 in/ft x 0.03) + (Dam height, in.) + (6" of freeboard)

In stall milking barns, the maximum channel depth at the end opposite the discharge is 54".

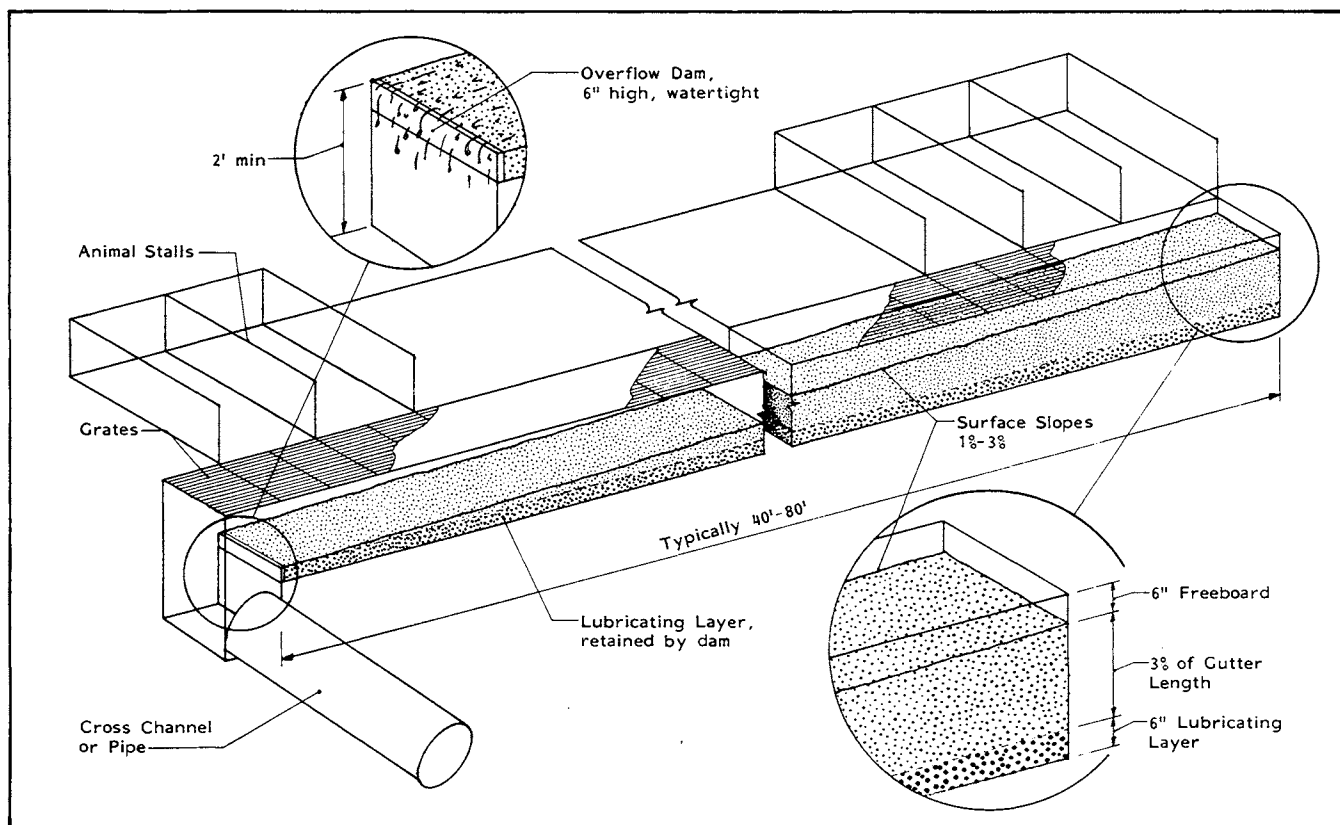


Fig 3-30. Gravity flow channel.

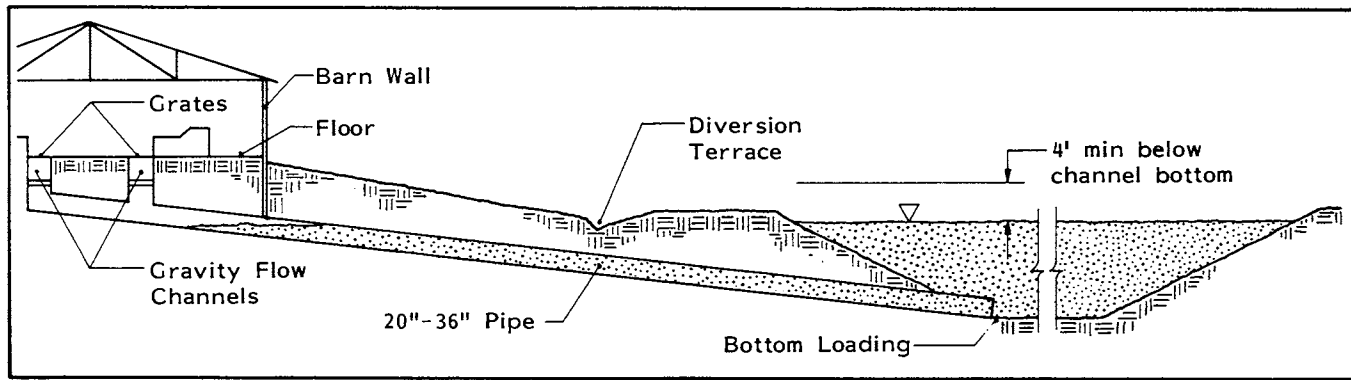


Fig 3-31. Cross channel and outlet pipe.
Transfers manure from gravity flow channels to storage.

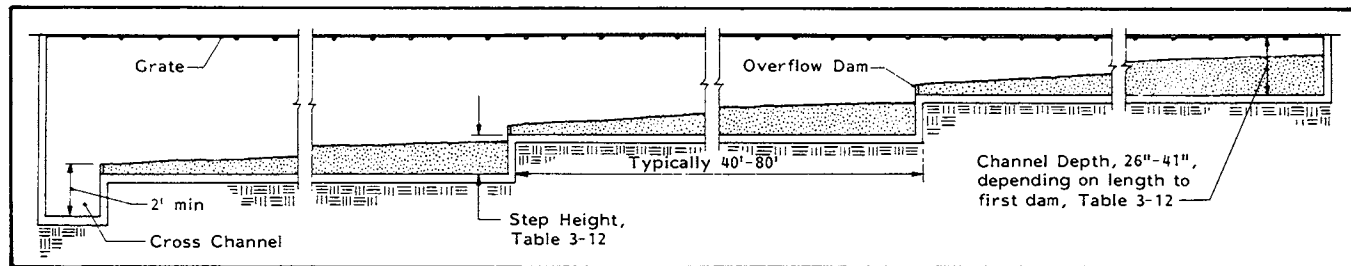


Fig 3-32. Stepped gravity flow channels.
Long channels are typically incremented so there is a dam every 40'-80'.

Channel lengths typically range from 40' to 80'. Long channels must be deep, so costs become prohibitive. If the channel must be longer than 80', consider incrementing the length into steps, Fig 3-32.

Construct the overflow dam from concrete blocks, a steel plate, or pressure preservative treated wood. Dam construction must be watertight. Removable dams make it easier to completely clean the channel.

Before putting animals in the building, fill the channel with 3"-6" of water to form the lubricating layer. Avoid bedding, especially long straw. Do not add milking center wastewater containing disinfectants to the channels or biological activity may be reduced. Contact your milk inspector for approval before installing this system in a stall milking barn.

Table 3-12. Gravity flow channel depth and step height.
Channel depth includes an allowance for a 6" dam and 6" freeboard.

Channel length ft	Channel depth in.	Step height in.
40	26	14
50	30	18
60	34	22
70	37	25
80	41	29

Waste Transfer to Storage

Transfer wastes from an animal facility to storage with a large piston pump, pneumatic pump, centrifugal pump, or gravity. The system selected depends on the individual farm's:

- Waste characteristics.
- Housing system.

- Bedding practices.
- Labor availability.
- Waste storage system.

Mechanical pump transfer is very reliable. The success of a system depends on the careful matching of pump capabilities to waste characteristics. See the section on pumps for information on large piston and pneumatic manure pumps.

Gravity Flow Transfer

Gravity flow transfer uses the hydraulic head exerted by the relatively liquid waste to force the wastes to flow. Pipe size to storage is determined by how liquid the manure is. In general, two pipe size categories are practical. Small diameter (6"-8") pipes work for wastes which are quite liquid, such as swine manure or milkhouse waste. Little or no bedding should be in the waste. Large diameter (20"-36") pipes work for dairy or beef manure with well mixed bedding at a quantity up to about 3 lb/cow-day.

For very large operations or sewers that service a large number of buildings, contact a knowledgeable engineer.

Small diameter pipes

Small diameter pipe gravity flow is most often found with flushing, gravity drain, and deep narrow gutter systems. A disadvantage is the loss in storage capacity in order to maintain the necessary elevation changes. This can be alleviated by constructing the building on fill, pumping the manure to the storage, or locating the storage at an elevation lower than the building.

Slope the pipe its entire length, Table 3-13. Level pipes lead to solids settling out and plugging. Avoid

90° bends in pipe; use wide sweep 45° elbows if turns are necessary. Install pipe below the frost line to prevent freeze-up. In northern climates, bottom load the storage, because top loading leads to freezing problems. In bottom loading systems, keep the end of the pipe 1'-2' off of the floor to reduce settled solids blocking the pipe. Cover the pipe end with at least 1' of liquid at the time of winter freeze-up. Provide cleanouts every 200' and at any bends, Fig 3-33.

Table 3-13. Small diameter pipe gravity flow design.

Limit dry matter content to less than 6%.

Pipe dia. in.	Pipe slope %
6	1
8 or larger	½

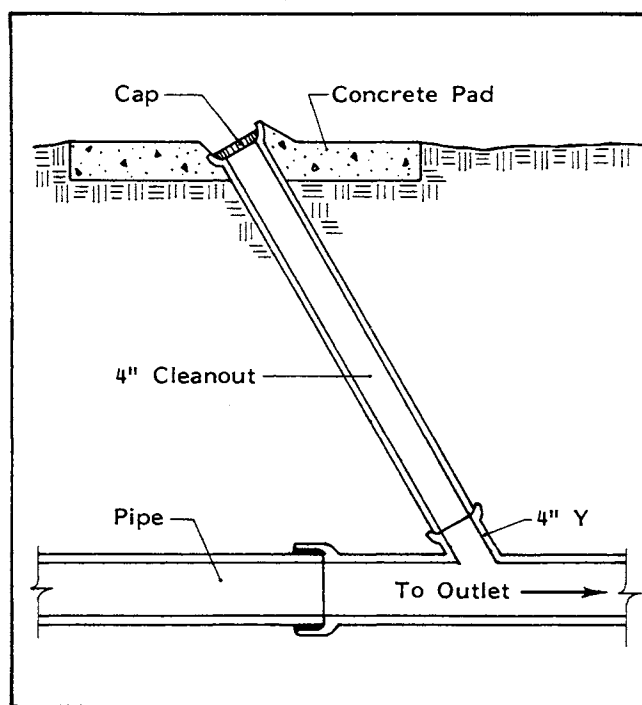


Fig 3-33. Cleanouts for small diameter pipes.

Locate at least 200' o.c. and at any bends.

Large diameter pipes

Large diameter pipes work for semi-solid manures having a dry matter content of 8%-12%. They are typically used to transfer dairy manure but should work for other animals. Table 3-14 summarizes current design recommendations.

Manure with excess bedding or long hay may not flow well unless water is added or elevation is increased. Avoid bends. Mix the extra bedding that is wasted on days when stalls are refilled with the manure before it enters the pipe. If more than about ¼ of the daily manure production is frozen, do not push it into the drop structure. If the manure dries during

summer, add water. Have another way to handle manure on days when the manure is frozen or too dry to be pushed into the pipe.

Include a drop structure for in-barn waste collection, Fig 3-34. Size this structure to hold at least one day's volume of manure and waste. Slope the drop structure floor 45° to the pipe. The drop structure may be cast-in-place concrete, concrete block, or a vertical culvert. Enclose it or provide an insulated cover and install a safety grating. Milkhouse wastes may be discharged into the drop structure. Locate the drop structure for easy access to load the building waste.

The large diameter pipe must be submerged in 1'-2' of manure where it enters the storage structure during winter. Top loading the storage with large pipe gravity flow is not recommended. Earth storages are typical with large pipe systems, but other storages work.

Table 3-14. Large diameter pipe gravity flow criteria.

Parameter	Design range
Pipe diameter	20"-36"
Bedding	Less than 3 lb bedding/cow-day
Frozen manure	Less than ¼ of daily volume
Manure pack	Not allowed
Pipe material	Concrete, steel, or PVC
Ground cover over pipe	More than 4' in cold climates
Minimum elevation difference	4'-6' between top of collection pit and material in storage for transfer distances up to 300'

Reception Pit and Pump

Another transport-to-storage method is to collect manure in a small concrete pit and then pump it to an outside storage with a centrifugal chopper pump. Locate the reception pit so manure can be easily moved into it by the collection system. Size the pit to hold at least one day's waste and preferably several days' accumulation.

The pump is usually electric. Both vertical shaft pumps with the motor above the pit and submersible pumps are available. Choose a pump capable of handling manure with bedding and which develops sufficient head to pump manure from the bottom of the pit to the maximum level in the storage. Pumps should be able to pass 1½"-2" diameter solids for swine and 2"-3" solids for beef and dairy. See section on pumps.

Install a check valve between the pump and storage to prevent backflow. Also install a manual shut-off valve, particularly if the maximum elevation in storage is above the barn floor level. Size the pipe for reasonable friction loss (less than 2'-3') between pump and storage. If there is very little elevation difference, friction loss is less critical.

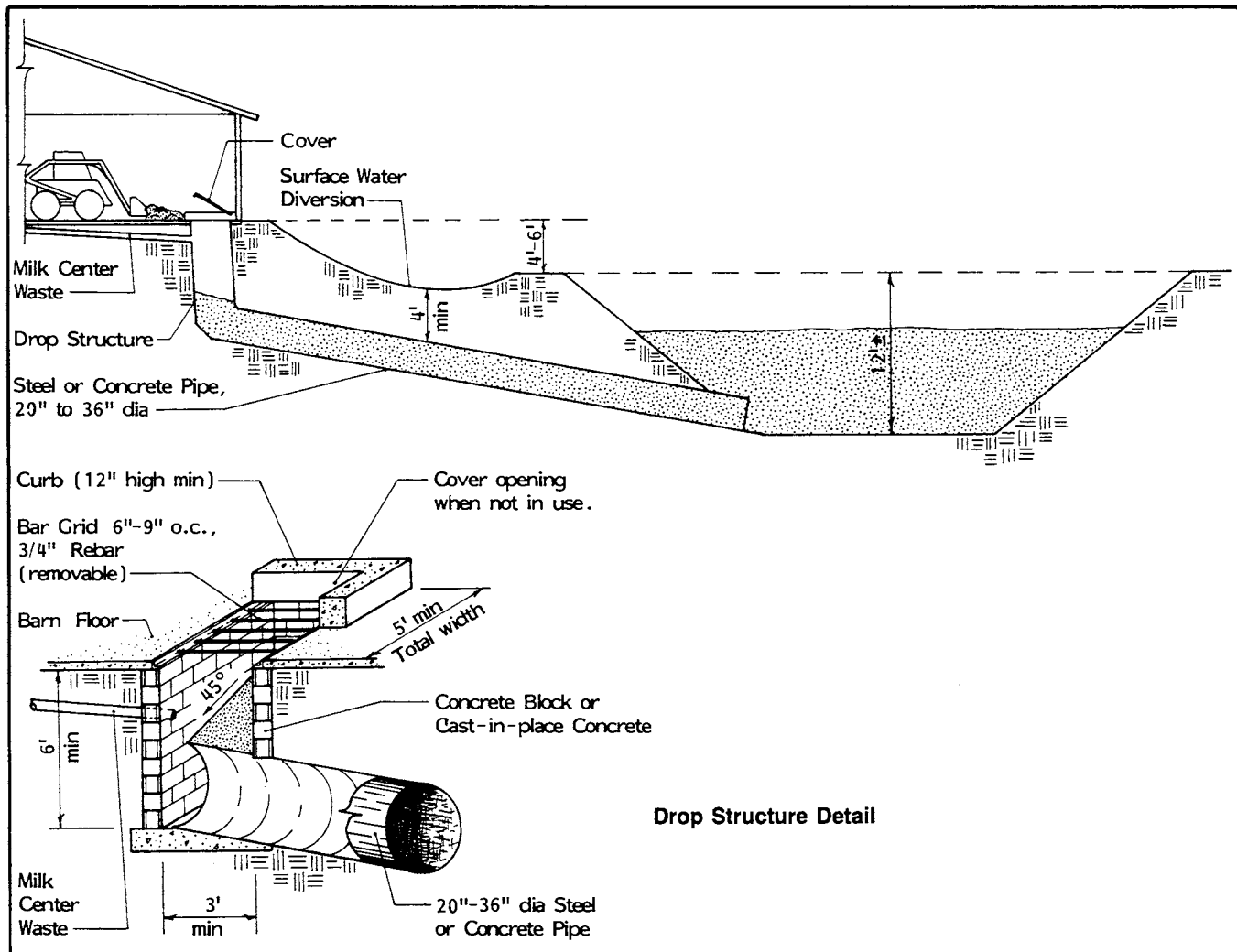


Fig 3-34. Gravity flow manure transfer and storage system.

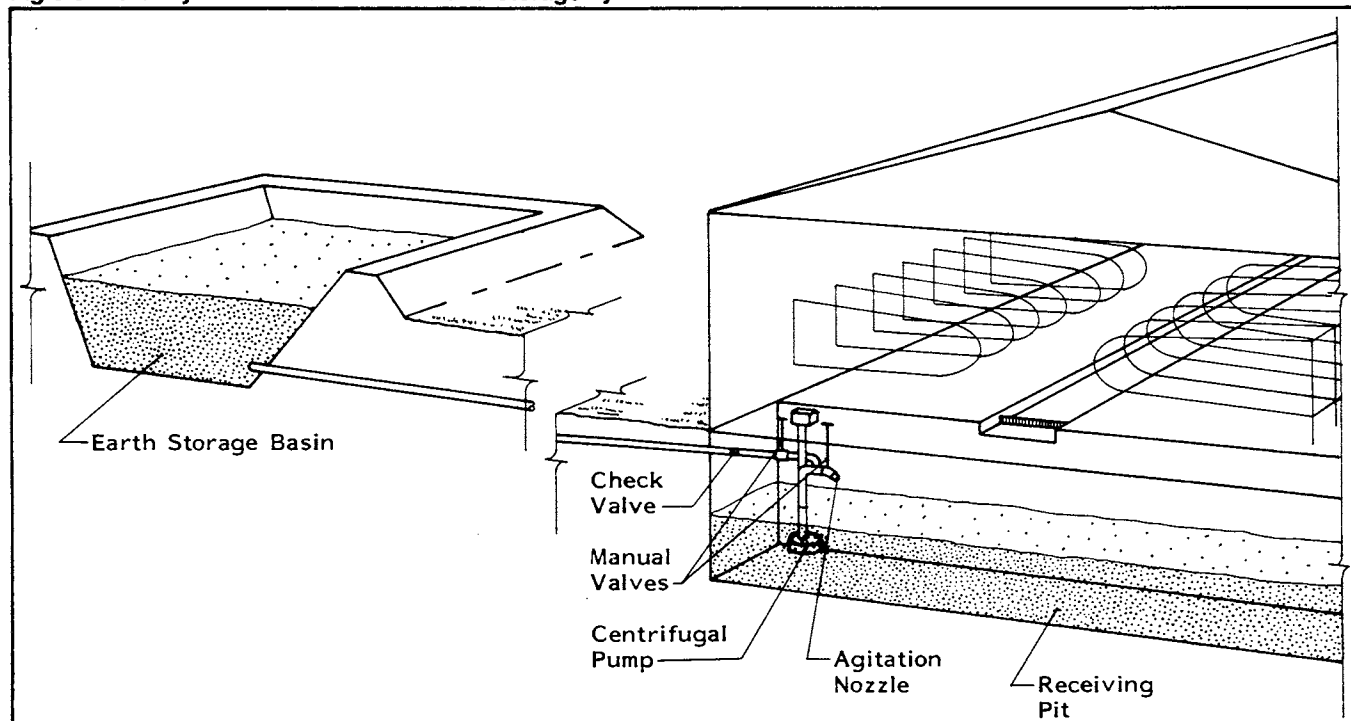


Fig 3-35. Reception pit and pumps.

4. HANDLING OPEN LOT WASTE

Lot Runoff

Runoff from outdoor livestock areas transports manure, soil, chemicals, and debris, and requires facilities for both pollution control and drainage. Proper assessment of the pollution potential depends not only on the size and other physical characteristics of the lot but also on rainfall intensity, duration, and frequency.

In this book, "lot" means any outdoor animal area—beef feedlot, handling area, outdoor dairy feeding and/or resting areas, sow feeding pens, etc. A lot may be completely paved, partially paved around feeders and waterers, or unpaved.

Where livestock spend only part of their time outdoors, estimate the proportion of total manure exposed to lot runoff. See Table 4-1 for cattle. Where sows are let outdoors at least daily for feeding, a large proportion of their manure is exposed to lot runoff.

Table 4-1. Cattle manure in buildings and lots.

If animals have free access to lot, manure in lot = table value x total manure/day. If animals are released to lot for controlled periods, manure in lot = total manure/day x hr/day in lot ÷ 24.

Housing type	Proportion of manure on lot
Free stall dairy	
Inside feeding	0.5
Lot feeding	0.6
Manure pack bedded area and lot feeding	
Dairy cattle and heifers	0.5
Beef cows	0.7
Beef feedlot cattle	0.7

Unpaved Lots

Runoff from unpaved lots is affected by slope, rainfall amount and intensity, and maintenance timing and practices. Soil type has little long-range effect because of compaction and mixing of manure and soil. Frequent deep scraping leaves little loose soil or manure to wash off, but is not recommended because replacement soil is costly. Deep scraping also destroys the interface layer which forms between the manure and the soil. The interface layer acts as a seal to prevent nitrites and other pollutants from seeping down to the groundwater. Bedding added to mounds may reduce runoff but increases the amount of material to be scraped off.

Divert clean roof and surface water around the lot to a "clean water" drainage system that is independent of the waste management system, Fig 4-1. This reduces the amount of water that the waste system must handle, prevents excessive solids erosion from the lot, and maintains the settling facility's effectiveness.

Solids removed by runoff

Rainfall runoff has up to about 1.5% solids content which is equivalent to about 10½ tons of solids per acre-foot (a-ft) of runoff (1 a-ft = 43,560 ft³). High rainfall intensities result in more solids.

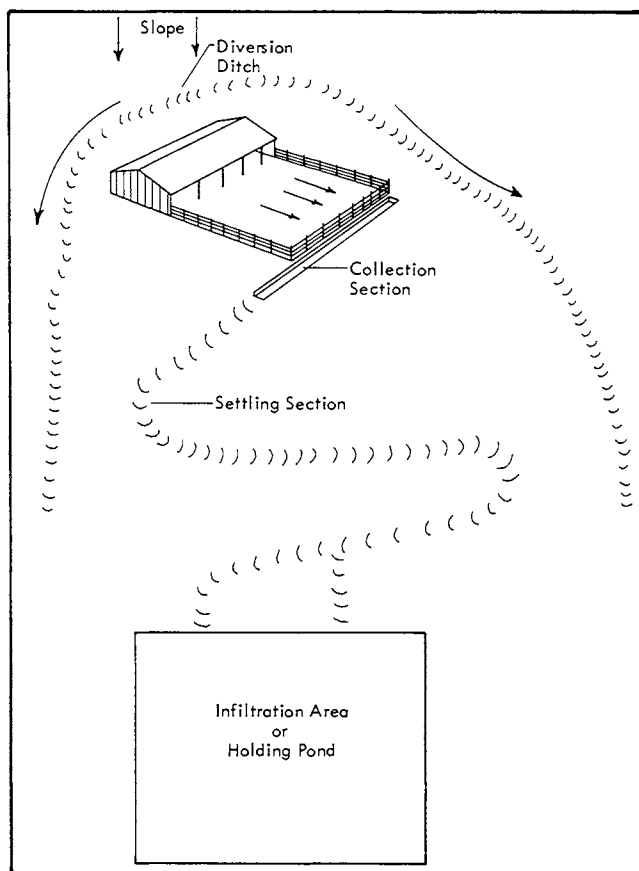


Fig 4-1. Divert clean runoff around lot.

More manure is usually transported by snowmelt runoff than by rainfall runoff. Solids content may be as much as 10 times higher. Thawing manure, soil, snow, and ice may be too thick to flow, solids may not settle out, and the slurry may be difficult to handle with a loader. Scrape the slurry to an area where it can drain and dry out, or scrape it to a holding pond for dilution and pumping.

Longer and steeper slopes require more frequent solids removal from settling units and increased lot management. Studies of settling channels for unpaved feedlot runoff showed an accumulation of about 2 yd³ (or about 2 tons) of solids/head-yr from a lot with a 15% slope and 340' long. From a 7% and shorter slope, the settled solids were only 0.6 yd³ (tons)/head-yr.

Lot drainage can be improved by increasing slope and by decreasing slope length, but a steeper slope causes greater solids movement and erosion on unpaved lots. If a manure mulch is maintained, the soil erodibility is low. In fact, solids erosion from an unpaved lot may be only half as much as the soil losses from similar slopes in cultivated fields.

Solids removed by cleaning

In most lots, accumulations of partially decomposed manure are removed mechanically from the lot and/or mounded in the lot. Remove solids from unpaved lots with care—avoid disturbing the 3"-4" of compacted manure next to the soil surface. This interface layer reduces mixing of manure and soil by ani-

Exhibit 1100

mals in wet conditions, which reduces the amount of soil removed with the manure so less soil has to be replaced. The interface layer also is an anaerobic zone for denitrification and reduces liquid percolation down into the soil.

Liquid runoff

Most of the runoff volume on an unpaved lot is water, so estimating the amount of water closely approximates the total runoff to be handled by the runoff control facilities.

1. Determine the runoff area.
2. Determine storm rainfall = P, in. of rain. If design storm intensity is not otherwise regulated, use the 25-yr, 24-hr storm for your area, Fig 11-7.
3. An unpaved feedlot holds about the first ½" of rain, unless it has rained within the previous few days. Thus, a storm of less than ½" usually results in little runoff from an unpaved lot. For a storm with P over ½", determine runoff from:

Eq 4-1.

$$RO = [(P - \frac{1}{2}) \div 12] \times LA$$

RO = lot runoff, ft³

P = rainfall, in.

LA = lot area, ft²

Paved Lots

Solids removal

Daily scraping removes almost all solids, but during a heavy rain, up to one day's manure can be in the runoff. Periodic scraping, which is more typical of paved or partially paved lots, removes a major portion of the solids during drier and unfrozen periods. Therefore, the portions of solid manure removed by scraping and by runoff depends on management practices.

Liquid runoff

For a paved lot scraped daily, almost all rainfall runs off, so design the facilities for the total rainfall, P.

Eq 4-2.

$$RO = (P \div 12) \times LA$$

RO = lot runoff, ft³

P = rainfall, in.

LA = lot area, ft²

If the lot is scraped only periodically, assume about ¼" is retained on the lot, and the remaining (P - ¼)" is runoff.

Eq 4-3.

$$RO = [(P - \frac{1}{4}) \div 12] \times LA$$

RO = lot runoff, ft³

P = rainfall, in.

LA = lot area, ft²

Runoff Control Facility Design

The following design sections help you select appropriate channels, gutters, pipes, or culverts for liquids with solids content less than about 5%. Thicker liquids flow more slowly and require larger channels and steeper slopes.

Contact your district SCS engineer for help with the design of waterways draining **large** areas—cropland, pastures, woodlots. The capacity of those channels is not included here.

Fig 4-2 illustrates the channels for which design tables are given. Read the discussion with each table carefully, as each is for a specific set of conditions.

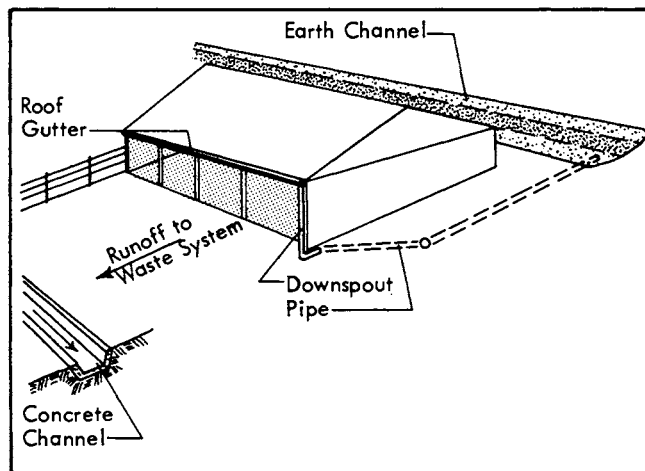


Fig 4-2. Gutters and open channels.

Runoff Intensity

1. Determine the runoff flowrate to be carried in a channel or pipe (Q) from the rainfall intensity, and the ground or roof area.

$$Q, \text{ cfs} = (\text{area, ft}^2) \times (\text{rainfall intensity, in/hr}) \div [(12 \text{ in/ft}) \times (3,600 \text{ sec/hr})] \\ = (\text{ft}^2) \times (\text{in/hr}) \div 43,200$$

Note that because 43,560 ft² = 1 acre:

$$Q, \text{ cfs (within 1\% accuracy)} = (\text{area, acre}) \times (\text{intensity, in/hr}).$$

Use rainfall intensity for 10-yr, 5-min storm found in Fig 11-2.

2. Select the type of channel, Fig 4-2, and then go to the appropriate following section to complete the design.

Open Channels

The common design equation for fluid flow in open channels (of any configuration) is Manning's Formula. To find channel capacity:

Eq 4-4.

$$Q = 1.486 \times S^{0.5} \times A^{1.667} \div (n \times P^{0.667})$$

Q = channel flow, cfs

S = slope, ft/ft, in/in, etc.

A = water cross-sectional area, ft²

n = surface roughness coefficient, Table 4-2a

P = wetted perimeter, ft

Liquid velocity in the channel:

Eq 4-5.

$$V, \text{ fps} = Q/A = 1.486 \times R^{0.667} \times S^{0.5} \div n$$

V = liquid velocity, ft/sec = fps

R = hydraulic radius = A/P, ft

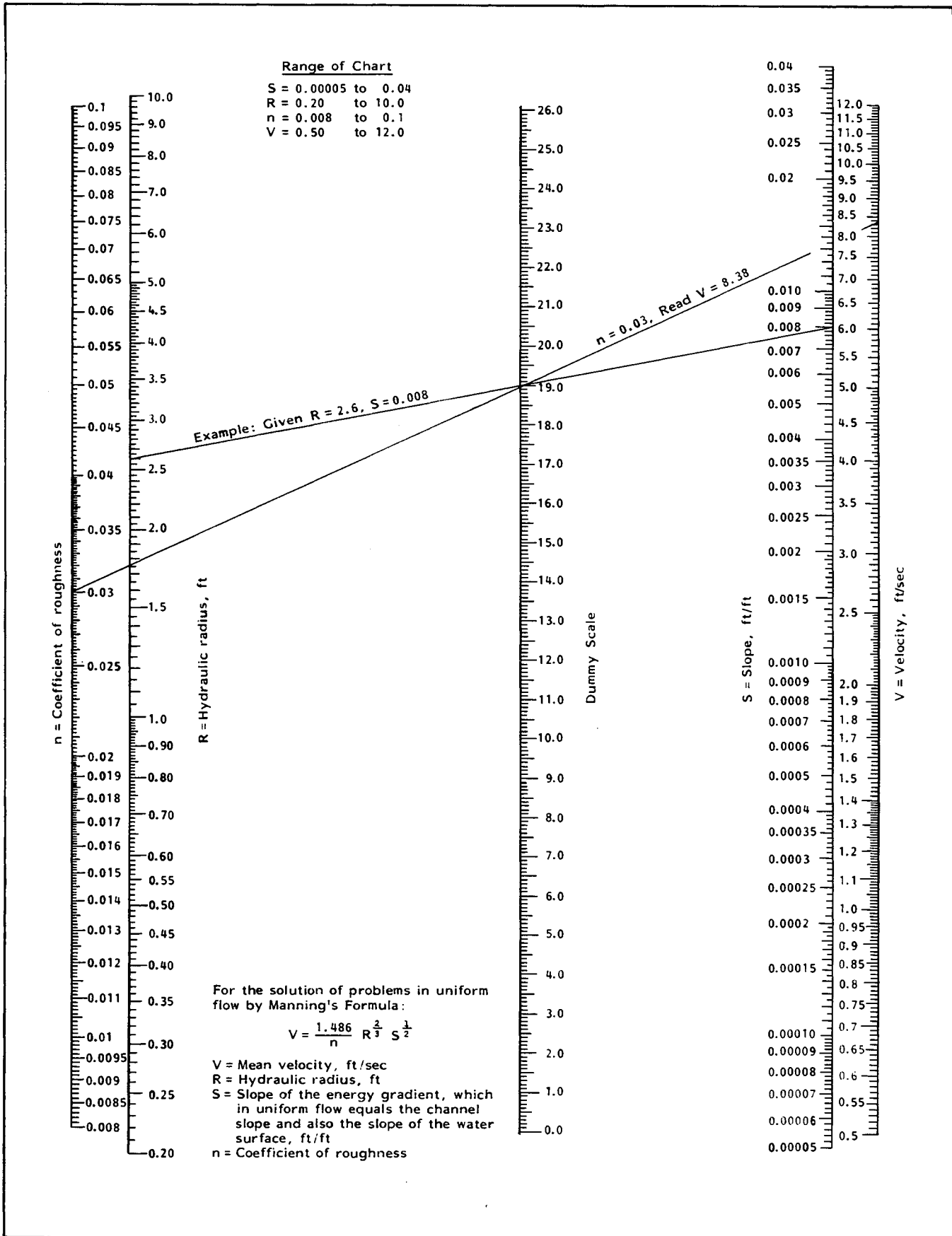
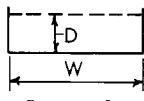
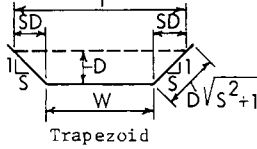
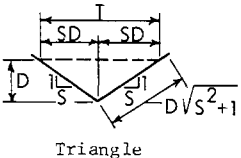


Fig 4-3. Manning's Formula chart.

Source: SCS.

Table 4-2. Channel properties.

4-2a. Surface roughness coefficients, n. For Manning's Formula.		4-2b. Elements of channel sections.				
Channel type	n	Section	Area A	Wetted perimeter P	Hydraulic radius R	Top width T
Channels, lined			WD	W+2D	$\frac{WD}{W+2D}$	W
Asphalt	0.014	Rectangle				
Concrete	0.015					
Shotcrete	0.017					
Channels, earth	0.040					
Channels, dense grass			$WD+SD^2$	$W+2D\sqrt{S^2+1}$	$\frac{WD+SD^2}{W+2D\sqrt{S^2+1}}$	W+2SD
Grass greater than 10" tall	0.04-0.23	Trapezoid				
Grass less than 2.5" tall	0.034-0.16					
			SD^2	$2D\sqrt{S^2+1}$	$\frac{SD}{2\sqrt{S^2+1}}$	2SD
		Triangle				

For common configurations, the area, wetted perimeter, and hydraulic radius are in Table 4-2b.

Manning's Formula can also be solved with Fig 4-3.

1. Determine or select the hydraulic radius (R), slope (S), and surface roughness coefficient (n, Table 4-2a).
2. As an example, assume that you know R, S, and n, and want to determine V. Connect R = 2.6 and S = 0.008 with a straight line to establish the pivot point of 19.0 on the dummy scale.
3. Pass a straight line from n = 0.03 through the pivot point (19.0) to the velocity scale.
4. Read the velocity V = 8.38 fps. If too great or too small, select another R and solve for V. Continue until desired V is achieved. If velocity is too great, you may need to change the channel lining (n) or channel slope (S). For example, you can lower velocity by increasing n or decreasing S. Velocity in the channel affects settling and erosion. If settling is not wanted, maintain velocities above about 1.5 fps. In settling channels, design for velocities below about 1.5 fps. Maximum velocity can be limited by surface conditions of channel. Velocities in excess of 4 fps may cause erosion under certain conditions in unlined channels.

Open concrete channels

Where a paved drive or similar channel carries runoff, select required width and depth from Table 4-3.

Although developed for vertical sides, the channels carry at least the listed capacities if the sides are sloped out. For wider channels, capacity is somewhat greater than the capacities of two channels of the same depth. For example, an 8" deep by 16' wide channel carries a little more than two 8' wide chan-

Table 4-3. Open rectangular concrete channel capacity.

n = 0.015; S = $\frac{1}{4}$ in/ft = 0.5%.

Dashed lines refer to Example 4-1.

Example 4-1:

Two 94'x800' gable roof buildings are separated by a 12' wide paved alley. The alley drains roof water and about 2 acres above the buildings. How deep must the alley be? Solids settling is not wanted, so design it for a velocity over 1.5 fps.

Solution:

Compute: 2 acres = 2 x 43,560 = 87,120 ft²

One half of each roof + the alley = 47' + 12' + 47' = 106' wide; 106' x 800' = 84,800 ft²

Total area drained = 87,120 + 84,800 = 171,920 ft².

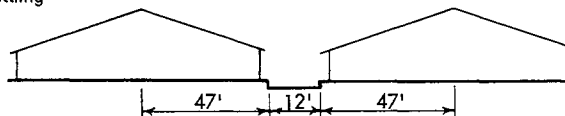
If intensity = 7 in/hr, Q = 171,920 x 7 ÷ 43,200 = 27.9 cfs.

A 6" deep, 12' wide channel carries 25.6 cfs, which is not quite enough; use 6½" depth.

Check velocity: V = Q ÷ cross-sectional area

Area = 12' x 6.5" ÷ 12 = 6.5 ft²

V = 27.9 ÷ 6.5 = 4.3 fps, which is greater than 1.5 fps so there is little settling



Depth in.	Width, ft							
	2	4	6	8	10	12	14	16
	----- Capacity, cfs -----							
2	0.6	1.4	2.1	2.8	3.5	4.2	5.0	5.7
4	1.9	4.1	6.4	8.7	11.0	13.2	15.5	17.8
6	3.4	7.8	12.2	16.6	21.1	25.6	30.1	34.6
8	5.2	12.0	19.1	26.2	33.4	40.6	47.9	55.1
10	7	17	27	37	48	58	68	79
12	9	22	35	49	63	77	91	106
14	11	27	45	62	80	98	117	135
16	13	33	54	76	99	121	144	167
18	15	39	64	91	118	145	173	200
20	17	45	75	106	138	171	200	240
22	20	51	86	122	159	197	230	270
24	22	57	97	138	181	220	270	310

nels. From Table 4-3, a 16' wide channel carries 55.1 cfs; two 8' wide channels carry $2 \times 26.2 = 52.4$ cfs.

Open earth channels, Table 4-4, 5

Low slope channels can settle solids from runoff, Table 4-4.

Diversion ditches to carry clean runoff around a building, farmstead, or lot are usually grassed waterways with a roughly trapezoidal cross section. Base capacity on a 10-yr, 5-min storm to provide adequate drainage.

Channel maintenance includes mowing, maintaining depth by cleaning and occasional dike rebuilding, and care at culverts.

Roof Gutters and Small Concrete Channels

Standard roof gutters and downspouts are not adequate for runoff from large roofs. To divert roof runoff away from the waste control system consider one of the following:

- Design a roof gutter to carry all water to one or both ends of the building. Select adequate downspouts and a pipe or gutter to carry the water away from the site.

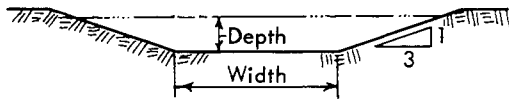
Table 4-4. Trapezoidal settling channel design.

These low slope channels settle solids out of runoff. The lower the water velocity, fps, the higher the settling rate. Construct channel at least $\frac{1}{2}$ ' deeper than the table value to allow for solids waste storage.
 $n = 0.04$; bottom slope as shown; sideslope 3:1.
 Dashed lines refer to Example 4-2.

Example 4-2:

Assume the same runoff as in Example 4-1 where $Q = 27.9$ cfs. A 0.1%, 1'x25' earth channel is adequate. At 1 fps velocity and 30 min detention, the channel length must be:

$$30 \text{ min} \times 1 \text{ fps} \times 60 \text{ sec/min} = 1,800' \text{ long}$$



Bottom slope	Depth ft		Bottom width, ft						
			10	15	20	25	30	35	
Earth channels									
0.1%	0.5	fps	0.6	0.7	0.7	0.7	0.7	0.7	
		cfs	3.7	5.5	7.4	9.2	11.1	12.9	
	1.0	fps	0.9	1.0	1.0	1.0	1.1	1.1	
		cfs	12.2	17.9	23.6	29.4	35.2	41.0	
	1.5	fps	1.2	1.2	1.3	1.3	1.3	1.4	
		cfs	25.1	36.0	47.1	58.4	69.7	81.1	
	2.0	fps	1.3	1.4	1.5	1.5	1.6	1.6	
		cfs	42.8	60.0	77.7	95.6	113.7	131.9	
	0.2%	0.5	fps	0.9	0.9	1.0	1.0	1.0	1.0
			cfs	5.2	7.8	10.4	13.0	15.6	18.2
		1.0	fps	1.3	1.4	1.5	1.5	1.5	1.5
			cfs	17.3	25.3	33.4	41.6	49.8	58.0
0.3%	0.5	fps	1.1	1.2	1.2	1.2	1.2	1.2	
		cfs	6.4	9.6	12.8	15.9	19.1	22.3	
	Concrete channels								
	0.1%	0.5	fps	1.6	1.9	1.9	1.9	1.9	1.9
cfs			9.9	14.7	19.7	24.5	29.6	34.4	

- Design a smaller gutter to carry the water to several intermediate downspouts and to an underground pipe leading away from the building.
- Where an open channel will not become polluted, eave gutters can be omitted, and roof water permitted to fall into a surfaced channel or stone filled, tile drained ditch. The building must have at least a 12" overhang.

Table 4-5. Trapezoidal drainage channel design.

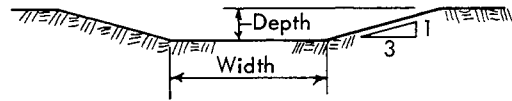
Select a velocity below 5 fps unless liner material is added to reduce erosion.
 $n = 0.4$; bottom slope as shown; sideslope 3:1.
 Dashed lines refer to Example 4-3.

Example 4-3:

Assume the same runoff as in Example 4-1 where $Q = 27.9$ cfs. A 1' deep, 6' wide channel is sufficient at 1% slope.

Velocity = 2.9 fps < 5 fps, which is OK.

For a 3% slope, select a 1'x2' channel and increase the depth slightly. To reduce velocity below 4.5 fps, make the channel wider so flow will be less than 1' deep.



4-5a. Longitudinal slope = 1%.

Depth ft	Width, ft						
	1	2	4	6	8	10	12
0.5	fps 1.4	1.8	1.9	2.0	2.1	2.1	2.1
	cfs 1.4	3.5	5.7	8.0	10.3	12.6	14.9
1.0	fps 2.3	2.6	2.8	2.9	3.0	3.1	3.2
	cfs 9.2	15.6	22.4	29.4	36.5	43.7	50.9
1.5	fps 3.0	3.3	3.5	3.7	3.8	3.9	4.0
	cfs 27.1	39.6	52.7	66.1	79.8	93.7	107.7
2.0	fps 3.7	3.9	4.1	4.3	4.5	4.6	4.7
	cfs 58.4	78.5	99.4	120.8	142.6	164.7	187.0
2.5	fps 4.2	4.5	4.7	4.9	5.0	5.2	5.3
	cfs 106.0	135.0	165.0	195.8	227.0	258.7	290.8
3.0	fps 4.8	5.0	5.3	5.4	5.6	5.7	5.8
	cfs 172.4	211.7	252.1	293.4	335.4	377.9	421.0

4-5b. Longitudinal slope = 2%.

Depth ft	Width, ft						
	1	2	4	6	8	10	12
0.5	fps 2.0	2.5	2.7	2.8	2.9	3.0	3.0
	cfs 2.0	5.0	8.1	11.3	14.6	17.8	21.1
1.0	fps 3.2	3.7	4.0	4.2	4.3	4.4	4.5
	cfs 13.0	22.1	31.7	41.6	51.6	61.8	72.0
1.5	fps 4.3	4.7	5.0	5.2	5.4	5.5	5.6
	cfs 38.3	56.0	74.5	93.5	112.9	132.5	152.3
2.0	fps 5.2	5.6	5.9	6.1	6.3	6.5	6.6
	cfs 82.6	111.0	140.5	170.8	201.6	232.9	264.5
2.5	fps 6.0	6.4	6.7	6.9	7.1	7.3	7.5
	cfs 149.9	191.0	233.4	276.8	321.1	365.9	411.2
3.0	fps 6.8	7.1	7.4	7.7	7.9	8.1	8.3
	cfs 243.8	299.4	356.6	414.9	474.3	534.5	595.3

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Table 4-5. Trapezoidal drainage channel design, continued.**4-5c. Longitudinal slope = 3%.**

Depth ft		Width, ft						
		1	2	4	6	8	10	12
0.5	fps	2.5	3.0	3.3	3.5	3.6	3.6	3.7
	cfs	2.5	6.1	9.9	13.9	17.8	21.8	25.8
1.0	fps	4.0	4.5	4.9	5.1	5.3	5.4	5.5
	cfs	15.9	27.0	38.8	50.9	63.2	75.6	88.2
1.5	fps	5.2	5.7	6.1	6.4	6.6	6.8	6.9
	cfs	46.9	68.6	91.3	114.6	138.3	162.3	186.6
2.0	fps	6.3	6.8	7.2	7.5	7.7	7.9	8.1
	cfs	101.2	136.0	172.1	209.2	247.0	285.2	323.9
2.5	fps	7.3	7.8	8.2	8.5	8.7	9.0	9.2
	cfs	183.5	233.9	285.9	339.1	393.2	448.1	503.6
3.0	fps	8.3	8.7	9.1	9.4	9.7	9.9	10.1
	cfs	298.6	366.7	436.7	508.2	580.9	654.6	729.1

Table 4-6 gives maximum capacities of small open channels of rectangular cross section, such as roof gutters and small concrete gutters. Bottom slope is $\frac{1}{16}$ in/ft (0.5%).

Where water is collected from relatively small areas, there is little time delay between peak rainfall and peak channel flow. Base the design on a 10-yr, 5-min peak rainfall, in/hr, Fig 11-2, and surface area drained, ft^2 .

Table 4-6. Roof and concrete gutter capacity.

Standard roof gutters are too small for large roof areas. Capacities given are for smooth metal, smooth concrete, or planed lumber gutters or channels. Dashed lines refer to Examples 4-4 and 4-5.
 $n = 0.012$; $S = \frac{1}{16}$ in/ft = 0.5%.

Gutter depth in.	Gutter width, in.						
	6	8	10	12	14	16	18
	Capacity, cfs						
2	0.16	0.23	0.30	0.37	0.44	0.52	0.59
4	0.41	0.60	0.80	1.02	1.24	1.46	1.68
6	0.68	1.02	1.38	1.77	2.17	2.58	3.00
8	0.96	1.46	2.00	2.58	3.19	3.82	4.46
10	1.24	1.90	2.64	3.42	4.25	5.12	6.00
12	1.5	2.4	3.3	4.3	5.4	6.5	7.6
14	1.8	2.8	4.0	5.2	6.5	7.8	9.3
16	2.1	3.3	4.6	6.1	7.6	9.2	10.9
18	2.4	3.8	5.3	7.0	8.8	10.7	12.7
20	2.7	4.2	6.0	7.9	9.9	12.1	14.4

Example 4-4:

What size metal gutter is needed where each downspout drains a section of roof $30' \times 300'$? Rainfall intensity for a 10 yr, 5-min storm = 7 in/hr.

Solution:

Compute flowrate: $Q = 30 \times 300 \times 7 \div 43,200 = 1.46$ cfs

From Table 4-6, select a gutter 8" wide by 8" deep. Additional depth may be desired to allow for silting and, if overflow is particularly damaging, some safety factor.

Example 4-5:

What size concrete channel is needed to divert runoff from a one acre ($43,560 \text{ ft}^2$) farm courtyard for the same rainfall? Solids settling is not wanted so design for a velocity over 1.5 fps.

Solution:

Compute: $Q = 43,560 \times 7 \div 43,200 = 7.06$ cfs

From Table 4-6, select a channel 12" deep x 18" wide; cfs = 7.6.

Check for velocity (may get settling below about 1.5 fps):

$V = \text{cfs} \div \text{channel area}$

Area = $12" \times 18" = 1' \times 1.5' = 1.5 \text{ ft}^2$

$V = 7.06 \div 1.5 = 4.7 \text{ fps} > 1.5 \text{ fps}$, which is OK.

Downspouts

Large roof gutters require large downspouts. Table 4-7 lists the downspout area needed based on gutter size. A square or rectangular downspout of that area will carry all the water the gutter can carry. Fig 4-4 converts the required area to the diameter of a round downspout.

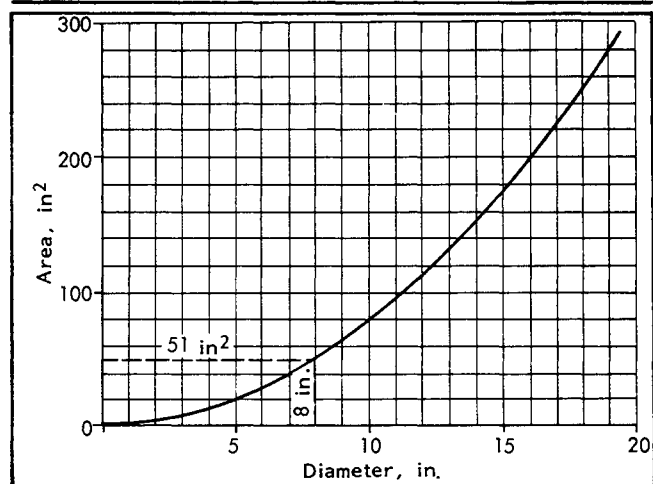
Table 4-7. Roof gutter downspouts.

Required cross-sectional area of vertical downspouts based on roof gutter size. Capacity of the downspouts is equal to the corresponding gutter capacity for the given width and depth. Dashed lines refer to Example 4-6. Solutions are for orifice flow with an orifice coefficient of 0.6. Total head is equal to the gutter depth.

Example 4-6:

The 8"x8" gutter in Example 4-4 requires a downspout of 51 in^2 . Use a downspout $6" \times 8\frac{1}{2}"$, $7\frac{1}{4}" \times 7\frac{1}{4}"$, etc. Or select a round one from Fig 4-4 with an 8" diameter.

Gutter depth in.	Gutter width, in.						
	6	8	10	12	14	16	18
	Cross-sectional area of downspout, in^2						
2	11	16	21	26	31	36	42
4	20	30	40	51	61	72	84
6	27	42	56	72	88	105	122
8	34	51	70	91	112	134	157
10	39	60	83	108	134	161	189
12	44	68	94	123	154	186	218
14	48	75	105	137	172	208	246
16	52	82	115	151	189	230	272
18	56	88	124	163	205	250	297
20	60	94	132	175	221	269	320

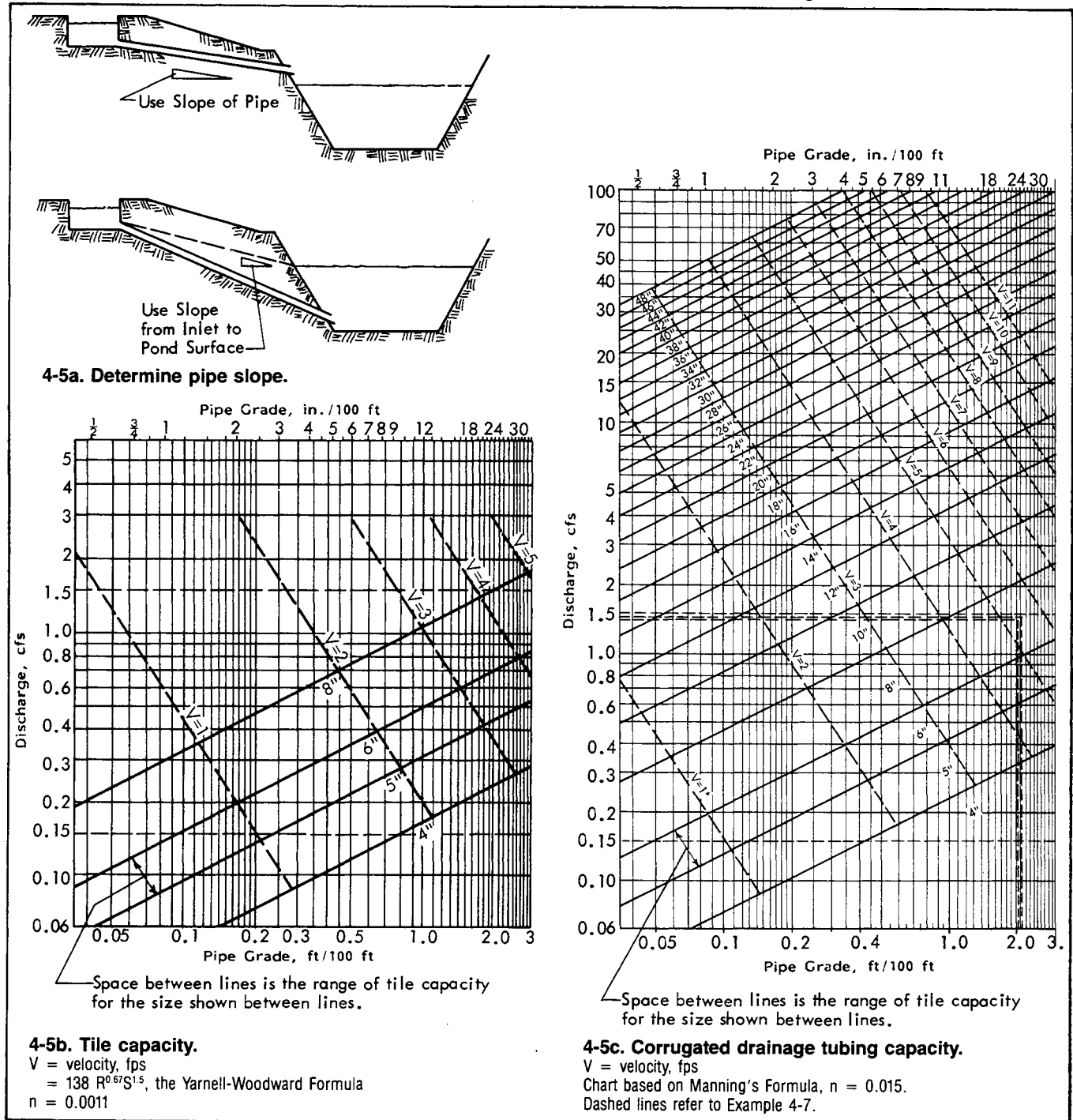
**Fig 4-4. Areas of round conduit.**

Area = $(3.14) \times (\text{conduit diameter})^2 \div 4$. Dashed lines refer to Example 4-6.

Pipe Capacities

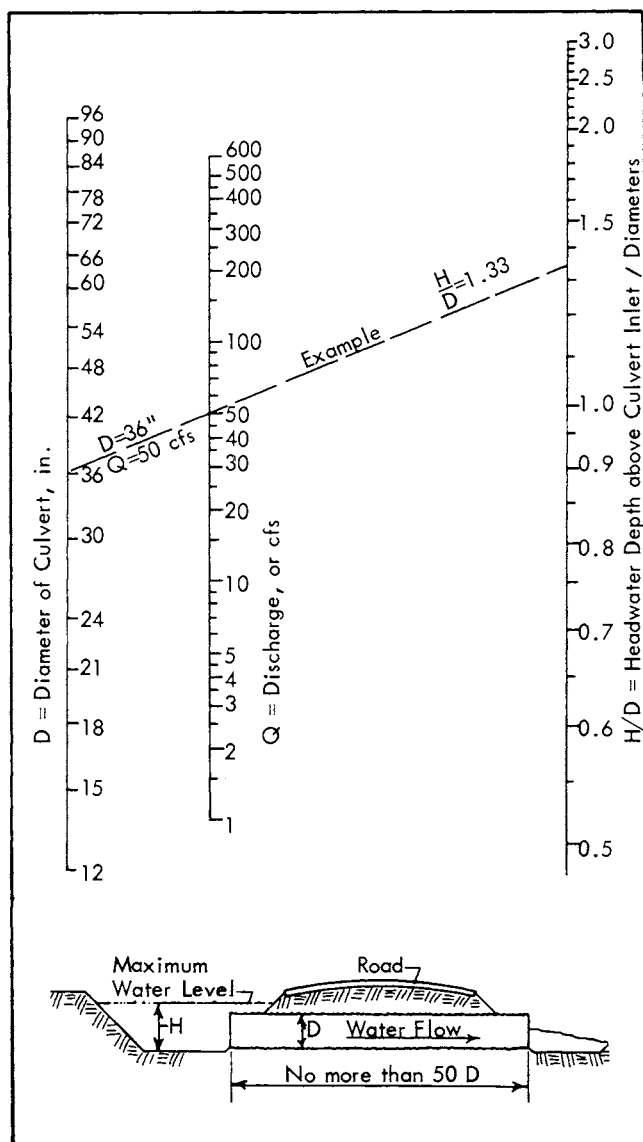
Pipe under relatively low pressure transfers liquid wastes from storage gutters and pits to a storage or lagoon, often by gravity and sometimes by pumping. The approximate pipe capacities in Fig 4-5 were developed for drainage tile but are accurate enough for low pressure pipes.

If the discharge end of the pipe is not submerged, use the slope of the pipe, in ft/100'. If the discharge end of the pipe is submerged, determine the slope from the pipe inlet to the surface of the liquid above the outlet.



Example 4-8:

If culvert capacity must be 50 cfs, try 36" diameter. Read $H/D = 1.33$; $H = (H/D) \times D = (1.33) \times 36" = 48"$. Water will pond 4' deep at the inlet end of the culvert at a flow rate of 50 cfs.

**Fig 4-6. Flow capacities of short culverts.**

Culvert length no greater than $50 \times D$. H = Water depth at culvert inlet.

Holding Pond

A holding pond temporarily stores runoff water from a lot or from a lagoon's overflow. Lot runoff must pass through a settling facility before going to the holding pond. A holding pond does not receive roof water, cropland drainage, or other unpolluted water.

Holding pond bottoms tend to seal naturally. If your pond is in sandy or gravelly soils or near fractured bedrock, seal the bottom by lining with an approved plastic or 6" of compacted clay.

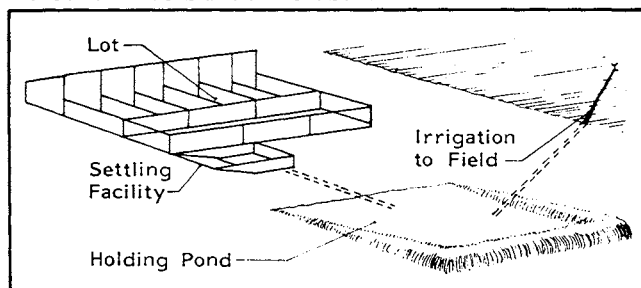
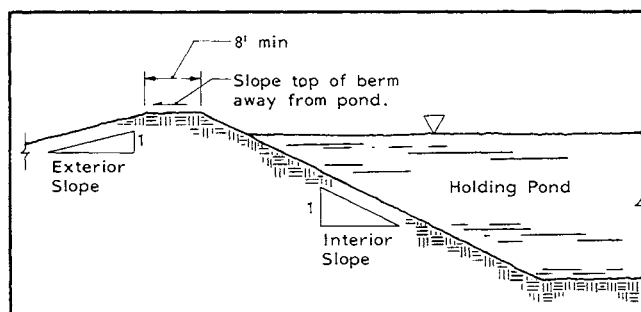
General embankment construction is in Fig 4-8. Before construction, consult your local Soil Conserva-

tion Service and regulatory agencies for assistance and information. Maintain sod and grass to prevent bank erosion.

Holding ponds do not treat manure as in a lagoon, but only store it until disposal. Empty a holding pond completely when pumping.

Emptying is usually by pumping and land application using some form of irrigation. Empty the storage when it is legal and wise—that is, before it is full; when wastes will infiltrate into the soil; when the soil is not frozen, frosted, too wet, or snow-covered; or as specified in applicable regulations.

If most of the solids have been settled out before the liquid reaches the holding pond it can be handled with equipment designed for clean water but screened inlets must be used.

**Fig 4-7. Holding pond.****Fig 4-8. Holding pond banks.**

Vertical dimensions are exaggerated to emphasize slopes. The steepest exterior sideslope is 3:1 (3 run:1 rise); 4:1 if it will be mowed. Interior sideslope varies from 1:1 to 4:1 depending on the soil construction characteristics. Make the berm at least 12' wide if equipment will travel on top.

Provide an emergency spillway in undisturbed earth near the holding pond dam. Make it 1'-2' below the top of the dam. Overflow from liquid storages is a potential pollutant and must be controlled. Run the spillway overflow to secondary treatment or a grassed disposal field.

Holding Pond Inlets

A submerged inlet will not freeze, but may plug with solids that settle in the pipe near the waterline, Fig 4-9. Settling the solids out before the liquids reach the pond reduces the plugging problem.

An inlet pipe above the maximum water surface elevation helps prevent plugging. Inlet pipes supported to discharge several feet out into the pond are preferred, but ice can lift and disturb most pipe supports.

Sizing

Design the pond capacity and pumping frequency so the pond holds the runoff from the design storm without overflowing. The design storm is typically

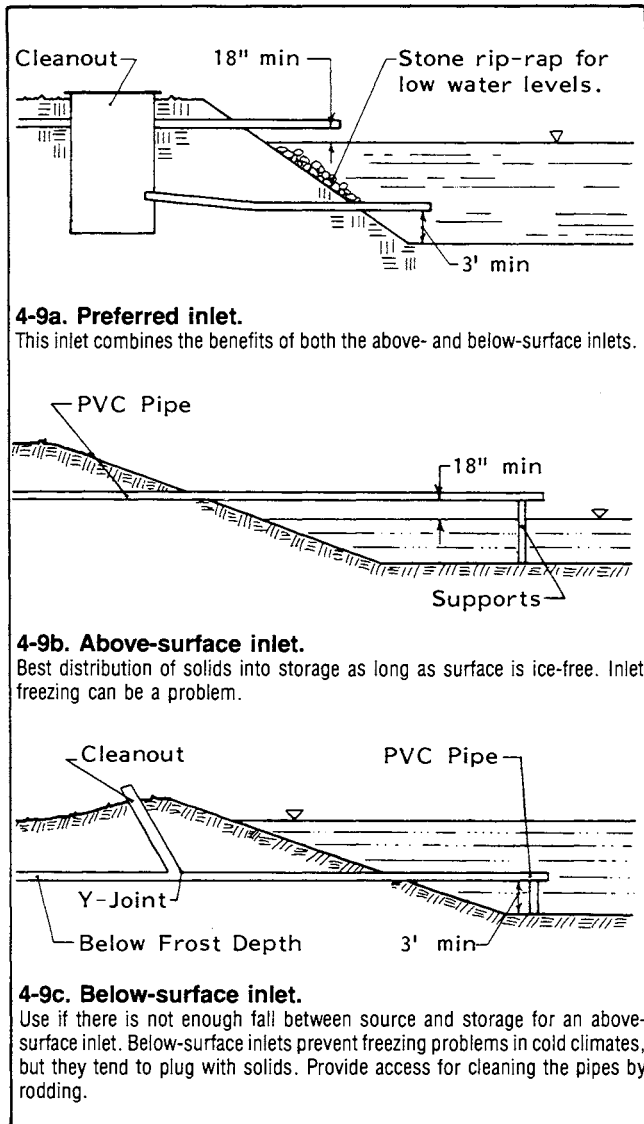


Fig 4-9. Holding pond inlets.

Slope inlet pipe to provide at least 2 fps velocity with dilute wastes (less than 5% solids). Minimum slope is $\frac{1}{2}\%$ and minimum pipe diameter is 8".

the 25-yr, 24-hr rainfall, unless otherwise regulated. Several factors affect the desired holding pond capacity:

- Duration of storage period. Storage time may be up to 180 days depending on local regulations and conditions. With additional capacity, emptying the pond can be delayed to fit labor and cropping schedules without fear that another runoff event will cause overflow.
- Source of liquids, which includes size and use of area drained and sources such as milkhouse wastes or animal washing water.
- Amount of liquids, which includes rainfall during storage period and amounts and frequencies of other sources.
- Proportion of rainfall that stays on the lot.
- Relative rainfall and evaporation during the storage period. In dry areas, stored volume is

reduced by relatively high evaporation; in wet areas, the pond must store rainfall that falls on its surface.

Although some elements of needed capacity are difficult to estimate, such as sludge buildup, most of the major elements can be predicted with adequate accuracy.

- **Estimating lot runoff** is discussed in the section on runoff from lots.
- **Net rain** directly into the storage is estimated from weather data. Estimate rainfall on the storage surface plus the banks of the storage that drain into the pond. The banks can add considerably to surface area. If the storage is emptied after each major storm, evaporation is negligible. If the storage is emptied only once or twice a year, estimate net rain from annual data for precipitation, Fig 11-12, and evaporation, Fig 11-14. Estimate evaporation from the liquid surface. Winter evaporation is relatively low. The required winter storage period usually governs pond size.
- **Identify other liquid sources** and estimate the amount of storage volume they require over the storage period.
- **Sludge buildup** can be the equivalent of a $\frac{1}{2}$ " layer of solids over the area drained. Unless these solids are settled out, design the holding pond to store them and provide for their removal. Buildup occurs less rapidly with good settling facilities and frequently scraped paved lots. It occurs more rapidly with little or no settling and unpaved lots.

Add the total capacity required for the above factors. Select storage dimensions from Tables 11-1 to 11-3.

Infiltration Areas

An infiltration area (or vegetative filter) is an alternative to holding ponds for runoff detention. Rainfall runoff flows from a settling facility to a vegetated (usually grass) field and infiltrates into the soil. **It is essential that a settling facility precede the infiltration area.** Most feedlot runoff infiltrates into the soil. Occasionally, runoff is not totally infiltrated, but it is diluted and treated enough by biological and physical processes during its movement over the vegetated area that it can be discharged. These systems are not practical for every situation, but they can provide successful, low-cost runoff control for many smaller operations.

The vegetated area may be either a long, grassed, gently sloping channel or a broad, flat area with little or no slope surrounded by a berm or dike. Divert all outside surface water so the only water on the disposal area is lot runoff and direct precipitation.

Infiltration areas do not need to be elaborate. The only management required is maintaining the vegetative cover. Harvest the vegetation when conditions permit.

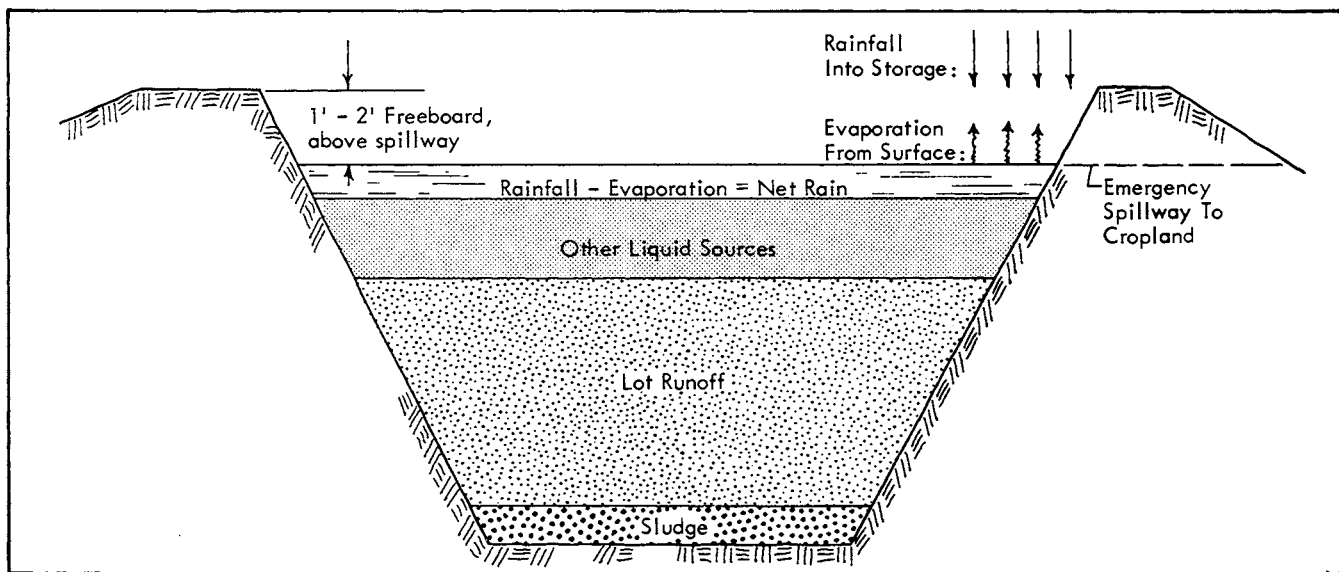


Fig 4-10. Liquids stored in holding pond.

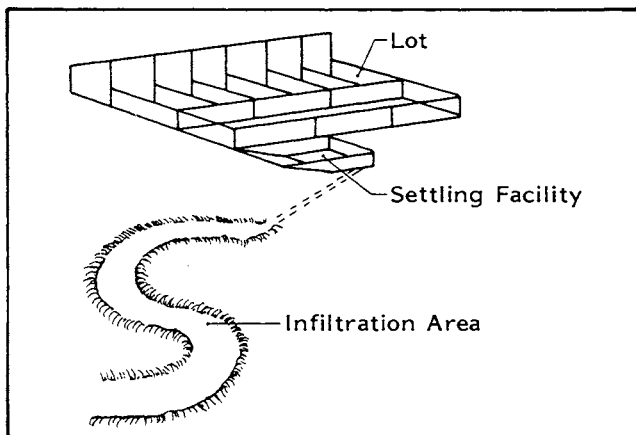


Fig 4-11. Infiltration area.

Design

Infiltration channel design varies with region. The following design procedure gives a reasonable estimate. It is based on the water-holding capacity of the top 5' of soil and the soil's infiltration capacity. To compute the infiltration area (ft²) required for runoff from the design storm (typically a 24-hr, 25-yr storm, but check local regulations):

$$\text{Infiltration area, ft}^2 = (\text{lot drainage area, ft}^2) \times (\text{design storm, in.}) \times (\text{soil texture multiplier, Table 4-8})$$

After determining the required channel area, divide it by desired channel width, Table 4-9, to find channel length. Use more than one channel if necessary to keep channel length under 1,000'. Grade the first 50' of the channel at 1% slope to prevent solids that escape the settling facility from blocking the channel. Grade the first half of the remaining channel at 0.4% and the remainder at 0.2%.

Because accurate design criteria are not yet established and these systems may not be acceptable in some areas, check local design criteria and regulations before installing a system.

Table 4-8. Soil texture multiplier.

Select multiplier for the soil type in the infiltration area.

Soil texture	Multiplier
Sand	0.10
Sandy loam	0.15
Silt loam	0.20
Silty clay loam	0.30
Clay	0.50

Table 4-9. Minimum infiltration channel dimensions.

Lot area, ft ²	Initial channel depth, in.	Initial channel width, ft
< 10,000	6	8
10,000 to 20,000	6	16
20,000 to 25,000	6	20
25,000 to 30,000	6	24

Infiltration Area Construction

An infiltration channel is not the same as a grassed waterway designed to convey water. In many locations, the channel can be laid out along the natural topography with little land leveling, and a diversion terrace can be built along the channel to prevent outside surface water from entering it.

Keep excavation to a minimum. Try to form the channel by berming the sides above the natural soil surface. If excavation is necessary, return the topsoil to the channel bed after removing the required amount of subsoil. It is also important that the channel not be compacted during construction. Work the soil only when dry to maintain the soil's infiltration capacity.

Sow a grass, such as rye or fescue, in the channel as soon after construction as possible. If a drainage tile is needed to control the seasonal high water table, the subsurface drainage tile should be 4" in diameter and installed 30"-40" deep, 10' on either side of the channel.

5. LIQUID-SOLID SEPARATION

Separate solids from liquids by gravity, centrifuges, screens or filters, or evaporation of water. After solids are removed, they can be spread as fertilizer, used for bedding, or recycled as livestock feed. Bedding may require additional composting; feeding may require short-term ensiling.

After larger solids have been removed, the liquids are easier to handle for irrigation, disposal on land, or recycling for waste removal flushing. Separation also reduces odors from holding ponds, reduces lagoon size requirements, and makes holding ponds and lagoons easier to manage and pump.

Removing Solids from Lot Runoff

Settling solids from lot runoff is the most common farm application of liquid-solid separation.

Contaminated runoff from lots carries many particles of organic matter and other solids. Design settling facilities to intercept all lot runoff, settle out most of the solids, and release liquids to a holding pond, lagoon, or infiltration area.

Settling separates solids from a dilute liquid slurry by reducing velocity. Fast moving liquids pick up and transport solids; when velocity slows, solids settle.

The most critical design situation is a high intensity, short duration rain storm. A large water volume picks up manure and carries it in the runoff. Experience has shown that the 10-yr, 1-hr storm is best for designing settling facilities. When a more intense storm occurs, the percent of manure solids removed by the basin is reduced slightly. However, a system can receive overload runoff peak flow and lose little in treatment efficiency.

Settling Tanks

Settling tanks work well with many swine feedlot runoff control facilities. A settling tank is sometimes installed in a waste transport pipe, such as between a flushing building and a lagoon and between a milkhous and disposal field.

Typically made of concrete, Fig 5-1, a settling tank is normally full of liquid, so the wastes are handled as a semi-solid. It must be cleaned often to be effective. Solids are removed with the liquids by agitation and resuspension, then pumped out. A settling tank can also be a covered, underground unit in a drain pipe to trap manure solids, bedding, feathers, or other solids, but cleaning is more difficult.

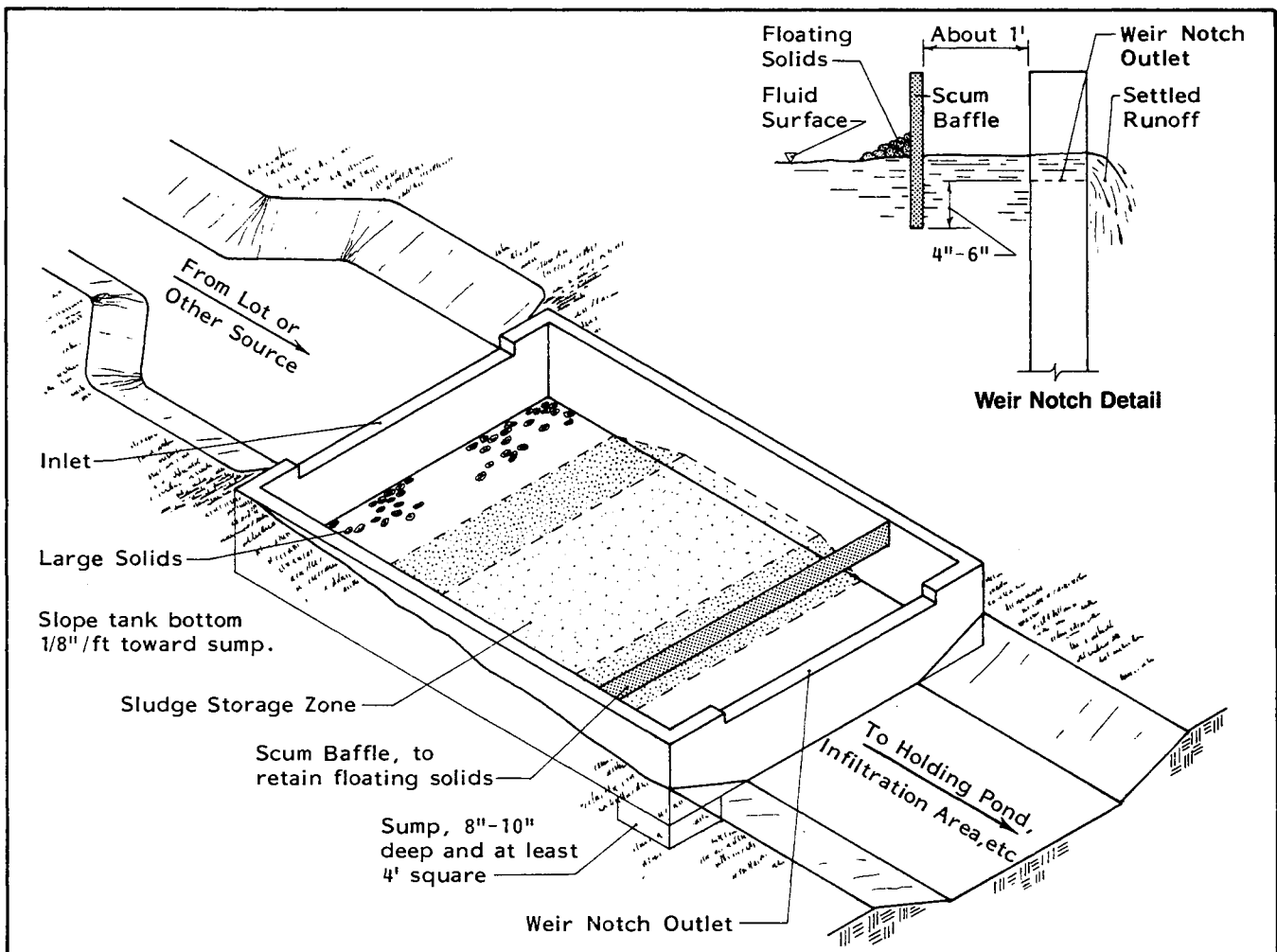


Fig 5-1. Concrete settling tank.

Liquid action near the inlet and outlet reduce sludge buildup at the ends; larger, more dense solids settle near the inlet. Slope tank bottom 1/8" per foot toward sump.

Some solids, such as straw, do not settle. They float and must be retained with a baffle. Settling tank outlets are either overflow weirs or standpipes.

Design

- Flowrate into the settling tank, cfs = (10-yr, 1-hr storm, in/hr) x (runoff area, ft²) ÷ (12 in/ft x 3,600 sec/hr).
- Length of outlet weir, ft = flowrate, cfs x 32.7.
- Surface area of tank, ft² = flowrate, cfs x 900.
- Assuming the outlet weir extends nearly across the width of the settling tank:
Tank length, ft = surface area ÷ weir length.
- Volume, ft³ = depth x surface area = depth x flowrate, cfs x 900.
- Detention time, hr = volume ÷ flowrate = depth ÷ 4.

With surface area computed as above, select depth to provide adequate detention time, about 30 min for lot runoff. Make the depth at least 2' plus whatever depth is needed for sludge storage. Recommended basin capacities are typically 5 to 10 ft³/100 ft² of feedlot area.

When a settling tank removes solids from flush water prior to discharging to a lagoon, the lagoon loading is reduced and lagoon size may be reduced accordingly. However, the settling tank would have to be cleaned much more frequently than if it received only periodic lot runoff.

Example 5-1:

Design a settling tank for a feedlot located in central Illinois. A 64'x160' area drains into the tank.

Solution:

1. Drainage area = 64'x160' = 10,240 ft²
2. From Fig 11-4, rainfall from a 10-yr, 1-hr storm in central Illinois is 2.2 in/hr.
3. Flowrate into the tank = 2.2 in/hr x 10,240 ft² ÷ (12 in/ft x 3,600 sec/hr) = 0.52 cfs
4. Outlet weir length, ft = 0.52 cfs x 32.7 = 17'
5. Tank area = 0.52 cfs x 900 = 468 ft²
6. Assume a tank width of 20' (it must be at least as wide as the outlet weir, which is 17' long).
Tank length = 468 ft² ÷ 20' = 23.4' long
7. Tank depth = 2' (for ½ hr detention time) + 1' (for sludge buildup) = 3'
8. Tank volume = 3' x 468 ft² = 1,404 ft³

Dewatering Settling Basin

A settling basin is different from a settling tank in that it temporarily retains runoff and permits liquids to gradually drain to a holding pond, lagoon, or infiltration area. Solids remain in the basin for drying and later removal with a tractor.

The best basin shape is relatively large and shallow and probably less than 3' deep if solids are to be removed from the basin with conventional solid manure handling equipment. In arid areas where the basins dry out readily, earth basins may be satisfactory, Fig 5-2a. The settled solids can be removed by driving unloading equipment on the basin floor. In

humid areas, concrete bottoms or complete concrete basins are necessary so equipment can enter the basin for cleanout, Fig 5-2b. Maximum slope for access ramps is 1" of fall per foot of horizontal run for front-end loaders. Basin bottoms are often sloped 0"-5"/100' with a uniform grade to the discharge point to prevent ponding.

Build earth basins with 3:1 sideslopes; if erosion is a problem, use a 4:1 slope on the inlet side. The top width of earth dams must be at least 12' wide for vehicle traffic; a 2' berm width is minimum for maintaining the design height of the dam. Plant and maintain grass cover where possible. Provide at least one vertical wall in concrete basins to buck against with a front-end loader when cleaning.

Maintenance and cleanout frequency greatly influence treatment efficiency. A properly managed open lot and settling basin can retain up to 85% of the nonfloating solids in the lot or basin, regardless of lot slope. Research indicates that ½ a-ft of settled solids per year can accumulate for each acre of unpaved lot. This value is much less for paved lots.

The required frequency of basin cleaning varies considerably depending on basin size, type of lot surface, amount of manure on the lot surface, and storm runoff characteristics. In some instances, cleaning may be necessary after each large storm, but a cleaning frequency of 2 to 6 times per year is adequate if the basin is designed large enough to store the accumulated solids.

Basin Outlets

Several types of basin outlets are available to drain the liquids from the full depth of the basin and allow the solids to dewater. The perforated or slotted pipe riser and the porous plank dam are examples.

Manure plugs outlet openings. Debris and bedding tend to plug even large openings. As the settling basin drains, the openings get more and more plugged because the solids concentration increases as liquid is drained off. You may have to unplug the openings before the basin will dry enough to remove the solids. Consider adding a slanted expanded metal screen (¾", No. 9) around the outlet to increase the screening area, Fig 5-2b. These screens are usually expanded steel, usually ¾", No. 9 or heavy quarry screen, with about 1'-1.5" openings. In practice, the screens tend to be bulky and are seldom removed during tractor cleaning of the basin. Therefore, place the screens on the sidewall, not the bucking (or end) wall. Any settling facility which passes runoff liquids through a screen **needs maintenance (solids removal and screen cleaning) after each runoff event.**

Perforated pipe outlets

Perforated pipe may be constructed with PVC plastic, galvanized steel, or concrete. The perforations can be ⅝"-1" diameter holes or 1" by 4" slots. Where excessive clogging of perforated pipes is a problem, an additional removable screen helps, Fig 5-2b.

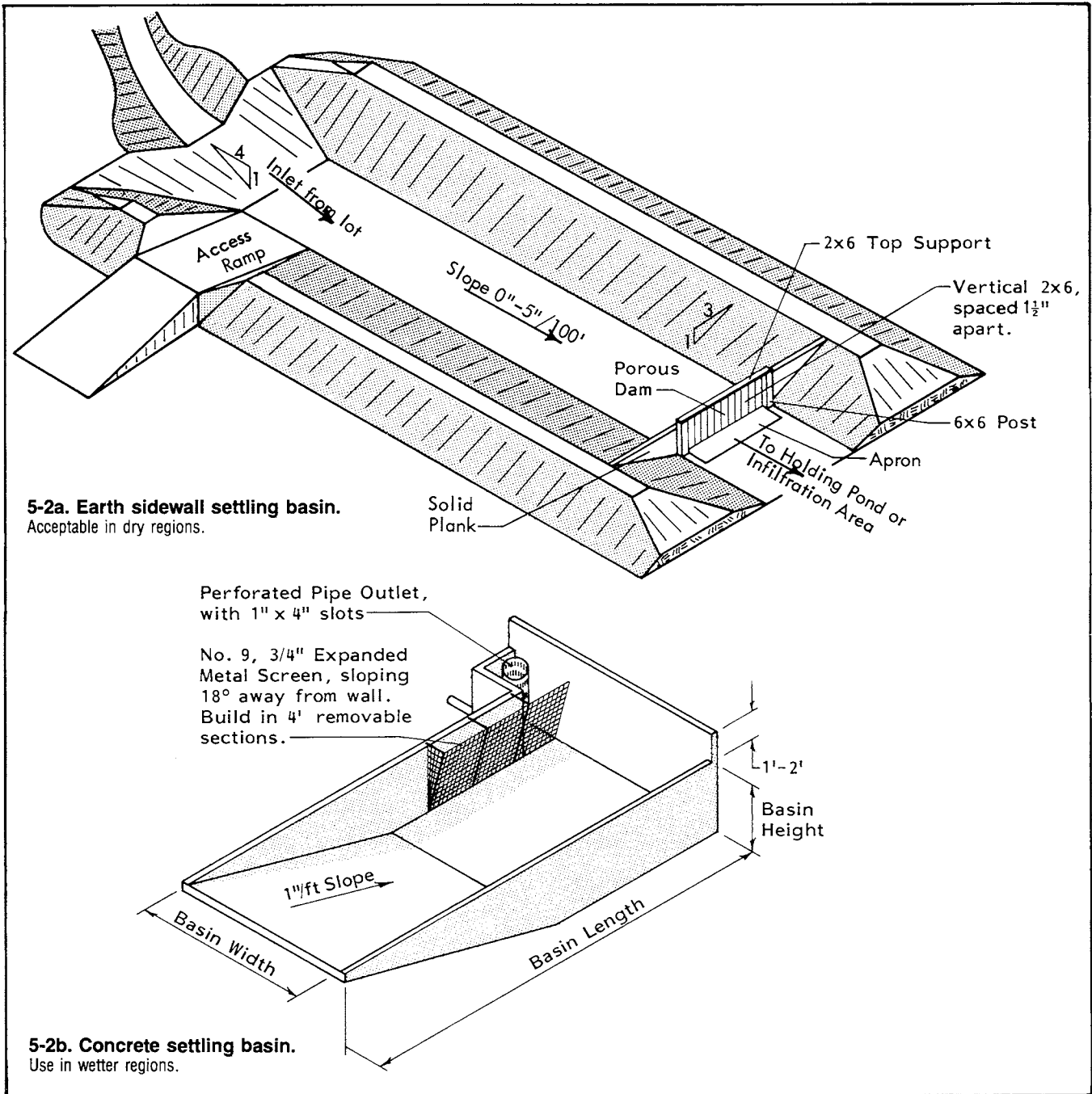


Fig 5-2. Settling basins.

The outlet is properly sized to match anticipated flowrates in order to ensure adequate detention time. Control flowrate by the open area (holes or slots) in a perforated pipe, by an orifice plate in a perforated pipe, or by spaced planks. See Fig 5-2. It is best to control the basin outlet flowrate with a properly sized orifice plate and not by the holes or slots in the perforated pipe.

At shallow depths, the design flow into the basin exceeds outflow, so detention results. As the basin fills, outflow rate increases. When the basin is full, outflow rate should equal inflow rate. With feedlot runoff, however, outlet openings often clog to some

degree, reducing the outflow rate. To prevent overflowing, provide a larger basin outlet (spillway) to handle peak flow when the basin is completely full, Fig 5-4.

Table 5-1 gives opening requirements for perforated pipe.

Table 5-2 gives designs for orifice plates. They are placed at the base of the riser pipe, typically a PVC end cap with a hole of specified size drilled in the center. The orifice plate permits outflow control while permitting large perforations in the riser pipe to reduce plugging. With an orifice plate, make total perforation area in the riser pipe at least 25% larger than indicated in Table 5-1.

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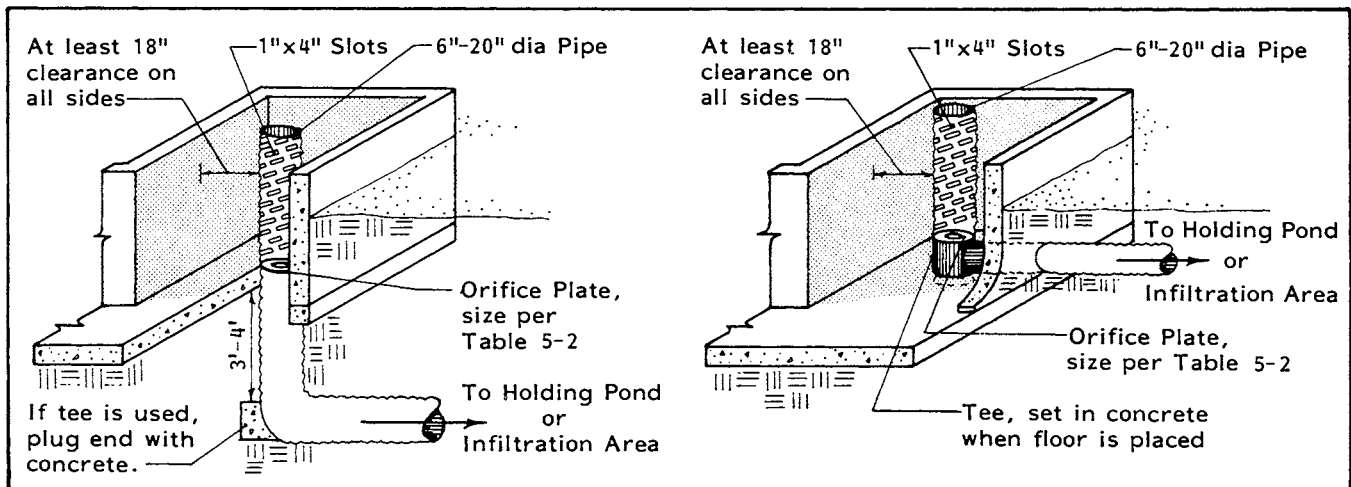


Fig 5-3. Riser pipe outlets for settling basins.

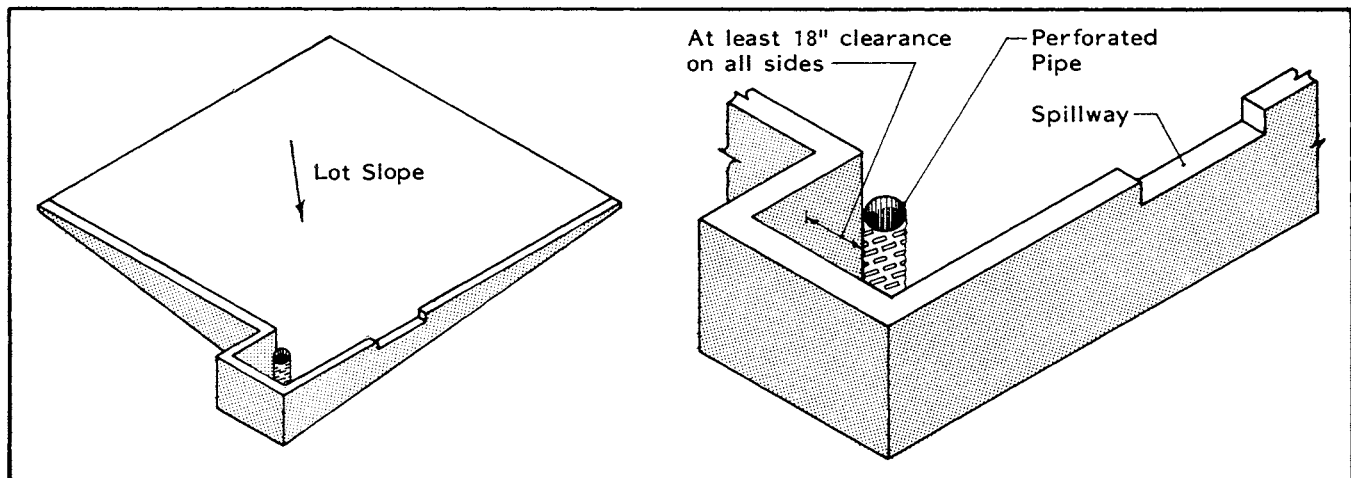


Fig 5-4. Settling in corner of lot.

Settling basins can sometimes be located within a large lot, if out of main animal traffic routes. Note the emergency overflow for larger storms.

Porous dams

Select a material for porous dams that can be easily cleaned by scraping the surface with a hoe. Spaced boards, welded wire fabric, or expanded metal mesh can be scraped clean. Design of spaced plank porous dams is included in Fig 5-5.

Settling Basin Design

Runoff solids that will settle, do so in less than 30 min. Therefore a detention time of 30 min in the settling basin is an acceptable design criterion, where no other criterion is available. Check with your local extension agent and the local Soil Conservation Service (SCS) office for additional information. A convenient rule of thumb is to make basin capacities in the range of 5 to 10 ft³/100 ft² of feedlot area.

When local criteria are not available, use the following design procedure.

1. Determine rainfall intensity for a 10-yr, 1-hr storm, Fig 11-4.
2. Peak flowrate off the lot, cfs = (lot area, ft² x rainfall intensity, in/hr) ÷ 43,200.

3. Surface settling rate = 4'/hr if the basin will be at least 2' deep. If site limitations (lack of fall away from lot) restrict depth to less than 2', over design the basin area by using a surface settling rate less than 4'/hr.
4. Basin surface area, ft² = (flowrate off lot, cfs x 3,600 sec/hr) ÷ (surface settling rate, ft/hr).
5. Basin liquids depth, ft = (surface settling rate, ft/hr) x (detention time, hr).
Maximum depth is 4' because excessive depth makes access difficult and hinders dewatering.
6. Solids storage volume, ft³ = (sludge buildup rate, ft³/ft²-mo) x (lot area, ft²) x (months between basin cleaning, mo).
Use a sludge buildup rate of 0.05 ft³/ft²-mo for unpaved lots; 0.01 ft³/ft²-mo for paved lots. Increase these values by 50% if lots have steep slopes or are poorly maintained.
7. Solids storage depth, ft = (solids storage volume, ft³) ÷ (basin surface area, ft²).
8. Overall basin depth, ft = (liquids depth, ft) + (solids storage depth, ft).

9. Size the sloping screen at inlet (if used). Size screen area to limit flow velocity through the screen to less than 2.5 fpm when basin is full. Assume an expanded metal screen has 60% open area.

$$\text{Screen area, ft}^2 = (\text{flowrate off lot, cfs} \times 60 \text{ sec/min}) \div (0.6 \times 2.5 \text{ fpm})$$

$$\text{Screen length, ft} = (\text{screen area, ft}^2) \div (\text{screen height, ft})$$

10. Minimum basin length, ft = [ramp length, ft] + [basin bottom length required for sloping screen, ft (if used)]
= [basin depth, ft x 12 (for 12:1 ramp slope)] + [screen length, ft]

Minimum ramp slope = 12:1

11. Basin width, ft = (basin surface area, ft²) ÷ (basin length, ft).

If site limitations restrict basin width, increase basin length and recalculate. The basin width must be at least 10' wide for tractor access to remove solids.

12. Design basin outlet to allow outflow to equal the peak flowrate off the lot when the basin is full.
- For a perforated pipe **without** an orifice plate, determine the required open area/ft of pipe height from Table 5-1.
 - For a perforated pipe **with** an orifice plate, size the orifice from Table 5-2. Determine the required open area/ft of pipe height from Table 5-1, then increase by 25%.
 - For a porous dam, determine required dam length from Fig 5-5.
13. Select an underground discharge pipe for the perforated pipe from Fig 4-5b. Size the pipe to discharge at least at the peak flowrate off the lot. Determine pipe slope as shown in Fig 4-5a.

Example 5-2:

Design a settling basin for a paved feedlot located in central Iowa. Drainage area that goes into basin is 25,000 ft². The basin will be cleaned every 4 mo (3 times/yr). The site restricts basin depth to less than 18". There will be a sloped screen and a perforated riser pipe with an orifice plate at the basin outlet. Size for ½ hr detention time.

Solution:

- Rainfall intensity for a 10-yr, 1-hr storm in central Iowa (Fig 11-4) = 2.4 in/hr
- Peak flowrate off lot = 25,000 ft² x 2.4 in/hr ÷ 43,200 = 1.39 cfs
- Because the basin depth has to be less than 2', use a surface settling rate less than 4'/hr. Use a surface settling rate = 2 for a basin depth of 1' + solids.
- Basin surface area = (1.39 cfs x 3,600 sec/hr) ÷ 2'/hr = 2,502 ft²
- Basin liquids depth = 2'/hr x ½ hr = 1'
- Sludge storage volume = 0.01 ft³/ft²-mo x 25,000 ft² x 4 mo = 1,000 ft³

$$\text{Solids storage depth} = 1,000 \text{ ft}^3 \div 2,502 \text{ ft}^2 = 0.4'$$

Solids move down the sloping access ramp and build up deeper in the rest of the basin, so increase the solids depth slightly. Use 0.5'.

$$\text{Overall basin depth} = 1' + 0.5' = 1.5'$$

$$\text{Screen area} = (1.39 \text{ cfs} \times 60 \text{ sec/min}) \div (0.6 \times 2.5 \text{ fpm}) = 55.6 \text{ ft}^2$$

With a 1.5' basin depth, the screen will be about 1.5' high.

$$\text{Screen length} = 55.6 \text{ ft}^2 / 1.5' = 37'$$

$$\text{Minimum basin length} = 1.5' \times 12 + 37' = 55'$$

$$\text{Basin width} = 2,502 \text{ ft}^2 \div 55' = 45.5'$$

If site conditions limit the basin width to less than 45.5', increase the length and recalculate.

12. First size the orifice plate from Table 5-2 for a flowrate of 1.39 cfs and a head of 1.5'. Orifice diameter is 6.5".

Next determine minimum open area in the perforated pipe from Table 5-1 for a 1.39 cfs flowrate and a 1.5' head.

Minimum open area is 34 in²/ft of pipe height. Increase the open area by 25%.

$$34 \times 1.25 = 42.5 \text{ in}^2/\text{ft of pipe height}$$

Because the orifice is 6.5", the perforated pipe will need at least an 8" diameter. To get 42.5 in² with 1"x4" slots, you need to put in 42.5 in² ÷ (1"x4") = 10.6 or 11 slots per ft of pipe height; 1.5' x 11 slots/ft = 16.5 or 17 slots in the 1.5' high pipe.

13. Select the underground discharge pipe using a discharge rate of 1.39 cfs. Assume the pipe discharges above the storage surface (top of Fig 4-5a) and the pipe slopes at 1%.

$$\text{Pipe grade} = 12 \text{ in/ft} \times 100' \times 0.01 = 12''/100'$$

From Fig 4-5b, a discharge of 1.39 cfs and a pipe grade of 12''/100' requires at least an 8" diameter pipe.

Example 5-3:

Determine the porous dam length required to handle a 1.39 cfs flowrate in a 1.5' deep settling basin. Use vertical 2x6s with 1½" spaces between for the porous dam.

Solution:

From Fig 5-5, 1.5' of head yields 0.52 cfs/ft of porous dam length.

$$\text{Dam length} = 1.39 \text{ cfs} \div 0.52 \text{ cfs} = 2.67' \text{ or } 3'.$$

Settling Channel

A settling diversion terrace, settling terrace, or settling channel is a wide, shallow, gently sloping, flat-bottomed waterway in which runoff solids settle, Figs 5-6 and 5-7. Wastes settle from the slurry; solids then dry naturally. It is typically tractor-scraped, so bottom width is 10' or more. The channel is sometimes grassed to improve settling and reduce erosion.

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Table 5-1. Riser pipe outlet design.

For settling basins. Dashed lines refer to Example 5-2.

Based on:

$$Q = (C)(A)(2gh)^{0.5}$$

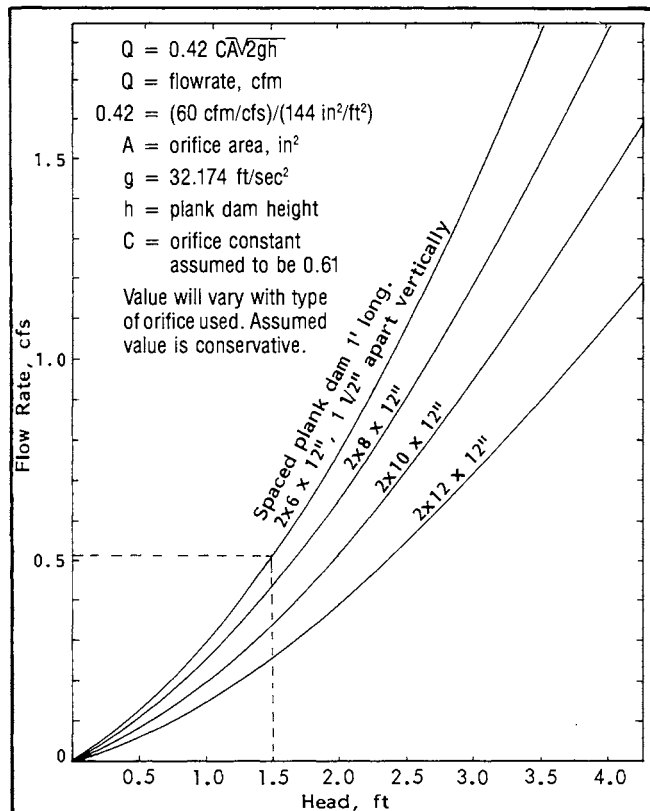
Q = flowrate, cfs

C = slot constant; assumed to be 0.61. The actual value varies with the type of slot. The assumed value is conservative.

A = open slot area, ft²g = 32.174 ft/sec²

h = head on openings, ft. The pipe height was divided into 0.5' increments. The head on all the slots in the first 0.5' increment assumed to be 0.25'. The head on the subsequent 0.5' pipe increments increase at 0.5' increments.

Open slot area/ft of pipe height in ² /ft	Head, ft							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Flowrate, cfs							
4	0.034	0.093	0.169	0.259	0.361	0.473	0.596	0.728
6	0.051	0.139	0.253	0.388	0.541	0.710	0.894	1.091
8	0.068	0.186	0.338	0.518	0.721	0.947	1.192	1.455
10	0.085	0.232	0.422	0.647	0.902	1.183	1.480	1.819
12	0.102	0.279	0.507	0.776	1.082	1.420	1.788	2.183
14	0.119	0.325	0.591	0.906	1.262	1.657	2.086	2.546
16	0.136	0.371	0.675	1.035	1.443	1.894	2.384	2.910
18	0.153	0.418	0.760	1.164	1.623	2.130	2.682	3.274
20	0.170	0.464	0.844	1.294	1.803	2.367	3.000	3.638
22	0.187	0.511	0.929	1.423	1.984	2.604	3.277	4.001
24	0.204	0.557	1.013	1.542	2.164	2.840	3.575	4.365
26	0.221	0.603	1.097	1.682	2.344	3.077	3.873	4.729
28	0.238	0.650	1.182	1.811	2.525	3.314	4.171	5.093
30	0.255	0.696	1.266	1.940	2.705	3.550	4.469	5.456
32	0.272	0.743	1.351	2.070	2.885	3.787	4.767	5.820
34	0.289	0.789	1.435	2.199	3.066	4.024	5.065	6.184
36	0.306	0.836	1.519	2.329	3.246	4.260	5.363	6.548
38	0.323	0.882	1.604	2.458	3.426	4.497	5.661	6.911
40	0.340	0.928	1.688	2.587	3.607	4.734	5.959	7.275

**Fig 5-5. Porous dam outlet design.**

For settling basins. Dashed lines refer to Example 5-3.

However, grass may not survive in the channel bottom and makes cleaning more difficult.

Settling channels are cleaned at least once a year. Clean when accumulations reduce channel volume and when sufficient drying permits handling with a scraper and loader.

In tight soils and climates with rainfall above 30"/yr, inadequate drying of stored solids limits the capacity and usefulness of unpaired channels.

Design and Construction

Sideslope varies with soil construction properties. Sideslopes of 3:1 to 4:1 are typical. Slope the bottom only 1'-3'/1,000' (0.1% to 0.3%) to maintain low velocities and rapid settling. Use a wide bottom for shallow flow.

Settling channel design methods vary throughout the Midwest, depending on local regulations and climate. One design method maintains 2 fps velocity at the 10-yr, 1-hr storm in the first 100' section to settle out relatively large solids and debris. Construct the next 100'-300' so the velocity is as low as 0.5 fps to settle out smaller solids. See Table 4-4 for trapezoidal settling channel sizing.

Another method designs the channel for a uniform bottom slope to achieve a maximum velocity of 1 fps and a detention time of 1 hr. Determine channel length from:

$$\text{Channel capacity, cfs} = (\text{lot area, ft}^2) \times (\text{rainfall intensity, in/hr}) \div 43,200.$$

Table 5-2. Sizing orifice in plate.

For orifices to control flowrate through riser. Dashed lines refer to Example 5-2.

Based on:

$$Q = (C)(A)(2gh)^{0.5}$$

Q = flowrate, cfs

C = orifice constant; assumed to be 0.61. The actual value varies with the type of orifice. The assumed value is conservative.

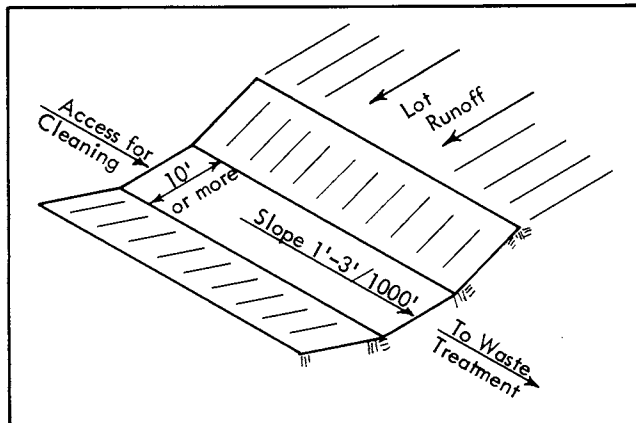
A = orifice area, ft²

g = 32.174 ft/sec²

h = head on orifice, ft

Diameter Area		Head, ft							
in.	ft ²	1.0	1.5	2.0	2.5	3.0	3.5	4.0	
Flowrate, cfs									
1.00	0.005	0.027	0.033	0.038	0.042	0.046	0.050	0.053	
1.25	0.009	0.042	0.051	0.059	0.066	0.072	0.078	0.083	
1.50	0.012	0.060	0.074	0.085	0.095	0.104	0.112	0.120	
1.75	0.017	0.082	0.100	0.116	0.129	0.142	0.153	0.163	
2.00	0.022	0.107	0.131	0.151	0.169	0.185	0.200	0.214	
2.25	0.028	0.135	0.165	0.191	0.214	0.234	0.253	0.270	
2.50	0.034	0.167	0.204	0.236	0.264	0.289	0.312	0.334	
2.75	0.041	0.202	0.247	0.285	0.319	0.350	0.378	0.404	
3.00	0.049	0.240	0.294	0.340	0.380	0.416	0.449	0.480	
3.25	0.058	0.282	0.345	0.399	0.446	0.488	0.527	0.564	
3.50	0.067	0.327	0.400	0.462	0.517	0.566	0.612	0.654	
3.75	0.077	0.375	0.460	0.531	0.593	0.650	0.702	0.751	
4.00	0.087	0.427	0.523	0.604	0.675	0.740	0.799	0.854	
4.25	0.099	0.482	0.590	0.682	0.762	0.835	0.902	0.964	
4.50	0.110	0.540	0.662	0.764	0.855	0.936	1.011	1.081	
4.75	0.123	0.602	0.737	0.852	0.952	1.043	1.127	1.204	
5.00	0.136	0.667	0.817	0.944	1.055	1.156	1.248	1.334	
5.25	0.150	0.736	0.901	1.040	1.163	1.274	1.376	1.471	
5.50	0.165	0.807	0.989	1.142	1.276	1.398	1.510	1.615	
5.75	0.180	0.882	1.081	1.248	1.395	1.528	1.651	1.765	
6.00	0.196	0.961	1.177	1.359	1.519	1.664	1.797	1.922	
6.25	0.213	1.043	1.277	1.474	1.648	1.806	1.950	2.085	
6.50	0.230	1.128	1.381	1.595	1.783	1.953	2.110	2.255	
6.75	0.249	1.216	1.489	1.720	1.923	2.106	2.275	2.432	
7.00	0.267	1.308	1.602	1.849	2.068	2.265	2.447	2.615	
7.25	0.287	1.403	1.718	1.984	2.218	2.430	2.624	2.806	
7.50	0.307	1.501	1.839	2.123	2.374	2.600	2.890	3.002	
7.75	0.328	1.603	1.963	2.267	2.535	2.776	2.999	3.206	
8.00	0.349	1.708	2.092	2.416	2.701	2.958	3.195	3.416	

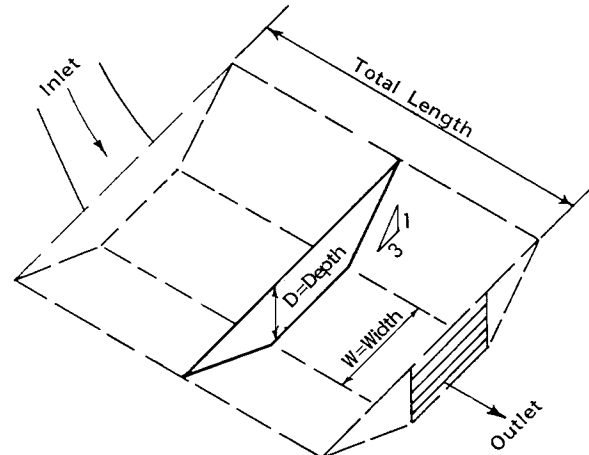
- From Table 4-4, find width and depth for a velocity of about 1 fps.
- Channel volume, ft³ = (channel capacity, cfs) x (detention time, hr) x 3,600 sec/hr.
- Determine volume/ft of channel length values from Table 5-3.
- Channel length, ft = volume ÷ volume/ft.

**Fig 5-6. Settling channel.**

Sideslope varies with soil construction properties.

Table 5-3. Settling channel volumes.

Assumptions: vertical ends, 3:1 sideslopes, bottom nearly flat. Volume = LD(W + 3D); use LD(W + 4D) for 4:1 sideslope.



Channel width, ft	Channel depth, ft					
	0.5	1.0	1.5	2.0	3.0	4.0
ft ³ /ft of channel length						
10	5.75	13	21.75	32	57	88
15	8.25	18	29.25	42	72	108
20	10.75	23	36.75	52	87	128
25	13.25	28	44.25	62	102	148
30	15.75	33	51.75	72	117	168
35	18.25	38	59.25	82	132	188
40	20.75	43	66.75	92	147	208
50	25.75	53	81.75	112	177	248
60	30.75	63	96.75	132	207	288

Example 5-4:

Design a settling channel for a lot area of 25,000 ft² located in central Illinois. Assume 3:1 sideslopes, a 1' maximum channel depth, and a 0.1% bottom slope.

Solution:

- Determine rainfall for a 10-yr, 1-hr storm in central Illinois. From Fig 11-4, rainfall intensity = 2.2 in/hr.
- Channel flow capacity, cfs = 25,000 ft² x 2.2 in/hr ÷ 43,200 = 1.273 cfs.
- From Table 4-4, determine channel depths and bottom widths which give a fluid velocity of about but not more than 1 fps:

Channel dimensions		Fluid velocity fps
Depth ft	Width ft	
0.5	10	0.6
0.5	15 to 35	0.7
1.0	10	0.9
1.0	15 to 25	1.0

- Determine minimum channel volume required for a 1 hr detention time:

$$\text{Minimum channel volume} = 1.273 \text{ cfs} \times 1 \text{ hr} \times 3,600 \text{ sec/hr} = 4,583 \text{ ft}^3$$

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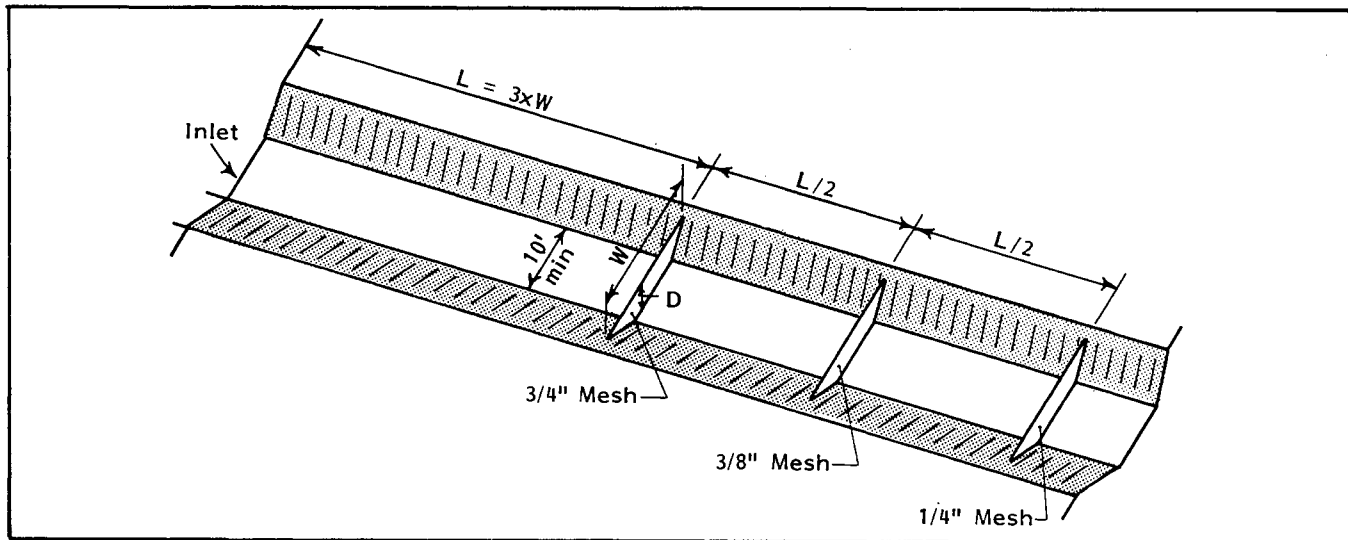


Fig 5-7. Dry climate settling channel.

Design channel for anticipated flow, Table 4-4. To determine L , provide enough channel behind the first screen to hold 66% of solids which accumulate between cleanings. Make the channel at least 3 times as long as it is wide ($L > 3 \times W$). Locate second and third screens as shown. Screens are galvanized hardware cloth or expanded metal mesh on preservative treated wood frames. Construct them so they are removable for channel cleaning.

5. Divide the minimum channel volume (determined in Step 4 as 4,583 ft³) by the volume/ft of channel length values in Table 5-3 to get the minimum channel length.

Channel dimensions		Volume per ft of channel ft ³ /ft	Minimum channel length ft
Width ft	Depth ft		
10	0.5	5.75	797.0
10	1.0	13.00	352.5
15	0.5	8.25	555.5
15	1.0	18.00	254.6
20	0.5	10.75	426.3
20	1.0	23.00	199.3
25	0.5	13.25	345.9
25	1.0	28.00	163.7
30	0.5	15.75	291.0
35	0.5	18.25	251.1

6. Choose the channel dimensions that best fit the site.

Another type of settling channel has three low wire screen dams which form small settling ponds behind them, Fig 5-7. It is used in drier regions (rain-falls below about 25"/yr). Select channel capacity to contain the amount of solids to be trapped. About 66% of the solids are trapped by the first screen, 22% by the second, and 12% by the third. Refer to Table 5-3 for earth settling channel volumes. Solids removal from earth channels is difficult in wet climates because the solids do not dry enough between runoff events.

Table 4-4 gives flowrate capacities of some low slope earth channels and a concrete lined one. Additional designs can be derived from Manning's Formula, Fig 4-3.

Other Separation Methods

Screening and Filtration

Commercial screening and filtration systems are available for treating livestock wastes. In general, they produce a solid with about 70%-80% moisture content.

There are several screening methods. One method has a stationary screen mounted on an incline with the slurry applied to the top edge of the screen. The liquid passes through the screen and is drained away. The solids move down the face of the screen and drop into a storage area or a conveyor.

The second screening method has a rapidly vibrating screen. The vibration aids movement of the solids across the screen and reduces clogging. There are many vibrating screen configurations.

Another method has a rotating screen. The slurry passes between cylindrical screens and press rollers in several steps. The liquid passes through to the center of the screen and out the other side to discharge. The solids are conveyed to the next screen section and then to storage.

In another method, slurry is applied on top of a porous belt which passes through rollers. The liquids are pressed through by the rollers and the solids are carried along on the belt. This system has been successful with livestock waste.

Evaporation Ponds

Where evaporation exceeds precipitation, evaporation ponds can remove water from livestock wastes. In arid regions, evaporation can be as much as 24" greater than rainfall. Design an evaporation pond large enough to accumulate all wastes during the wet season, plus runoff from the 25-yr, 24-hr storm. Increasing land values may discourage evaporation ponds except in low rainfall, high evaporation areas.

Dehydrators

A dehydrator can remove all or most manure moisture. Disadvantages include high initial investment, mechanical problems, high energy requirements, unpleasant odors, and severe corrosion of dryer parts. Also, it is difficult to establish an economical market for dehydrated manure.

Dehydrators usually have electrically driven rotating drums 30'-40' long and 4'-10' in diameter. The dryers are often direct-fired with natural gas. The dehydrators have a large electrical power demand

with 3-phase motors at 220 to 440 volts. The material entering the dryer should have a moisture content between 40% and 60%. Fresh raw manure cannot be dried in a rotary dryer because it has a tendency to form balls in the dryer.

Regulations may make dehydrated products difficult to sell. Before building a dehydrating plant, investigate your state's adoption of definitions and regulations proposed by the Association of American Plant Food Control Officials. Also investigate air pollution and zoning regulations.

6. MANURE STORAGE

Manure can be handled as a solid, a semi-solid, or liquid. The amount of bedding or dilution water influences the form. In turn, the form influences the selection of collection and spreading equipment and the choice of storage type.

Solid and semi-solid manure can be collected with tractor scrapers, front-end loaders, or mechanical scrapers. Conventional spreaders are usually used for land application.

Liquid manure can be collected with scrapers, flushing systems, gravity flow gutters, or slotted floors. Liquids are spread on fields with tank wagons, applied with irrigation equipment, or digested in a lagoon before field spreading.

Storage design varies by state because of climate and pollution control regulations. Check local regulations before planning a manure storage.

Evaluate site and soil conditions carefully to avoid contaminating ground and surface waters. Avoid locating unlined storages over shallow creviced bedrock or below the water table. If shallow bedrock is present, consult a qualified engineer or contact your board of health. Also avoid storage in sandy or gravelly soils or other areas where serious leakage can cause groundwater pollution. Consider the soil characteristics to a depth of at least 3' below the proposed storage bottom. Check for buried utilities and drainage tiles. A soil survey is helpful in evaluating a site. Contact your county extension office or SCS for help in site evaluation.

Consider all farmstead operations, building locations, and prevailing winds when locating storages. Allow at least 100' between a water supply and the nearest part of a storage. Dairy operators need to check with milk and health authorities for minimum spacing requirements between manure storages and milking facilities.

Locate, size, and construct storages for convenient filling and emptying and to keep out surface runoff. Provide all-weather access.

Required storage capacity depends on regulations, number and size of animals, amount of dilution by spilled and cleaning water, amount of stored runoff, and desired length of time between emptyings. Provide enough storage to spread manure only when field conditions, labor availability, weather, and local regulations permit.

Handling large volumes of manure can delay other farm activities. Large manure storages require many hours, usually over a period of several days, to remove material from storage and apply it to land. This job often comes at prime times for field work. If spring application is required, the land is often not ready for manure spreader traffic before it is time to till and plant. Post-harvest spreading saves time during busy spring planting activities. It also provides a chance for winter freezing and thawing to lessen effects of soil compaction from the spreading operation.

Liquid Manure

Manure Pits

In this handbook, pits have vertical sidewalls, are lined, and are below grade. They may be either in buildings under slats or solid floors; or outside and usually separated from the building. Below-ground storages can be used for semi-solid and liquid manure. Manure with up to about 15% solids can be agitated and pumped. Storage depth may be limited by soil mantle depth over bedrock, water table elevation, and possibly, effective pump lift.

Design and construction

Typical storage periods range from 5 to 12 months. Provide capacity for dilution water, rain, snow, and milking center waste. Provide at least 1' of freeboard—1½' with pit ventilation.

Pit design criteria are in TR-3, *Concrete Manure Tank Design*, and TR-4, *Welded Wire Fabric in Concrete Manure Tanks*, which can be ordered from the addresses listed inside the front cover of this book. Typical rectangular pit designs are in plan mwps-74303, *Liquid Manure Tanks*, and circular pit designs in TR-9, *Circular Concrete Manure Tanks*. SCS offices can also provide concrete pit designs. Pits must be designed to withstand all anticipated earth, hydrostatic, and live loads, plus uplift if a high water table exists.

With heated buildings, insulate the exposed sidewall and 2'-3' below grade of exterior pit walls with waterproof insulation. When construction is completed, clean out nails, lumber, and other foreign material that could damage pumps.

Consider agitation requirements when selecting storage dimensions. Check manure pump manufacturer recommendations. Interior pit walls are often required in cattle buildings to divide large pits into cells which can be adequately agitated. See Fig 6-3.

Protect openings with grills and/or covers and enclose open-top pits with a fence at least 5' high to prevent humans, livestock, or equipment from accidentally entering the pit. Provide removable grills over openings used for agitation and pumping. Install railings around all pump docks and access points for protection during agitation and cleanout. Provide wheel blocks and tie downs for pumps and tractors.

Filling pits

Add water to the pit before filling it with manure. Add 3"-4" to pits under slotted floors; add 6"-12" if the unit is loaded with batches of scraped wastes to reduce solids sticking to the pit floor.

It is often necessary to dilute waste to aid pumping. See the diluting manure discussion in the animal wastes characteristics section.

Frozen manure, long fibrous material, and debris may require special pumping equipment. Sand and gravel cannot be pumped.

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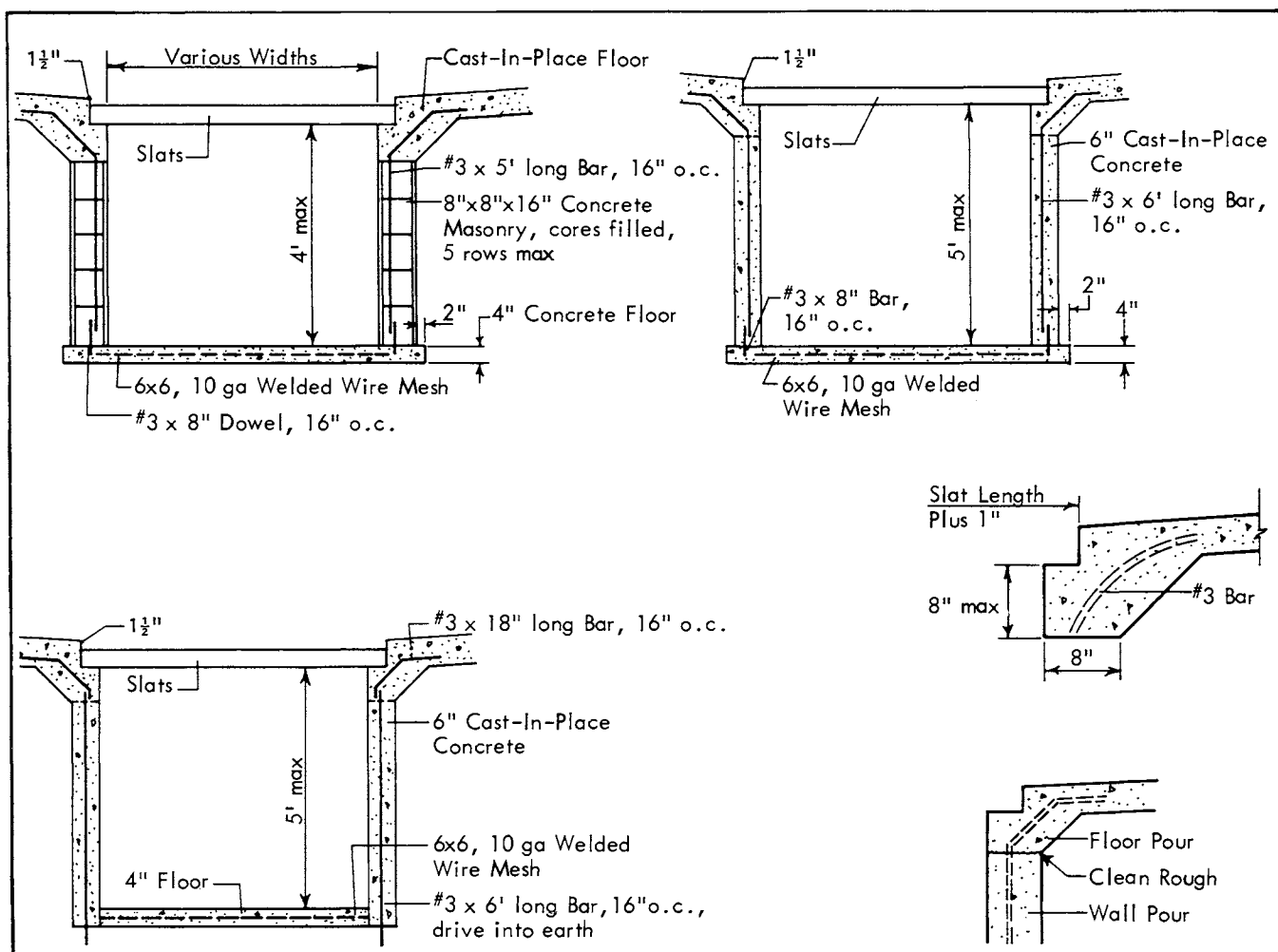


Fig 6-1. Shallow manure pits.

Ventilating manure pits

The primary hazard from manure gases results from inadequate ventilation. See the gases and odors discussion in the animal wastes characteristics section.

Provide maximum building ventilation when agitating or pumping waste from a pit. Harmful gases can be released in significant amounts; provide plenty of fresh air for workers and animals with open doors and windows and/or by operating large fans.

In buildings where humans spend considerable time, exhaust some ventilating air with pit fans at all times. Even a low volume continuous fan pulling air from above manure reduces problem gas accumulation, Figs 6-2a and 6-2b.

A gas trap prevents toxic gases from moving from an outside covered pit, through a sewer line, and into the animal shelter, Fig 6-2c. Air from an animal shelter can be exhausted through an outside covered pit to prevent freezing in the pit; the air flow must be continuous to prevent a reverse flow of air carrying toxic gases into the shelter.

Tightly closed buildings with underfloor manure pits can have a rapid buildup of gases at animal levels. Provide an alarm system (loud bell or readily noticed light) to warn of power failures in totally enclosed livestock buildings.

Agitating and emptying pits

Agitate the pit for 2 to 4 hr before hauling to get a uniform consistency and to incorporate all floating material. Complete agitation gives uniform consistency of manure for land application so the same nutrient concentration is applied everywhere. It also prevents a solids buildup in the pit so the original storage volume is maintained. Solids tend to resettle soon after agitation ceases, so continue to agitate, at least periodically, while hauling the manure.

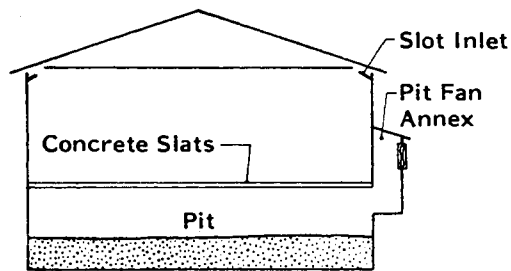
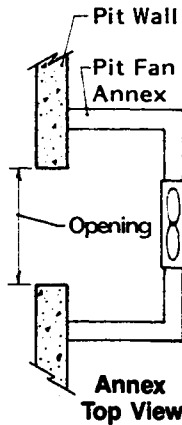
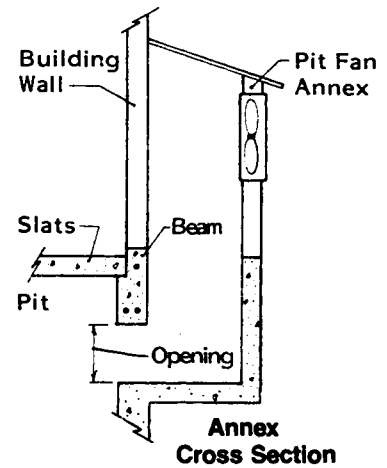
Caution: gases escaping from agitated manure can be deadly to animals and humans. Operate all ventilating fans and open doors and windows when agitating and unloading manure storages. **Remove animals if possible.**

Manure pit agitation equipment has improved significantly in recent years. The major improvement has been increasing the discharge capacity of the pumps so they move manure faster to agitate better. See section on pumps and check manufacturer's recommendations. Provide a paved equipment apron next to pit access.

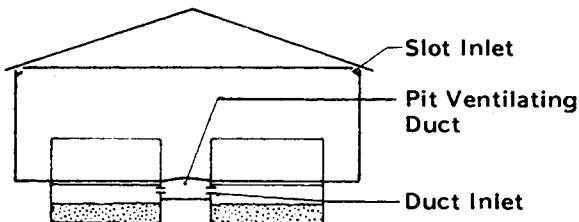
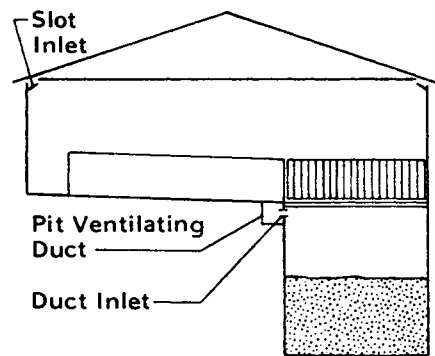
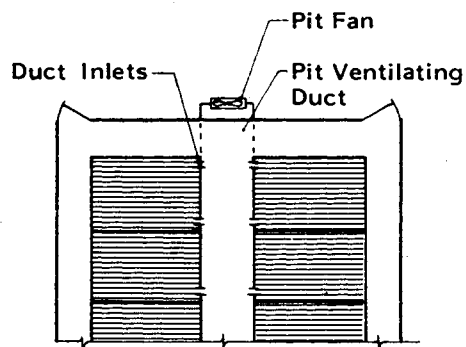
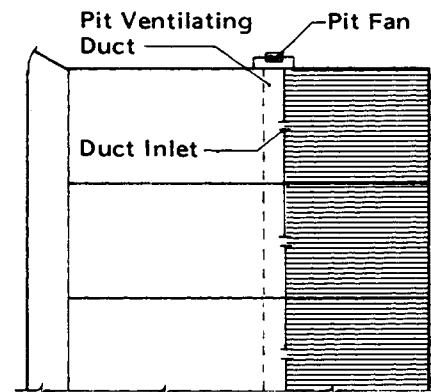
Land application of liquid manure from pits is typically done with liquid manure tank wagons and either broadcast spreading or injection. It may also be applied with irrigation equipment specially developed for manure handling.

Exhibit 1100

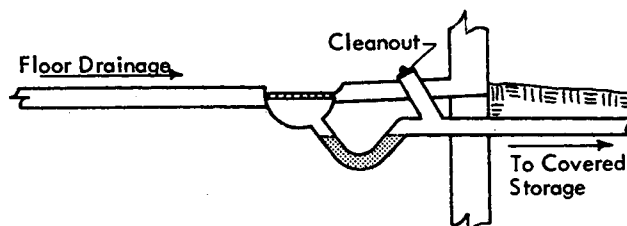
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**Building Cross Section****Annex Top View****Annex Cross Section****6-2a. Pit fan in annex.**

Works best with concrete slats; does not work well with more open flooring like wire mesh.

**Cross Section****Cross Section****Floor Plan****Floor Plan****6-2b. Pit ventilation through ducts.**

Duct inlets in tank wall can be tile or concrete blocks on edge.

**6-2c. Gas trap in drain line.****Fig 6-2. Manure pit ventilation.**

Provide some pit ventilation at pit level in closed buildings to reduce gases and odors.

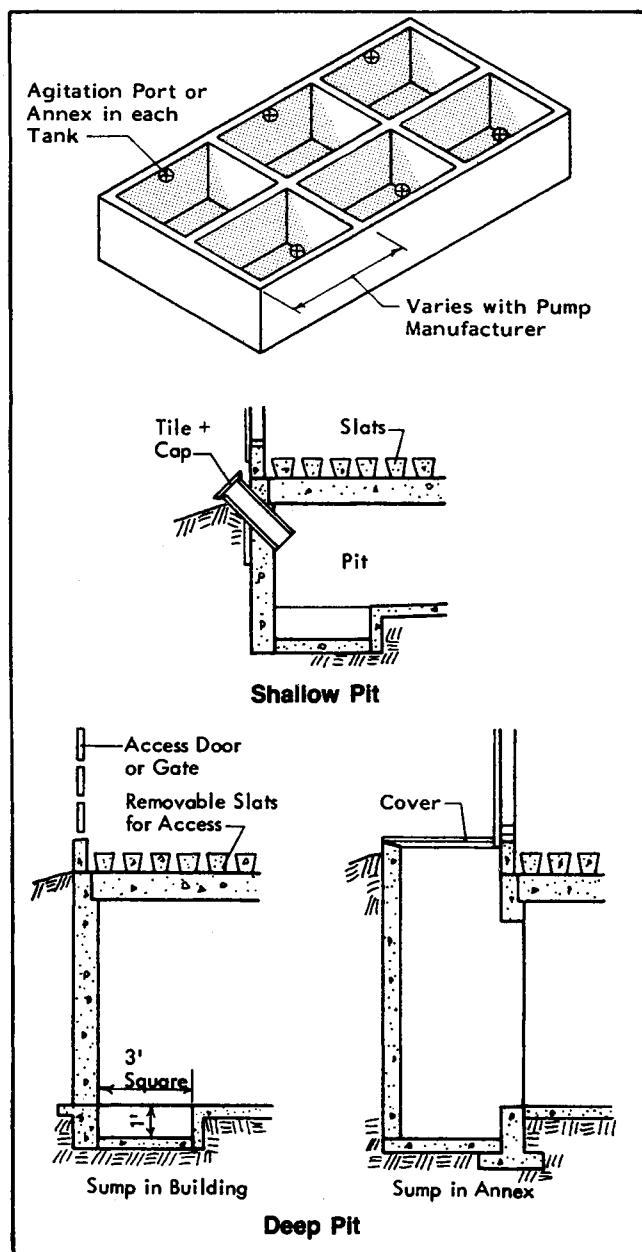


Fig 6-3. Agitating manure storage pits.

Earth Storage Basins

Earth basins are earth-walled structures formed by excavation and earth berms so they are generally partly above and partly below grade. They may or may not be lined. Earth basins can extend the capacity of indoor pits or provide total storage needs. Earth basins provide long-term storage at low to moderate investment. They are designed and constructed to prevent ground and surface water contamination. They also eliminate the problem of hazardous gas entrapment and reduce the potential of fatalities. Check with your SCS office for help in evaluating site suitability, dike construction, and bottom sealing.

Locate storages to reduce odor nuisances and avoid eyesores. During construction, use the excavated material to build a dike around the basin. Dikes help screen the contents from view. If a basin is prop-

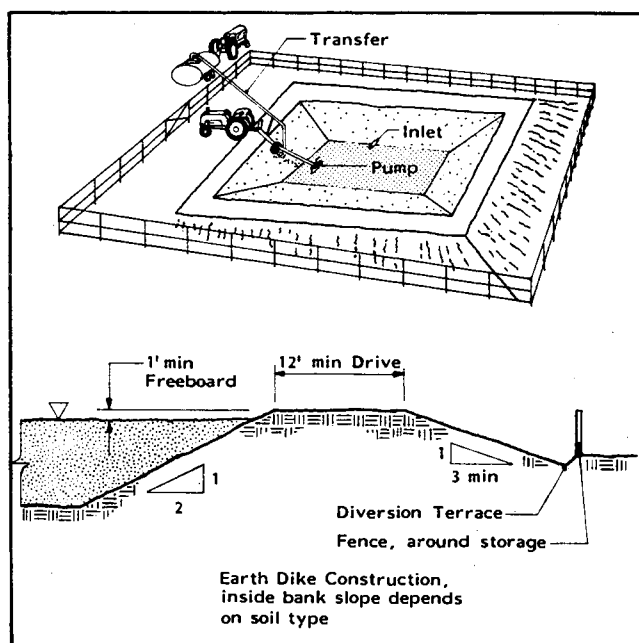


Fig 6-4. Earth storage basins.

Agitate and pump with modified 3-point mounted liquid manure pump or a self-loading manure tank wagon.

erly located, fenced, and its banks are well cared for, it should not be a nuisance. Locate storages downwind and as far as possible from all homes.

Earth basin design

- Keep the bottom of the storage at least 3' above bedrock and at least 2' above the water table, depending on local pollution control regulations.
- Study soil characteristics and check with your SCS office to determine basin wall sideslopes. Follow accepted construction methods for sealing, building dikes, and bank seeding. In general, steeper inside banks conserve space, reduce rainfall runoff entering the basin, and leave less manure on banks as the basin is emptied. Inside bank slopes of 2:1 to 3:1 (run:rise) are common for most soils. Make the outside sideslopes no steeper than 3:1 for easier maintenance.
- Make the embankment wide enough (at least 12') to mow and to get a tractor on for agitation.
- Determine the basin depth after considering the site, storage volume needed, groundwater conditions, and emptying equipment. A deeper basin requires less area for the same capacity. Less surface area allows a floating crust to form more readily which helps control odor. Also, there is less crust area to break up and resuspend when agitating.
- For concrete access ramps, use a slope no steeper than 10:1 if they are to be used for tankers or spreader access. A 5:1 slope is acceptable for tractor and pump access. Provide a rough surface for improved traction when wet. Form deep grooves or ridges (1" deep or more) across the ramp with the edge of a board, a garden rake, or fork before the concrete sets.

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- Fence around the basin to keep cattle and people away. Post signs on each side stating what the storage contents are and that it is a dangerous area.
- Maintain sod and mow vegetation.

Sizing

Example 6-1:

Size an earthen basin to store manure for 1 yr from 1,000 beef cattle averaging 1,000 lb each. The earth basin inside banks will have a 2:1 slope.

Solution:

1. Manure production/feeder is 0.95 ft³/day, Table 2-1.
 $1,000 \text{ feeders} \times 0.95 \text{ ft}^3/\text{feeder-day} \times 365 \text{ days} = 346,750 \text{ ft}^3$
 Add 25% to the volume to account for rainfall and dilution water = 86,688 ft³
 Total storage volume = 433,438 ft³
2. From Table 11-2, determine the earth basin dimensions. Several designs are available. If 15' deep, a 150' × 347' storage holds 475,000 ft³.

The volume of rectangular and square earth storages can also be determined from:

$$LW = EW - 2 \times FB \times S$$

$$LL = EL - 2 \times FB \times S$$

$$LD = ED - FB$$

LW = liquid width, ft

EW = earth basin width, ft

FB = freeboard, ft

S = sideslope, ft

= amount of run for 1' fall

LL = liquid length, ft

EL = earth basin length, ft

LD = liquid depth, ft

ED = earth basin depth, ft

Eq 6-1.

$$V = (LW \times LL \times LD) - (S \times LD^2) \times (LW + LL) + (4 \times S^2 \times LD^3 \div 3)$$

V = liquid volume, ft³

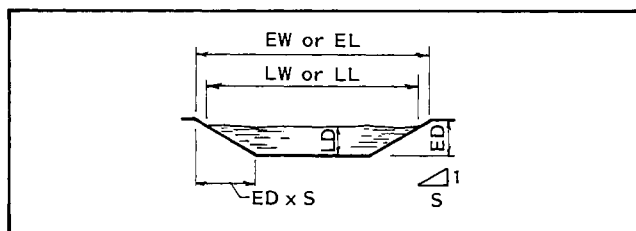


Fig 6-5. Earth storage dimensions.

Filling

Use **bottom loading** for pumped wastes that form a surface crust, such as cattle wastes. The crust reduces fly and odor problems and conserves nitrogen. Keep the inlet pipe 1'-3' above the bottom to prevent blockage.

Top loading is suitable for a storage that will not crust over, e.g. swine wastes. It is also suitable or necessary for some of the methods listed below.

Top-loaded solids pile up around the loading point, because the manure does not flow away, particularly in cold weather. Bottom loading pushes solids away from the inlet and distributes them more evenly.

Top loading methods:

- **Barn cleaner extension.** Locate the storage next to the barn. Freezing of machinery and manure can be a problem.
- **Tractor scraper or loader.** Locate the storage next to the barn. Manure pileup at the push-off point can be a problem in freezing weather.

Bottom loading methods:

- **Conventional chopper-type liquid manure pumps.** Manure collects in a small sump or tank and a chopper pump transports the manure to the storage basin. The pump chops long bedding material for easier pump-out later. If the sump is outdoors, pump freezing can be a problem.
- **Piston manure pumps.** Piston pumps move manure through 10"-15" diameter PVC or steel pipe. The pump is usually in the barn and the storage may be up to 300' from the barn.
- **Pneumatic manure pumps.** Compressed air is injected into a sealed tank and forces manure through 12" diameter PVC pipe to the storage.
- **Centrifugal and other liquid manure pumps.** Liquids from milkhouses, etc., can be pumped.
- **Gravity loading.** Storages below the level of the barn can sometimes be gravity-loaded. See section on gravity transport.

Agitating and emptying

Agitate prior to pump-out to mix liquids and manure solids and to break up the crust. A high volume, chopper-type, liquid manure pump is best for agitation. Earth basins are usually agitated with a 3-point hitch or trailer-mounted pump at the end of a long boom, Fig 6-6. The pump is lowered down an embankment or ramp placing the pump inlet just under the manure surface. For agitation, the discharge from the pump is directed up and over the surface of the storage, impacting 60'-70' away from the pump. This action helps to break up the surface crust and develops a circulation pattern that floats chunks of crust toward the pump. These pumps have a chopper and/or rotating auger section at the inlet that further breaks up the crust and draws the solids into the pump for thorough agitation. Typical pump discharges during agitation are 3,000 to 5,000 gpm.

Some earth storage basins have a vertical wall or a dock built out over the surface so a vertical shaft liquid manure pump can be used for agitation. Vertical shaft pumps discharge under the surface for agitation and the pump is located at the bottom of the vertical shaft, well below the surface. While these pumps can agitate small earth basins, they do not have the capability of moving pieces of surface crust to and through the pump and therefore are not as effective for breaking up a tough crust.

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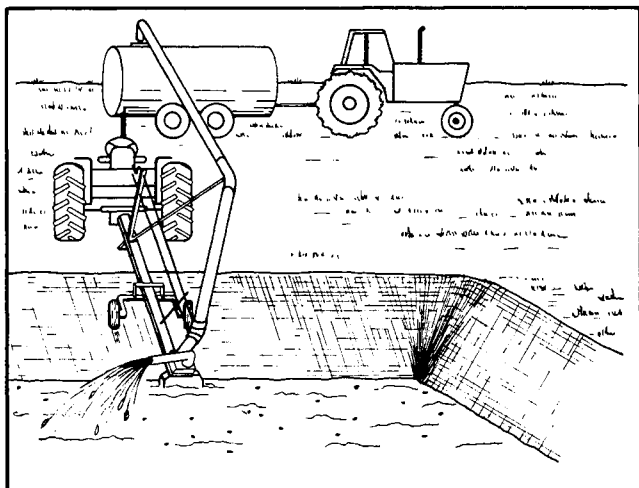


Fig 6-6. Earth basin agitation pump.

Provide a firm base for the tanker loading area. Design for drive-through loading to avoid backing or maneuvering the tank wagon. When using a standpipe discharge, locate the outlet at the highest point on the line so the line drains after the pump is shut off.

Propeller-type agitators are also available on 3-point hitch mounted booms which can be lowered over an earth embankment for agitation. They have the capacity to move large volumes of manure. Agitation devices for earth embankments are now available with both a propeller and a pump.

Land application from earth basins is usually done with liquid manure tank wagons. They are usually loaded by the agitation pumps that go in the basin. Consider connecting a long hose to a stationary standpipe outside the basin, so the tank wagons can be filled without backing them down the ramp. There are self-loading wagons with paddle-type conveyors to load the wagon, but the wagon has to be backed down to the basin. Typical loading flowrates are in the range of 2,000 gpm.

Above-Ground Tanks

Above-ground manure tanks are circular silo types or rectangular structures. They are more expensive than earth basins and are usually not used to store runoff or dilute wastes. They are a good alternative where basins cannot be used due to site limitations such as space constraints, shallow creviced bedrock, or where earth basins are not aesthetically acceptable.

Above-ground tanks work well for enclosed buildings, but they are difficult to use for open lots because of the variation in manure consistency. In addition, an above-ground tank is too expensive to be used for lot runoff water, which must be handled separately.

Construction

Construction options include:

- Concrete stave.
- Reinforced monolithic concrete.
- Lap or butt joint coated steel.
- Spiral wound coated steel.

Leaks from joints, seams, or bolt holes can be unsightly, but most small leaks quickly seal with manure. The joint between the foundation and the

sidewall can be a problem if improperly constructed. The reliability of the dealer and construction crew are as important as the tank material in assuring satisfaction.

Sizing

Size above-ground tanks for the manure volume, intercepted rainfall, and either milking center wastewater, if included, or added dilution water. Base the desired storage period on when land and labor are available for land application. Next, calculate the volume of waste that will accumulate over the storage period and determine the required storage size from Table 6-1.

Example 6-2:

Size an above-ground tank to provide 180 days of storage for 350 pigs averaging 150 lb/pig. Assume 20% additional storage for water wastage, etc.

Solution:

1. Daily manure production/150 lb pig is 1.2 gal/day, Table 2-1.
 $350 \text{ pigs} \times 1.2 \text{ gal/pig} \times 180 \text{ days} = 75,600 \text{ gal}$
 Add 20% to the volume for additional water = 15,120 gal
 Total storage volume = 90,720 gal
2. Select tank dimensions from Table 6-1. Several alternatives are available, such as 40'D $\times$ 10'H (94,200 gal).

Table 6-1. Round storage capacities.

D = diameter; H = height.

Size DxH	gal	ft ³	Size DxH	gal	ft ³
40'x10'	94,200	12,600	60'x10'	212,000	28,300
x15'	141,400	18,800	x15'	318,100	42,400
x20'	188,500	25,100	x20'	424,100	56,500
x25'	235,600	31,400	x25'	530,100	70,700
45'x10'	119,200	15,900	72'x10'	305,300	40,700
x15'	178,900	23,800	x15'	458,000	61,100
x20'	238,500	31,800	x20'	610,700	81,400
x25'	298,200	39,800	x25'	763,400	101,800
50'x10'	147,200	19,500	80'x10'	377,000	50,200
x15'	220,900	29,400	x15'	565,500	75,400
x20'	294,500	39,300	x20'	754,000	100,500
x25'	368,100	49,100	x25'	942,500	125,600
55'x10'	178,100	23,700	100'x10'	589,000	78,500
x15'	267,300	35,600	x15'	883,600	117,800
x20'	356,300	47,500	x20'	1,178,100	157,100
x25'	445,400	59,400	x25'	1,472,600	196,300

Filling

Some tanks are loaded with a large piston or a pneumatic manure pump through a large diameter underground pipe. Piston and pneumatic manure pumps can move material into storage that may be difficult to remove. With above-ground tanks, use little bedding, use only chopped bedding, and add extra dilution water to reduce agitation problems. Provide a water faucet at the pump to add dilution water during loading.

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A conventional chopper-type liquid manure pump is preferred for tank filling. The pump can be in a collection sump or pit in the barn. Locate the collection pit or sump where manure can be conveniently scraped into it. Add water (possibly milking center wastewater), agitate, and pump the waste to the tank through a 4"-6" diameter buried pipe, Fig 6-7. The same sump can also empty the storage for land application. See the section on transport to storage.

Loading pumps cannot handle frozen manure. Dry manure requires additional water for loading and does not rewet easily.

Provide check valves and a manual safety valve if bottom loading the storage. Make sure the pump can handle the maximum head. Include head loss from sump depth, storage height, and pipe friction from pump to storage.

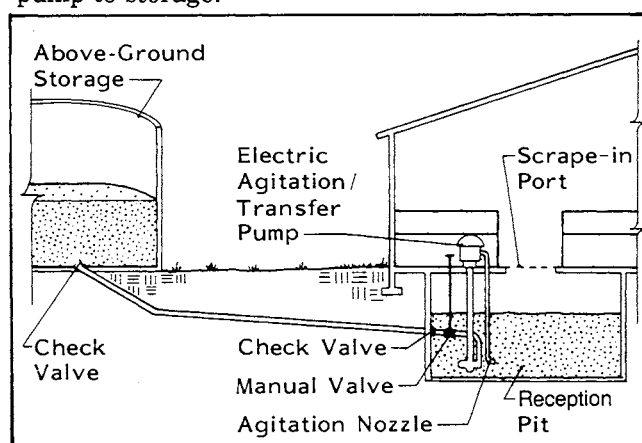


Fig 6-7. Reception pit and transfer pump.
For above-ground storage.

Agitating and emptying

Agitation is usually done with a centrifugal pump mounted on the storage foundation, Fig 6-8. A tractor PTO operates the pump. The inlet at the base of the tank has a large slide valve. For agitation, the pump discharges over the top into the storage.

After agitation, a two-way valve on the discharge pipe is changed to pump into tank wagons. This system is simple and relatively troublefree, although slide valves sometimes freeze.

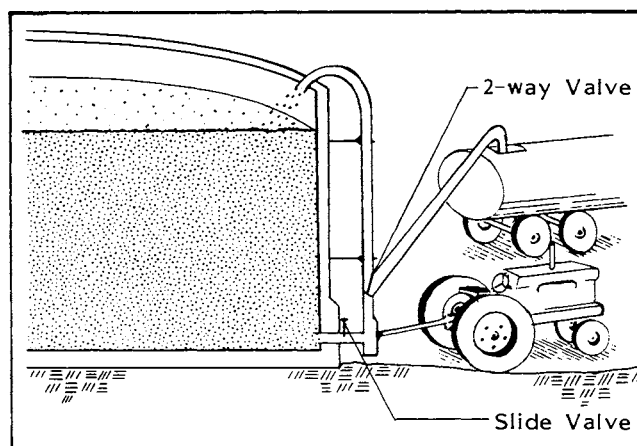


Fig 6-8. Side-mounted liquid manure pump.
Large diameter tanks may have a center agitation nozzle.

Agitation can be a problem if the tank becomes too full or has too much long bedding. Sand and ground limestone settle to the bottom of the storage and are impossible to pump out. Do not use sand as free stall bedding with any liquid manure system, particularly above-ground tanks, unless equipment can enter and remove the solids after all pumpable liquid has been removed.

A chopper-type liquid manure pump in a sump outside the storage can also agitate and unload, Fig 6-9. A large pipe or duct (usually 12") with a valve drains the storage to the sump. The sump, under-drain piping, and valving add to the cost, but only one pump is needed for filling and emptying. Take care during pumping and agitating so the gravity drain fills the sump at the same rate as the pump empties it. The manure at the bottom of the tank must be liquid enough to flow to the sump for recirculation to start.

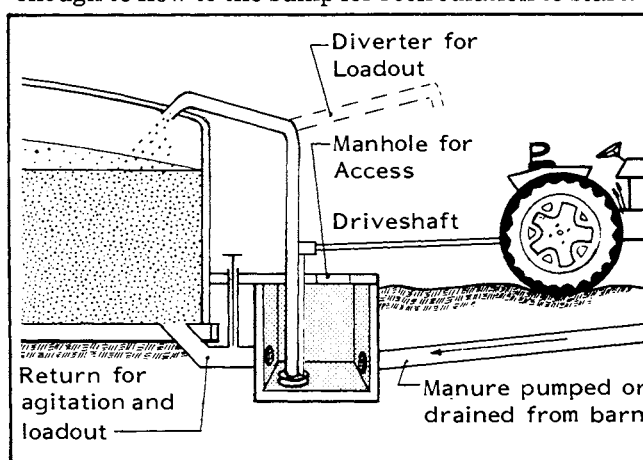


Fig 6-9. Chopper liquid manure pump.

Management

Try to keep out materials that cannot be agitated and pumped. Limit excess water unless dilution water is needed. Be sure adequate storage space is available for long periods, such as winter or cropping.

Remove ladders or other climbing devices to protect uninformed people, but maintain access to the storage for unloading. Do not enter covered sumps until the toxic gases are removed. Follow manufacturers' instructions for draining pumps, pipes, and valves during cold weather. Do not allow runoff from the loading area or storage into streams or road ditches.

Semi-Solid Manure Systems

Semi-solid manure is manure with excess liquids drained off and some bedding added to increase solids content. Solid manure has relatively large amounts of bedding added to give it a stackable consistency. Both semi-solid and solid manure can be handled with conventional equipment already present on many farms. Thus, a semi-solid manure storage allows waste from many sources to be stored in one facility and handled with the same set of equipment. For example, dairy stanchion barns, calf pens, mater-

nity pens, and often youngstock housing produce various consistencies of manure that can be handled in one semi-solid storage. Semi-solid storages can be an outside facility with picket dams to drain off rainwater or roofed structures.

The hauling schedule from a semi-solid storage facility is flexible. Storages can be designed for any period of storage, from a few days to several months. Whenever time allows, you can haul a few loads of manure without planning ahead to agitate the storage facility, as is required with liquid manure. Also less total material is hauled from storage because no water is added.

Drained Storages

If rainwater is drained from an uncovered storage, manure with semi-solid characteristics when it goes into storage can be handled with loaders and endgate or flail-type spreaders. Drained storages allow a producer to deposit semi-solid manure in an uncovered storage and maintain semi-solid handling characteristics by draining off rainwater. Keep all excess water out of the manure storage. A picket dam removes only rainwater that falls on the storage; it does not reduce the water content of the manure. Do not expect to put a slurry in and get a solid out. Limit the dimensions of drained storages to 100' to enhance drainage.

Provide a structure that allows rainwater to drain from the storage regardless of the manure level. A picket-type structure with continuous vertical slots about $\frac{3}{4}$ " wide between standing planks (pickets) holds manure solids back but allows liquids to drain through, Fig 6-10 and Table 6-2. Vertical slots work much better than horizontal slots. Load the storage with a stacker, a piston pump of a type that does not require the addition of water during pumping, or a tractor push-off ramp.

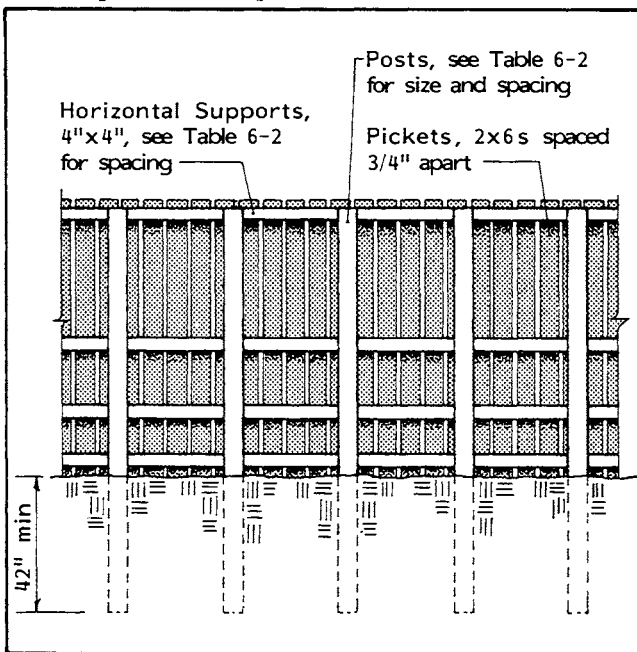


Fig 6-10. Back view of picket dam.

Table 6-2. Picket dam design.

Posts and horizontal supports are rough sawed timbers. Pickets are pressure preservative treated 2x6s; rough sawn or surfaced.

Posts			Horizontal supports		
Picket height	Size	Spacing	Distance from top of pickets	Size	Spacing
0'-4'	4"x6"	5'	0'-4'	4"x4"	3'
5'	6"x6"	4'	4'-6'	4"x4"	2.5'
6'	6"x8"	4'	6'-8'	4"x4"	2'
7'	8"x8"	3'			

Picket dams may be in earth storages, Figs 6-11 and 6-12, or in the walls of bunker-type storages having concrete or post-and-plank walls. The manure surface is highest at the loading point and slopes toward the surrounding earth walls. A channel for runoff water forms where the manure meets the earth dike. When a drainage structure is properly located, water runs off the crusted surface of the manure, flows around the edge along the channel formed between the manure and earth bank, and runs through the vertical slots of the structure. Provide a channel behind the picket for the liquids to drain away. It is critical to locate a picket dam anywhere water will accumulate. Dam length is not as important as location. One picket dam must extend $\frac{2}{3}$ of the way up the ramp to drain water from the ramp.

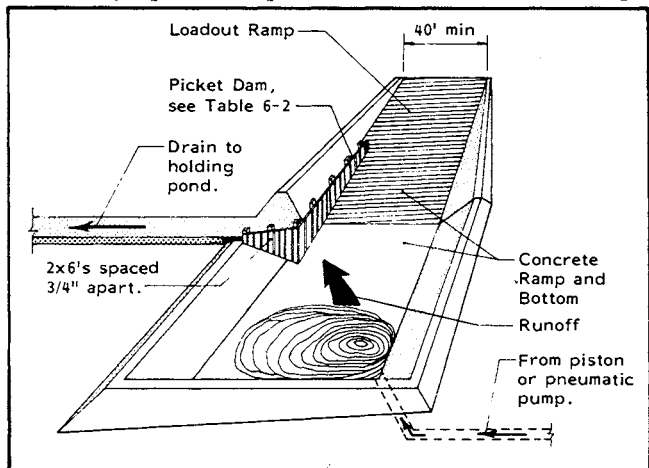


Fig 6-11. Picket-drained storage loaded by piston pump.

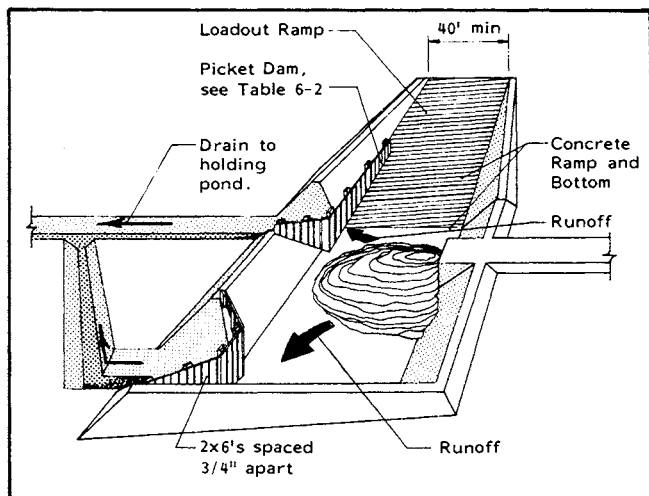


Fig 6-12. Picket-drained storage loaded from a ramp.

Make the concrete load-out ramp in Figs 6-11 and 6-12 no steeper than 10:1—preferably flatter. Make the ramp at least 40' wide to allow for parking a spreader along one side, and roughen the ramp to improve traction. Grooves can be angled across the ramp to provide small channels to guide the rainwater that falls on the ramp toward the pickets. Storage walls can be 1'-2' higher than the top of the ramp because the manure pile slopes down to the ramp. Make the storage floor a flat concrete slab.

These storages require that some bedding be added to the manure for convenient handling with conventional spreaders having endgates. Do not use this storage for sand-bedded free stalls.

The drainage water from the manure storage is polluted—do not let it enter public waters, pollute groundwater, or leave your own property. Direct this drainage to a holding pond, a lagoon, or an infiltration area.

When the storage is cleaned, remove any solids that have accumulated behind the pickets or in the vertical slots between the pickets.

Above-Ground Roofed Storage

This system was developed for dairy comfort stall barns in high rainfall areas where large amounts of bedding are mixed with manure. However, some dairy producers are now building them for free stall barn manure because new equipment designed for handling semi-solid manure is now available. The roof protects collected manure from rainwater to keep it as dry as possible. Manure in storage crusts over, reducing odor and fly breeding problems. This system provides an aesthetically pleasing structure that appears to be another building on the farmstead.

Provide a concrete floor and a concrete footing down to 3' below existing grade. The walls can be 12'-16' high post-and-plank or concrete with earth backfill to resist the internal fluid pressure, Fig 6-13. Translucent roof panels on the south slope may enhance manure drying. However, once the manure crusts over, it may not dry much more even with solar energy. Provide a ventilation space between the top of the walls and the trussed roof.

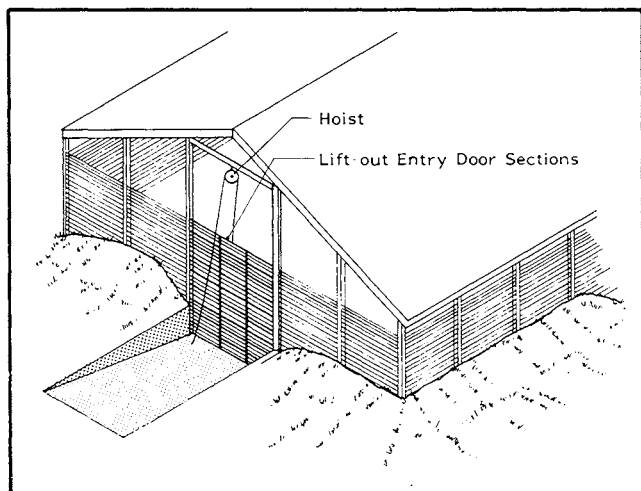


Fig 6-13. Roofed above-ground storage.

Filling and emptying

These storages are typically bottom-loaded with a large diameter piston pump.

A hoist on a beam above the doorway lifts horizontal planks from a bulkhead in one end of the storage. Manure then flows over the bulkhead onto a concrete slab where a front-end loader fills a conventional spreader. When all planks are removed, the loader can go inside the structure to load-out the remaining contents.

Solid Manure

Solid manure storage is used where manure dries sufficiently or where enough bedding is added to make it a stackable solid. If located in a walled structure outside, install picket dams to drain rainwater. See discussion of semi-solid manure systems.

Provide for convenient filling with a tractor-mounted manure loader or scraper, elevator stacker, or piston pump. Unload with a tractor-mounted bucket; provide a bucking wall, Fig 6-14. Locate stor-

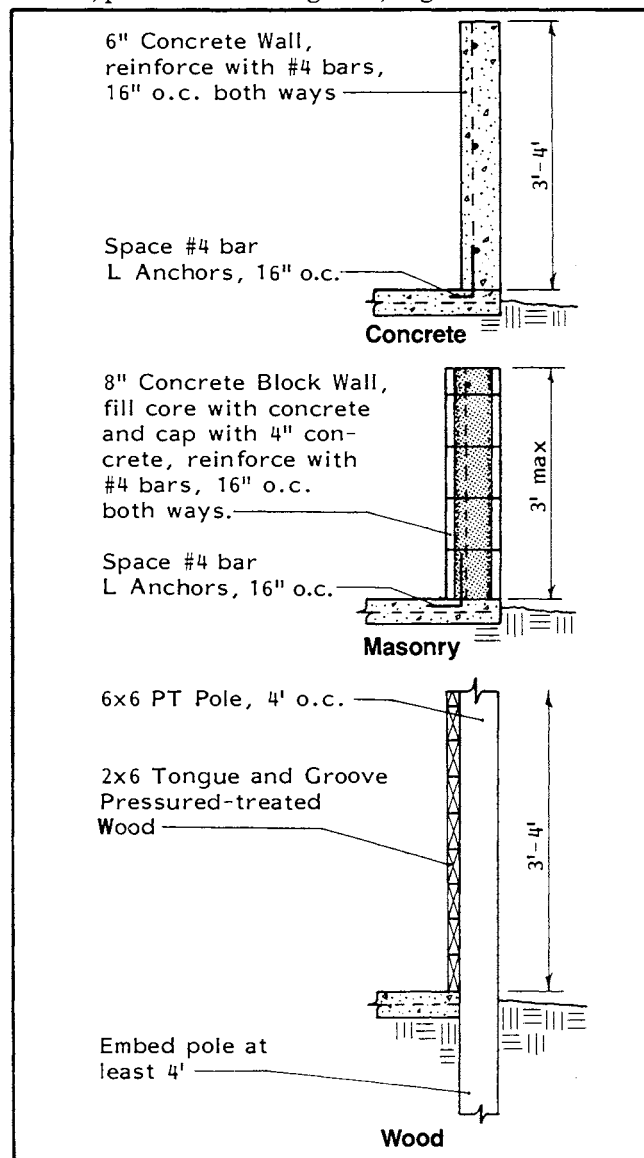


Fig 6-14. Bucking walls.

age for year-round access so manure can be spread when field, weather, and regulations permit. Prevent surface runoff water from entering the storage.

Sizing

Adequate storage is needed for convenience and to avoid spreading manure when weather or soil conditions are wrong. Up to about 180 days of storage is recommended in cold climates, with less needed in warmer climates.

See section on animal wastes characteristics to determine solid manure storage size.

Construction

Provide convenient access for unloading and hauling equipment. Slope entrance ramps upward to keep out surface water. Provide a load-out ramp at least 40' wide with a 10:1 slope (20:1 preferred), Fig 6-15. A roughened ramp improves traction. Angle grooves across the ramp to drain rainwater. Concrete floors and ramps are recommended. Use a 4" concrete floor over 6" coarse gravel or crushed rock (up to 1½" aggregate size). Two inches of sand can replace gravel as fill under concrete when over undisturbed or compacted soil.

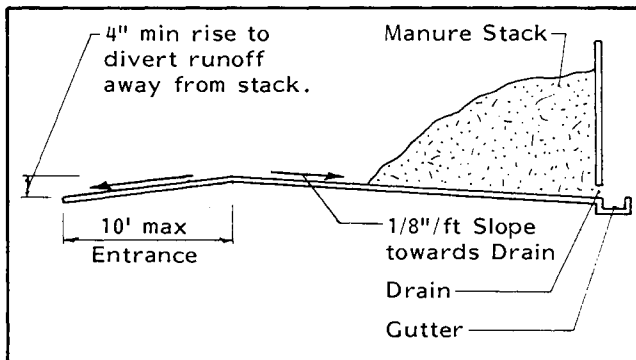


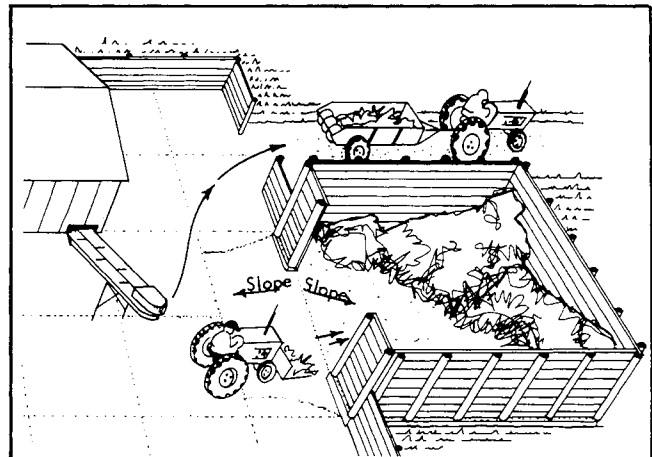
Fig 6-15. Stack slope and drainage.

Walls are usually concrete or post-and-plank. Provide one or two sturdy walls to buck against for unloading, Fig 6-14.

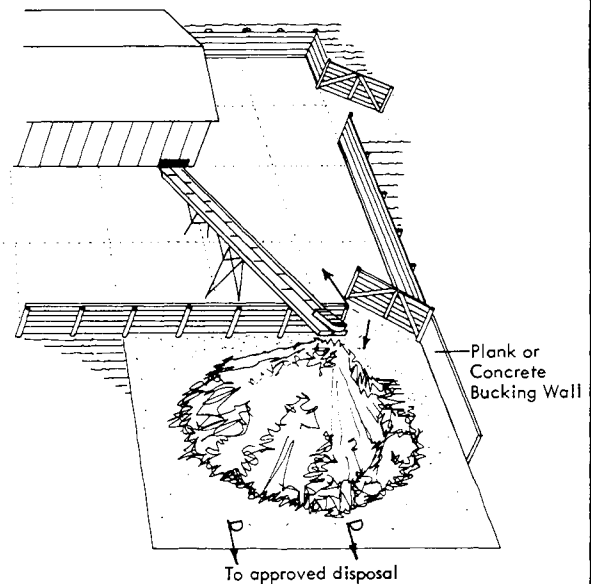
If liquids (urine, snowmelt, and rain) are to be retained in the storage, slope the floor toward a closed end.

To drain off liquids:

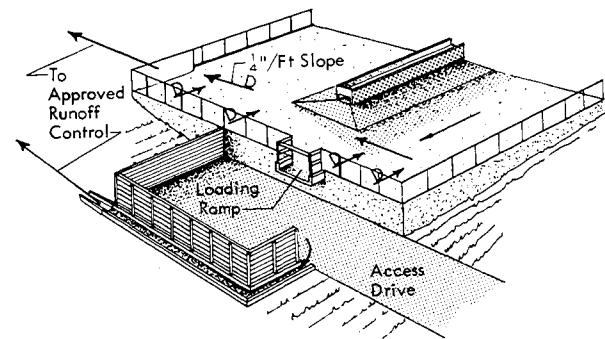
- Slope the floor to one or both sides, with openings on the low side to a gutter or surface drain.
- Provide floor drains with removable grills. Install underground corrosion resistant 8" pipe to carry away liquids. Or, start the stack with 6" of wood or bark chips or corn cobs to absorb some liquids and permit the rest to drain.
- Provide a gutter to carry runoff away. Use removable grill covers of pressure-treated wood planks spaced about ¼" apart.
- Start stacking at the high end.



6-16a. Barn cleaner to spreader or tractor stacking.



6-16b. Stationary elevator stacker.



6-16c. Yard layout for sloping sites.

Extend welded pipe fencing around loading ramp for safety.

Fig 6-16. Solid manure storage layouts.

Divert surface drainage around lots and storage. Fence cattle away from storage. Divert lot drainage away from storage to approved disposal.

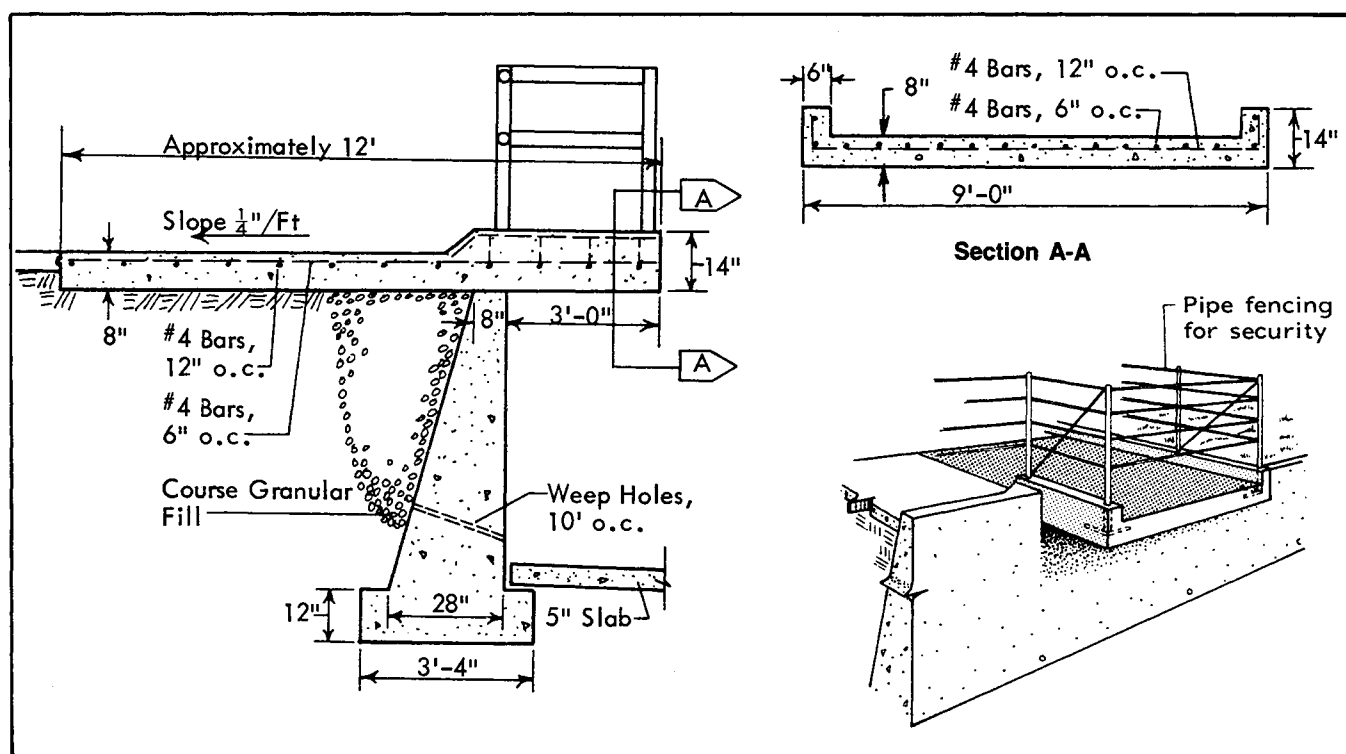


Fig 6-17. Solid manure loading ramp.

Fig 6-17: Solid manure loading ramp.
Provide pipe, or equivalent, guardrail along the wall and around the ramp for safety.

7. BIOLOGICAL TREATMENT

A biological treatment system is designed and operated for biodegradation—converting organic matter (feed, bedding, body byproducts) in animal wastes to more stable end products.

Anaerobic processes occur without free oxygen and liquefy or degrade high BOD (biochemical oxygen demand) wastes. They can decompose more organic matter per unit volume than aerobic ones.

Aerobic processes require free oxygen and are generally considered uneconomical for livestock operations. They are helpful in reducing odor.

Facultative microorganisms can function either anaerobically or aerobically, depending on their environment.

Ideal conditions are not required, because there are many different microorganisms so that at least one group can adapt. Anaerobic and facultative bacteria in animal excreta multiply rapidly. However, extreme environmental changes alter microbial activity. When microorganisms are stressed by the environment, waste treatment processes malfunction and odors can become a problem.

Anaerobic Lagoons

In the Midwest, lagoons are most common for swine wastes. Earth basins (which are storages, not lagoons) are more common for dairy and beef operations, even those using flushing and recirculation. See the earth basins discussion in the manure storage section.

Advantages

- In addition to labor savings from removing liquid manure from buildings, further labor can be saved by using irrigation to dispose of liquids.
- Long storage times permit pumping flexibility while bacteria break down solids.
- The high degree of stabilization can reduce odors during spreading.
- High nitrogen reduction is an advantage if disposal must be on small areas.

Disadvantages

- Odors are produced if environmental or management changes reduce biological activity—lagoons are sensitive to sudden changes in temperature and loading rates.
- Where winter water temperatures are near or below freezing, lagoons experience spring and fall turnover (bottom water rises and top water drops). After a winter of little bacterial action due to low temperatures, odorous material from the lagoon bottom rises to the surface. Higher spring water temperatures increase microbial action, and foul odors are generated during the bacterial buildup stages.

- Because higher temperatures improve manure decomposition, anaerobic lagoons work best in summer and in areas without cold winters.
- Fertilizer value reduction is a disadvantage if lagoon effluent is used to fertilize crops. Up to 80% of the nitrogen is lost in a lagoon. Phosphorous may precipitate to the bottom but can be recovered when sludge is removed.

Function

Anaerobic lagoons handle high loading rates but give off some septic odors. Well designed and managed lagoons have a musty odor. Foul odors indicate malfunction. Do not use an anaerobic lagoon where odors may be a nuisance. Aeration of the top few inches of a lagoon may start aerobic conditions and reduce odors but can be costly and difficult.

Mineral buildup, resulting from water evaporation leaving dissolved salts behind, requires periodic dilution and pumping. Water from roof drains and other sources is often added to a lagoon.

Anaerobic lagoons liquefy and break down manure solids, but not all wastes added are completely degradable. Sludge accumulation depends on management, environment, waste characteristics, and loading rate. After about 2 yr, sludge buildup rate in a properly functioning lagoon may decrease. Because complete treatment is not practical, periodically pump or drain to cropland. Enough land area must be available to dispose of lagoon effluent and sludge.

Swine Lagoon Design

Use two-stage lagoons for recycled flush water to improve flush water quality and decrease levels of pathogenic organisms. Dilution water improves treatment and odor control—add as much dilution water as manure. Empty at least $\frac{1}{3}$ of lagoon volume once or twice a year. Properly designed and managed swine lagoons have a useful life of 8 to 12 yr before sludge removal is required. See Fig 7-1 and Tables 7-1 and 7-2 for design information.

Example 7-1:

Design a two-stage lagoon for a central Iowa farrow-to-finish operation that markets 2,000 head/yr. The lagoon inside slopes will have a 2:1 slope.

Solution:

1. From Fig 7-1, central Iowa is in Zone 2.
2. From Table 7-1b, size the first stage lagoon at:
 $360 \text{ ft}^3/\text{head} \times 2,000 \text{ head} = 720,000 \text{ ft}^3$
 From Table 7-2b, size the second stage at:
 $50 \text{ ft}^3/\text{head} \times 2,000 \text{ head} = 100,000 \text{ ft}^3$
3. First stage: 720,000 ft^3 volume. From Table 11-2 on the 800,000 ft^3 row and for a 20' lagoon depth, select the dimensions of: 200' $\times$ 326' $\times$ 20'
4. Second stage: 100,000 ft^3 volume. From Table 11-2 on the 100,000 ft^3 row, select the dimensions of: 150' $\times$ 123' $\times$ 10'
5. Increase total dimensions to include berm widths and exterior berm sideslopes.

Table 7-1. Single stage swine lagoon volumes.

Also use for first stage of two-stage lagoons. Always provide 1'-2' of freeboard.

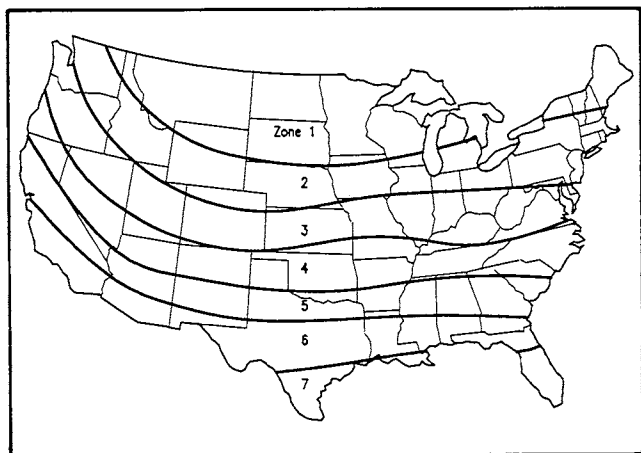
7-1a. Individual animals.

		Climatic zone , Fig 7-1						
Animal	Weight, lb	1	2	3	4	5	6	7
		ft ³ /hd						
Sow and litter	400	585	500	440	390	350	320	295
Prenursery pig	20	60	50	45	40	35	35	30
Nursery pig	55	160	135	120	105	95	90	80
Growing pig	115	330	280	245	220	200	180	165
Finishing pig	190	540	465	405	360	325	295	270
Gestating pig	325	260	225	195	175	160	145	130
Boar	400	320	275	240	215	195	175	160

7-1b. Swine operations.

Based on 16 pigs sold per productive sow-yr. Lagoon volume per productive sow accounts for all animals in the operation such as pigs in nursery, growing, etc. and boars.

Operation	Climatic zone, Fig 7-1						
	1	2	3	4	5	6	7
Feeder pigs produced sold at 50 lb (ft ³ /productive sow)	740	630	560	490	450	410	370
Pigs fed 50-220 lb (ft ³ /p/g sold-yr)	190	160	140	120	110	100	90
Farrow to finish (ft ³ /productive sow)	6,660	5,720	5,010	4,480	4,070	3,710	3,400
(ft ³ /p/g sold-yr)	420	360	310	280	250	230	210

**Fig 7-1. Climatic zones for anaerobic lagoons.**

Based on volatile solids loading rates recommended by the American Society of Agricultural Engineers (ASAE).

Lagoon Construction**Location**

Locate a lagoon as far from the farm home as practical, and where the prevailing winds will carry odors away from houses. Court action can force you to revise your waste management system to stop the production of objectionable odors. To some people, lagoon odors are objectionable at distances of ½ mile and detectable at distances of a mile or more.

Locate the lagoon near the waste source. If the lagoon is downhill from the source, gravity can transport the waste. A sump and submersible sewage lift pump can elevate wastes into a lagoon if necessary.

Locate the lagoon over impervious soil, where bottom and sidewalls can be impervious. Soil Conservation Service and Agricultural Extension Service

Table 7-2. Volumes for the second stage of two-stage lagoons.

Use Table 7-1 to size the first stage of a two-stage lagoon. Second stage lagoons are not as dependent on climate as first stage lagoons. This table is for typical Midwest climate where evaporation is about equal to rainfall. Provide an extra 1'-2' of depth if rainfall greatly exceeds evaporation in your area. Always provide 1'-2' of freeboard.

7-2a. Individual animals.

Animal	Weight, lb	ft ³ /hd
Sow and litter	400	345
Prenursery pig	20	16
Nursery pig	55	36
Growing pig	115	75
Finishing pig	190	125
Gestating sow	325	105
Boar	400	130

7-2b. Swine operations.

Based on 16 pigs sold per productive sow-yr. Lagoon volume per productive sow accounts for all animals in the operation such as pigs in nursery, growing, etc. and boars.

Operation	ft ³ /p/g sold-yr	ft ³ /productive sow
Feeder pigs produced, sold at 50 lb	—	300
Pigs fed, 50-220 lb	40	—
Farrow to finish	50	750

personnel can evaluate your soil. Avoid a site where the bottom of the lagoon would be less than about 20' above limestone, depending on soil type. Remove any field tile in the area.

Lagoons on some soils require sealing with liners, clay, or soil cement. Sealing may be accomplished biologically—animal waste solids are a good sealant in many soils, but this process takes time. Clay or soil cement delays leaking while biological sealing develops. Membrane sealing (plastic, vinyl, rubber, etc.) is positive and effective, but is expensive and difficult to install.

Consult your Agricultural Extension Service or state health or pollution control authorities for regulations governing the location of lagoons relative to wells. If the lagoon must be built near a locally recharged shallow well, the bottom of the well must be higher than the top of the lagoon.

Inlets and outlets

Extend lagoon inlets beyond the cut slope of the embankment to reduce erosion and to uniformly distribute the waste load. A lagoon freezes over in very cold weather. If this is likely, either avoid direct loading, or allow enough storage capacity above ice level. With an exposed inlet, increase inlet height to leave room above the ice for winter manure. Or, provide separate manure storage until the lagoon thaws. See Fig 4-9 for inlets. When planning diversions for surface water, consider that some surface water may be needed for dilution. Locate pumping outlets for irrigation away from inlets to reduce transfer of unliquefied solids.

Shape

Build single stage lagoons approximately square or round to provide roughly uniform loading over the lagoon area, and to allow economical construction and maintenance. Build each stage of a multi-stage lagoon no more than 5 times as long as wide. Install inlets and outlets at the ends to ensure transferring only wastes that have been in the lagoon for the design detention time. Make the lagoon as deep as practical to limit area needed, to reduce the surface area producing odors, and to increase vertical mixing of lagoon contents. A berm or dam width of at least 12' is needed for machine operation.

Management

Fill a new or recently cleaned lagoon $\frac{1}{3}$ to $\frac{1}{2}$ full with water. Add manure regularly, frequently, and in increasing amounts. It is best to start loading in the spring, so several warm months of bacterial action can ensure good operation. After the lagoon is filled to its design level, divert surface water away to prevent overflow. Maintain the lagoon depth at the design level.

It is very important to load lagoons continuously—put manure in at least once a week, with once a day recommended. "Slug loading" (large amounts of manure loaded at extended intervals) causes a rapid increase in volatile acids, lowered pH, and high odor. If slug loading is unavoidable, consider a holding tank that can be slug-loaded and emptied gradually into the lagoon.

If the manure contains bedding, which is slow to decompose, allow for additional sludge accumulation. Remove sludge when it causes the lagoon to be inefficient. Apply sludge to land, avoiding runoff; plowing under or soil injection is recommended.

Keep arsenic, copper, antibiotics, and other toxic feed additives out of the lagoon or at a minimum, because they may retard biological activity.

With good management, and if design loading rates are not exceeded, lagoons usually establish equilibrium in about 2 yr and operate consistently. Odors are usually stronger during spring warm-up. If odors are a problem, take lagoon liquid samples frequently to measure pH. If pH is below 6.7, add hydrated lime or caustic soda (lye): 1 lb/1,000 ft² of lagoon surface each day until the pH is neutral (pH = 7). Even with normal pH of 6.7 to 7.2, the lagoon can have excess odorous volatile acids. The spring warm-up period can be shortened by agitating the lagoon on warm days.

During the winter, when digestion in the lagoon is very slow, store or haul as much manure as possible to reduce the load on the lagoon.

Irrigate from the lagoon when winds can carry odors away. The best time to irrigate with lagoon effluent is in the fall after crop removal and early in the spring before the lagoon temperature rises significantly. Odor should be minimal at these times of the year.

When irrigating lagoon water, place the inlet near the bottom to lower the solids content of the lagoon, to move more nutrients to the crop, and to reduce sludge

buildup. With two stage lagoons, irrigate from the first stage, then refill the first lagoon to its operating depth from the second lagoon.

Use gravel rip-rap around the waterline on steep banks to prevent erosion. Control weeds around the water's edge to control mosquitos. Remove vegetation for 3' above and below the waterline. Herbicides can destroy weeds, but use them with caution and only if necessary. Apply pesticides weekly to control insect larvae.

Install a fence to keep out animals, children, and trespassers. Post warning signs and keep the gate locked.

Keep the area neat and consider landscaping to provide an attractive farmstead. Seed the bank with low-growing spreading grasses and keep it mowed. Sheep and goats can be grazed on slopes too steep to mow if supplemental feed and water are provided.

Methane Generation

Methane can be produced from animal wastes by a biological process called anaerobic digestion. This process converts the biodegradable organic portion of animal wastes into biogas (a combination of methane and carbon dioxide). The remaining semi-solid is relatively odor free but still contains all the nitrogen, phosphorous, and potassium originally present in the animal waste. However, half of the nitrogen can be lost after 72 days of storage in a holding pond. The solid portion of the semi-solid can be separated and used as bedding.

Anaerobic digestion is a stable and reliable process, as long as the digester is loaded daily with a uniform quantity of waste, digester temperature does not fluctuate widely, and antibiotics in the waste do not slow biological activity.

Major problems with digestors include manure handling—pumping, grinding, mixing, and screening miscellaneous debris. Gas leakage (methane is explosive at 5%-15% in air) and pipe and valve corrosion have also been problems. To reduce these problems, obtain competent engineering design and purchase quality materials.

To be economical, digester capital cost must be offset by energy savings, fertilizer use, and bedding replacement. Operation size greatly affects initial capital cost per animal unit, Fig 7-2. Table 7-3 gives typical daily biogas production and fuel equivalents per 1,000 lb of animal body weight.

Composting

Composting is a biological process in which organic matter (volatile solids) is degraded to a relatively stable humus-like material. It can be either anaerobic or aerobic, but modern composting is usually limited to aerobic systems.

Objectives of composting are to:

- Stabilize putrescible organic matter.
- Kill pathogens and weed seeds.
- Conserve the nitrogen, phosphorus, potash, and resistant organic matter found in the raw material.

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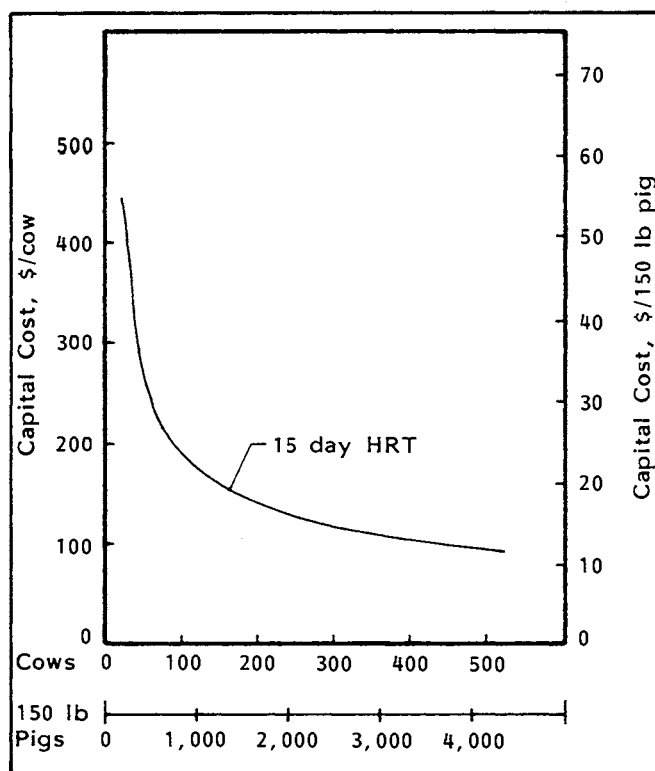
Table 7-3. Typical net^a biogas production and fuel equivalents.

These values are from well managed commercial scale digesters. Biogas production rates 50% of these values have also been reported.

Animal	Biogas production ft ³ /day-1,000 lb bodyweight	% methane	Heat value Btu/day	Fuel equivalent			
				Propane gal/day	Natural gas ft ³ /day	Diesel fuel gal/day	Electricity ^b Kw-hr/day
Dairy	39	54	20,700	0.22	21	0.14	1.21
Beef	22	53	11,700	0.13	12	0.08	0.68
Swine	28	58	16,400	0.18	16	0.11	0.96
Poultry							
Layers	37	60	22,700	0.25	22	0.16	1.33
Broilers	51	60	30,400	0.33	31	0.21	1.78

^aAbout 1/3 of the energy from methane production heats the digester and operates pumps and mixing equipment.

^bWhen methane is burned in an internal combustion engine to drive an electric generator, the conversion efficiency is about 20%.

**Fig 7-2. Typical capital costs of plug flow digestors.**

HRT = Hydraulic retention time = digester volume ÷ inflow rate of animal wastes.

A plug flow digester is a relatively low cost alternative. From NRAES-13, *Methane Technology for Agriculture*.

- Produce a uniform, sterile, relatively dry end product, free from odors.
- Conduct the process free from insects, rodents, and odors, and as inexpensively and dependably as possible.
- Produce a valuable fertilizer and soil conditioner.

Composting is a biological process, so environmental factors influence organism activity and determine the speed and extent of the composting cycle. The most important factors are material particle size, moisture content, aeration, temperature, and initial carbon-nitrogen ratio. Ideally, the smaller the particles, the greater the surface area, and the more access for the degrading organisms. Particle size may need to be reduced by grinding, such as crop residues like corn stalks.

The moisture content for optimum composting is 50%-60%, depending on particle size and aeration. If aeration is maintained, the moisture content can be above 60%. At high moisture content, voids fill up with liquids, and aeration is hindered. Low moisture levels retard or stop microbial activity, although some composting occurs with moisture as low as 25%.

If adequate aeration can be maintained despite high moisture content, fresh animal manures can be composted directly because of favorable particle size. Overaeration has no advantage and tends to reduce temperatures.

Aeration can be accomplished by forced air or turning. Commercial systems usually put the compost in 6'-8' high windrows which are turned at 1 to 60 day intervals to aerate the mixture.

High rate composting in a large rotating drum is another common method. Forced air is supplied to drums up to 12' in diameter and 8' long. The material rolls in these drums for 2 to 10 days.

High temperatures are sustained long enough in most operations to destroy pathogens, weed seeds, and insect eggs and larvae. Generally, the interiors of compost piles reach these elevated temperatures but not the outer surfaces. Turning the pile mixes the two areas.

Composting also depends on microbe food and nutrient supplies. Mineral content of livestock wastes is usually adequate. Carbon is an energy source, and with nitrogen also builds protoplasm. More carbon than nitrogen is required, but activity decreases with too much carbon. The proportion of carbon to nitrogen is the C/N ratio. A C/N ratio of 30:1 is about optimum for rapid composting.

If all other factors are near optimum, composting time varies with C/N ratio, Table 7-4.

Table 7-4. Composting time based on C/N ratio.

C/N ratio:	20	20-50	78
Days required:	12	14	21

With C/N ratios lower than 20, nitrogen is lost during composting and escapes as ammonia. In animal manure, the C/N ratio is usually 10-15:1. Composting animal manures with bedding or other plant wastes, or with municipal wastes containing large amounts of paper, has been successful.

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If the pile does not reheat after turning, the process is complete. Finished compost is dark brown to black in color, practically insoluble in water, has a slightly earthy to musty odor, and has a loose friable texture.

Composting, though sometimes expensive, degrades organic material to an inert humus with some fertilizer value. Usually composted livestock manure contains 0.5% nitrogen, 0.4% phosphorus, and 0.2% potassium. While not rich in fertilizer value, the material is odorless, sterile, and weed free. Adding compost improves soil moisture retention of light soils and pore volume of heavy soils. Compost-improved soils have a relatively stable structure and are erosion resistant.

Deep Pit System for Poultry Wastes

Deep pit systems can yield a solid manure from hens and started pullets. It is necessary to prevent waterers from leaking so the manure remains dry enough to handle as a solid. Dry manure collects in 8'-10' deep pits under the cages until cleaning is required. See Fig 7-3 for an example layout.

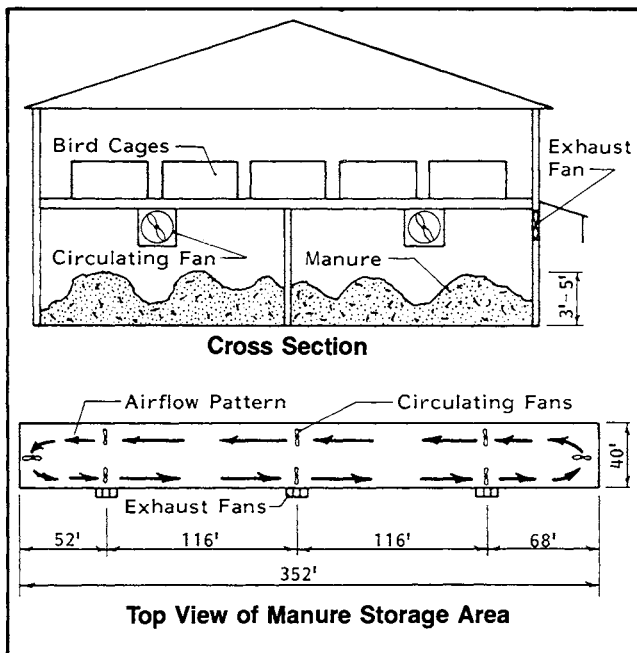


Fig 7-3. Typical high-rise poultry building.

Bird Density

The trend in housing laying hens has been to increase bird density, birds/ft², which results in more odor and difficult-to-handle manure. Presently with densities of 2 to 3 birds/ft² for a high-rise house, the

manure is dried to a moisture content of 50% or less, which gives few odor and handling problems. However, as the trend continues to triple-deck systems with densities of 5 or more birds/ft², manure does not dry below 50% moisture.

System Design

With sufficient air velocity in the manure area, ridges form under the cages and the manure is dried enough to handle as a solid, Fig 7-4. Exhaust building ventilating air through the pit and install circulation fans in the pit, Fig 7-3, to achieve the proper air velocity.

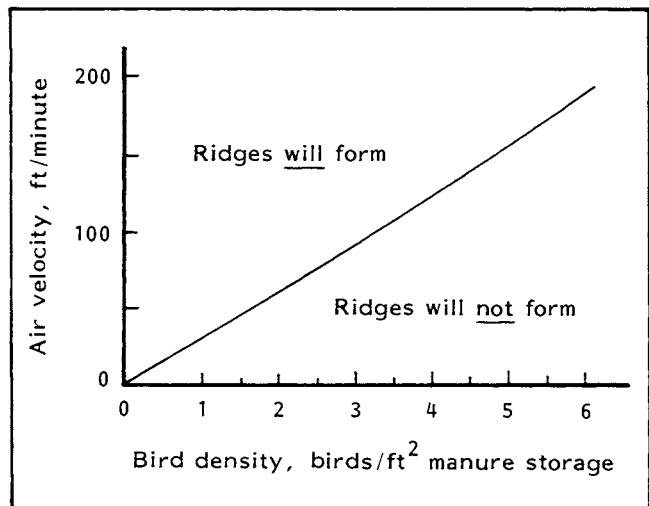


Fig 7-4. Conditions for manure ridge formation. In a high-rise poultry house.

Keep all extra water out of the pit. Faulty waterers and inadequate drainage away from the pit increase moisture content of manure which increases cleaning and odor problems. Check waterers and pipes frequently for leaks or malfunction. Also, high manure moisture content slows the volume reduction rate, which leads to more frequent cleanout. Install drain tile around the outside of the foundation to a positive outlet or sump. Use concrete for the pit floor if it is below grade. With a high water table, build the storage partly or wholly above ground to reduce groundwater problems. Design and construct pit walls as for other manure storages.

Stirring the manure increases drying and composting, especially in houses with high bird density. A time clock-operated rake dragged through the pit on a cable stirs the droppings. The rake can be adapted to scrape for building cleaning. Arrange facilities and management schedules for emptying the pit after each laying cycle.

8. PUMPS

Pump Selection

Solids content and required pumping pressure are the major factors in selecting a waste handling pump, Table 8-1. Selecting the correct pump for the job improves performance and reduces repairs.

- **Solids content** varies with livestock type, housing, and waste collection system. Fewer pumping problems result if solids are settled out (as in a lagoon) or if dilution water is added (as by rain on a feedlot). Table 8-2 has estimates of solids content for various livestock waste systems.
- **Pressure** requirements vary considerably with the application—sprinkler irrigation requires high pressures; others only need to lift waste 10'-20' to a manure tanker or earth storage.

Table 8-2. Solids in liquid waste handling systems.

System	Solids content, %
Manure pit	
Swine	4-8
Cattle	10-15
Holding pond	
Pit overflow	1-3
Feedlot runoff	less than 1
Dairy barn washwater	less than 1
Lagoon	
Single or first stage	
Swine	½-1
Cattle	1-2
Second stage	less than ½
Flushing waste	½-2

Table 8-1. Waste handling pumps.

Pump type	Maximum solids content %	Agitation ability	Agitation range ft	Pumping rate gpm	Pumping head ft of water	Power requirements hp	Applications
Centrifugal							
Open & semi-open impeller	10-12	Excellent	50-75	1,000-3,000	25-75	65 +	Gravity irrigation Tanker filling Pit agitation Transfer to storage
Vertical shaft chopper							
Inclined shaft chopper	10-12	Excellent	75-100	3,000-5,000	30-35	60 +	Earth storage agitation Gravity irrigation Tanker filling
Submersible transfer pump	10-12	Fair	25-50	200-1,000	10-30	3-10	Agitation Transfer to storage
Closed impeller	4-6	Fair	50-75	500 +	200 +	50 +	Recirculation Sprinkler irrigation
Elevator	6-8	None	0	500-1,000	10-15	5 +	Transfer to storage
Helical screw	4-6	Fair	30-40	200-300	200 +	40 +	Agitation Sprinkler irrigation Transfer to storage Holding pond and lagoon pumping Tanker filling
Piston							
Hollow	18-20	None	0	100-150	30-40	5-10	Transfer cattle manure without long fibrous bedding
Solid	18-20	None	0	100-150	30-40	5-10	Transfer cattle manure with unchopped bedding
Pneumatic	12-15	None	0	100-150	30-40	—	Transfer to storage
Self loading tanker							
Centrifugal, open impeller	6-8	None	0	200-300	N/A	75 +	Tanker loading
Vacuum pump	8-10	Poor	20-25	200-300	N/A	50 +	Tanker loading

Centrifugal Pumps

Centrifugal pumps are not positive displacement—the impeller can slip in the liquid. This feature permits some flowrate control by valving down the discharge side.

Centrifugal pump performance depends on the pump impeller design, Fig 8-3. Closed impellers are efficient with water but cannot handle liquids with large solids. Closed impeller pumps develop high

pressures and are good for irrigating and recirculating water from a lagoon or pumping settled runoff.

Semi-open impellers have a plate or shroud on only one side of the impeller and handle water with some larger solids, e.g. pumping from a first stage cattle lagoon or unsettled lot runoff. Open impeller pumps handle liquids with up to 15% solids. They often have a sharp rotating blade at the pump inlet to chop large material such as bedding, hay, or silage, Fig 8-1. The larger the pump size, the larger the

solids particles it can pump. Open and semi-open impeller pumps are sometimes called trash pumps and may or may not develop enough pressure for sprinkler irrigation systems.

Most centrifugal pumps for handling livestock waste are self-priming. But for liquids with high solids content, foot valves can leak, requiring hand priming. Avoid priming problems by installing pumps below the reservoir level.

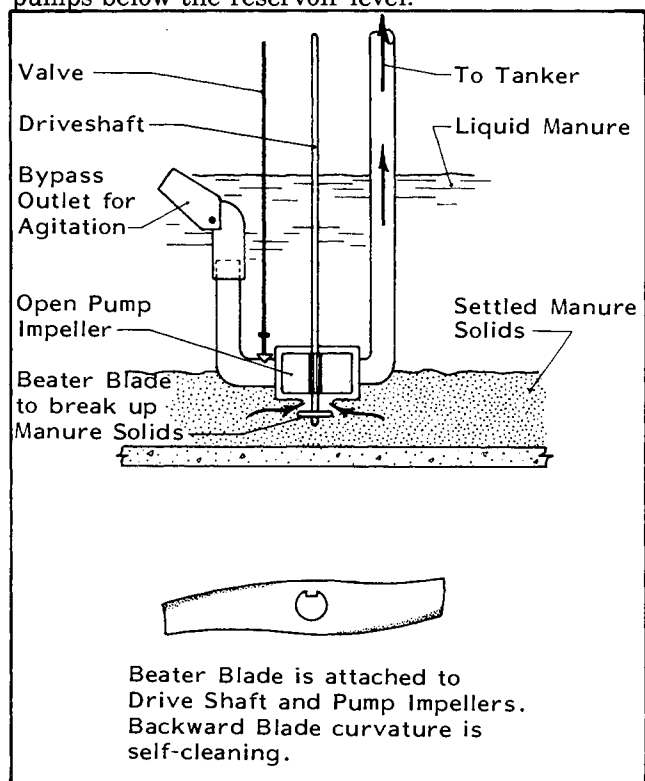


Fig 8-1. Open impeller chopper-agitator pump.

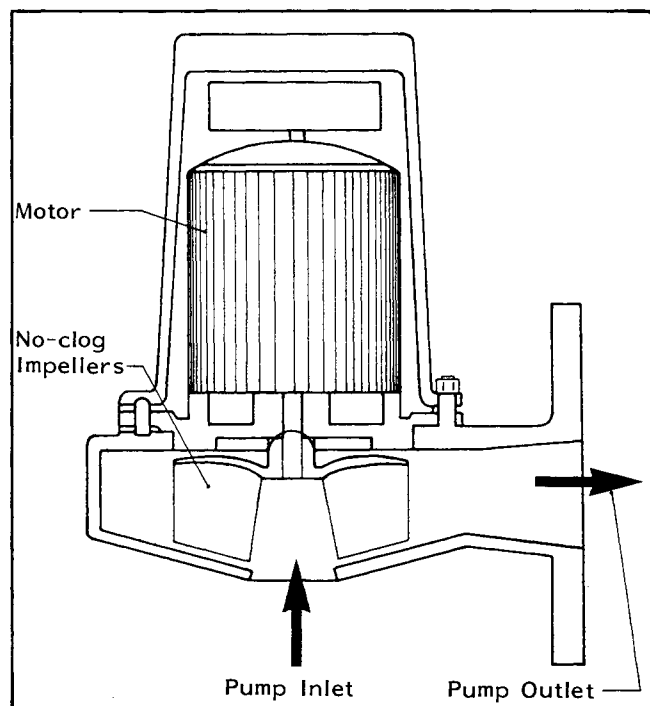


Fig 8-2. Cross section of a submersible sewage lift pump.

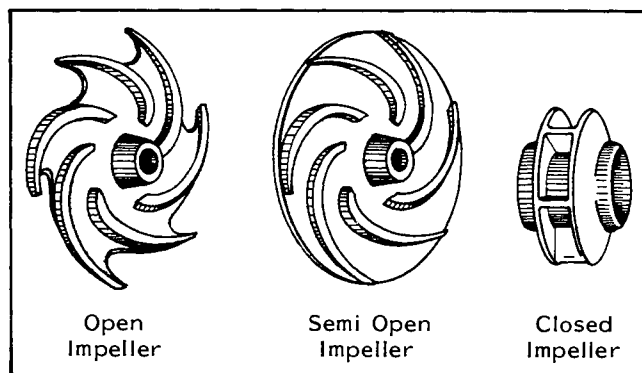


Fig 8-3. Centrifugal pump impellers.

Screw Pumps

Positive displacement screw or rotary pumps handle liquids with high solids content, but they must be free from hard and abrasive solids such as nails, stones, and ID tags. The most common screw pump for livestock waste is the helical screw, Fig 8-4.

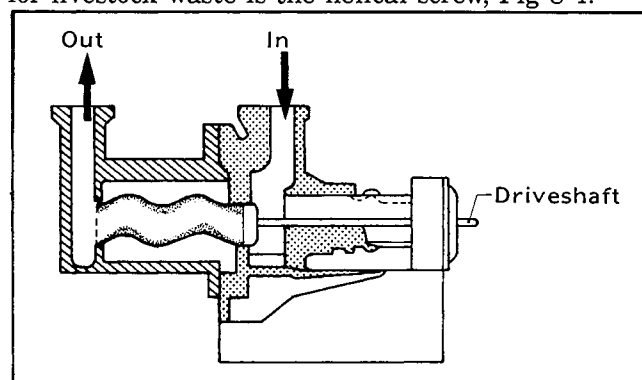


Fig 8-4. Helical screw rotary pump.

Do not operate these pumps dry—add a small stream of fresh water directly into the pump casing during operation. With positive displacement pumps, monitor line pressure when sprinkler irrigating directly out of liquid manure pits. If irrigation nozzles plug, pressure buildup can burst pipes.

Piston Pumps

Piston pumps transport manure from cattle barns to outside storage. They can handle liquids high in solids—up to whatever can flow or be pushed into the pump inlet.

Piston pumps have positive displacement and pulsating discharge. Except for leaks or bypasses, the piston or plunger capacity equals the piston area times the stroke length.

Piston pumps generate very high pressure if the discharge pipe is plugged. However, relief valves are seldom used to protect manure pumps, because the discharge piping is large (10"-15") and seldom plugs. Piston pumps are usually hydraulic driven and have stalling pressures many times higher than their normal discharge pressure.

A tractor, automatic scraper, or gutter cleaner can scrape the manure into a below-grade hopper. Manure flows by gravity from the hopper to the piston

chamber. One-way check valves at the piston chamber exit prevent manure from backing up into the pump.

There are two piston types—hollow and solid. Hollow pistons handle fairly dilute manure while the more expensive solid ones handle manure with large amounts of bedding.

Hollow pistons are rectangular (from 8"x8" to 8"x12") and run in a loose fitting square cylinder at the base of a sloping hopper, Fig 8-5a. They have a flap valve on the end of the piston. On the return stroke, the flap valve opens and manure in the hopper flows through the piston as it is pulled up into the hopper. On the down or pumping stroke, the piston flap valve closes and manure is pushed through the cylinder, past the cylinder check valve, and into the underground pipe. When the piston begins the return stroke, the manure in the pipe is prevented from backing up by the check valve.

The piston drive unit is above floor level for easier service. It usually has a 7½ to 10 hp electric motor. The piston is driven by a connecting rod running in the manure hopper. The connecting rod movement helps manure flow to the piston, but straw or other large material can build up around it.

Solid piston manure pumps have round, square, or triangular pistons. The piston lines up with the transport pipe and is at the base of a hopper. The solid piston pulls back through the loading hopper and manure falls in front of it. Also, the close fitting piston creates a vacuum in the cylinder on the return stroke, helping to pull waste down into the cylinder. On the forward stroke, the piston pushes the manure into the cylinder and out through the underground pipe to storage, Fig 8-5b. The check valve prevents material from flowing back from the pipe.

Solid pistons are usually operated by a hydraulic cylinder, a hydraulic pump, and a 7½ to 10 hp electric motor either in the pit or on the barn floor. This pump handles long straw bedding, because the manure does not go through a piston or around connecting rods.

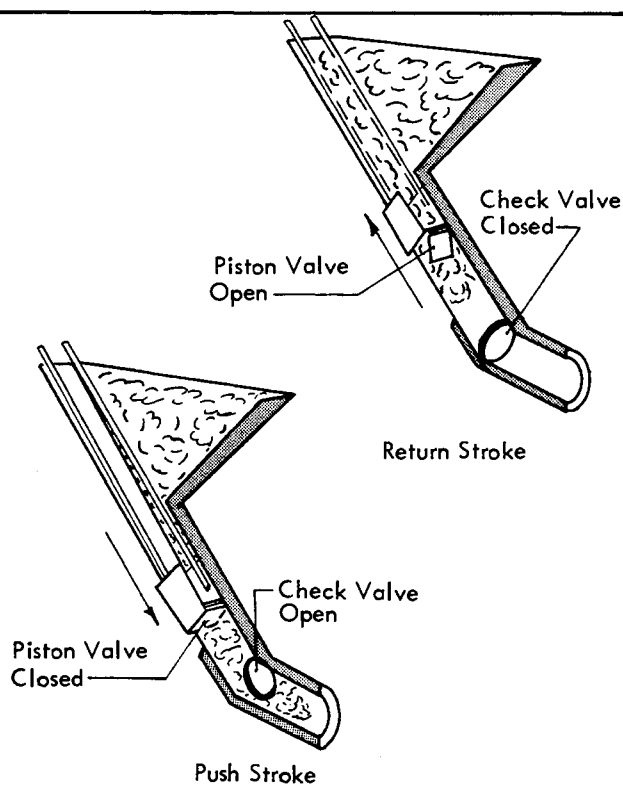
Air Driven Pumps

Vacuum tank wagons and pneumatic manure pumps are two types of air driven pumps for livestock waste.

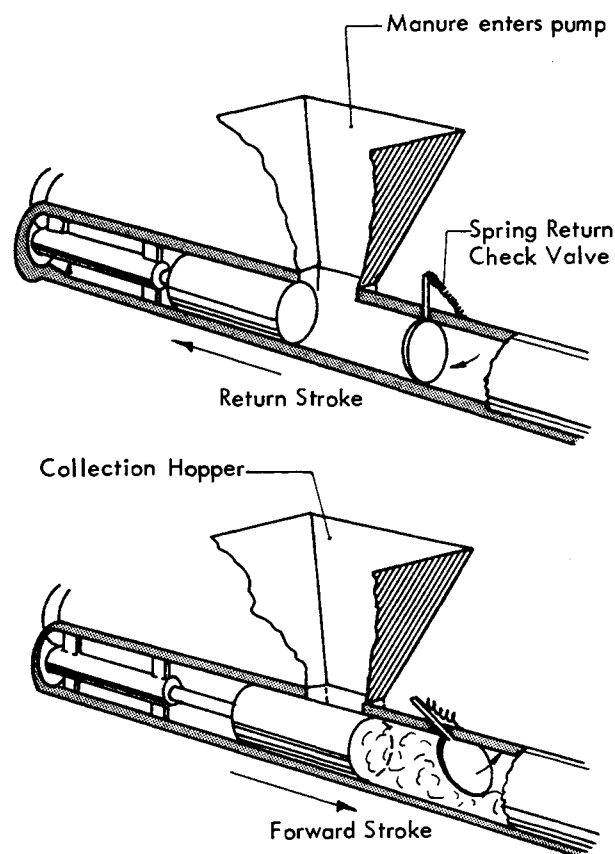
Vacuum tank wagons are filled by suction developed by a PTO driven vacuum pump. In many vacuum tanks, the pump can also pressurize the tank to improve unloading. Vacuum tanks pump liquid manure with up to about 10% solids.

Common tank wagon capacities are 800 to 4,500 gal. Tractor power required for vacuum tanks depends on tank size and field spreading conditions. The vacuum pump needs only about 10 hp. Typically, the filling rate is 500 to 700 gpm, when loading liquid manure from below-ground storage. Vacuum pumps generally can not pump manure higher than 12'.

Manure pits can be agitated by filling the tank wagon and discharging back into the storage. However, agitation by a vacuum tank wagon alone is not



8-5a. Hollow piston pump.



8-5b. Solid piston pump.

Fig 8-5. Piston pumps.

adequate where heavy floating crusts form or where settled solids become relatively dense.

Pneumatic manure pumps have a large (about 1,500 gal) underground steel holding tank and a supply of compressed air, Fig 8-6. Manure from a gutter cleaner or tractor scraper collects in the tank. To empty the holding tank, the loading hatch is closed manually or with an air cylinder, and compressed air is pumped into the top of the holding tank. As pressure in the tank builds up, manure is forced out of the tank through a large underground PVC pipe to storage. The tank outlet has a flapper valve to prevent backflow. Enough air is required to move the manure and to supply leaks around the loading hatch.

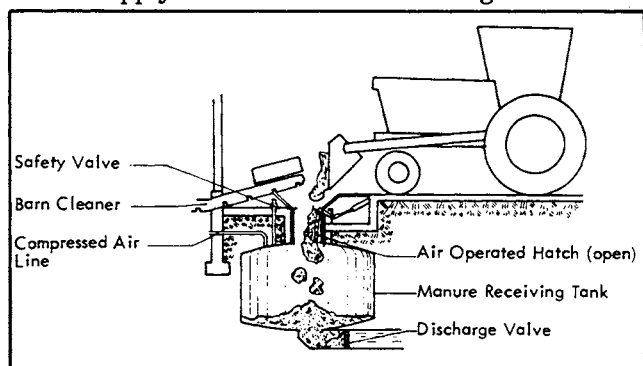


Fig 8-6. Pneumatic manure pump.

Agitation Pumps

Agitation pump types include open impeller centrifugal chopper-agitators and inclined propellers. They can pump liquid manure with fibrous solids up to about 15%.

The pumps agitate by recirculating the liquid back into the storage through an agitator nozzle, Fig 8-7. The stream from the nozzle breaks up the surface crust, stirs up settled solids, and makes the manure a more uniform slurry. Most chopper-agitator pumps can effectively agitate up to about 40' from the pump. Some commercial auger and propeller devices agitate but do not empty the storage.

Chopper-agitators pump 1,000 to 3,000 gpm. Some smaller ones can develop the high pressures needed for sprinkler irrigation. These dual purpose pumps are discussed further in the section on irrigation pumps.

Power requirements for chopper-agitators depend on pumping pressures and capacities—20 hp for some to over 75 hp for larger capacity pumps.

Agitation characteristics of manure vary with feed ration, amount of drying before manure enters the tank, and storage time. Liquid swine manure is easier to agitate than cattle manure. Heavier solids settle and pile up near where they are deposited, such as along feed bunks. Lighter solids float, dry out, and become caked.

Agitate and pump as much manure out of storage as possible, then agitate remaining solids and dilute if necessary. Diluting wastes to 90% water or more is often required. Many cattle barns with slotted floors

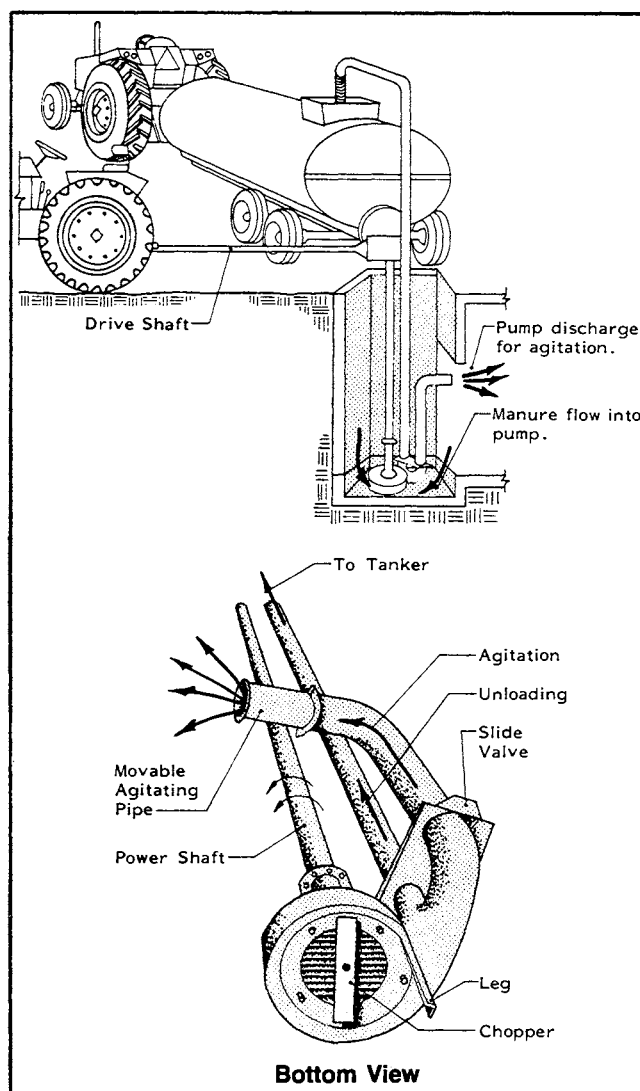


Fig 8-7. Agitating with submerged centrifugal pump. With chopper blade.

divert roof runoff into the storage pit. The main disadvantage of dilution water is the larger volume to handle.

Gases escaping from agitated manure can be deadly to animals and humans. Operate all ventilating fans and open doors and windows when agitating and unloading manure storages. Remove animals if possible.

Irrigation Pumps for Semi-Solids

Wastes with 10% or less solids are satisfactorily pumped through long pipelines, sprinklers, and gated distribution pipe. Some agitation before or during pumping helps keep solids in suspension and breaks up larger solids that might clog nozzles, gates, or intakes.

For irrigating semi-solids, semi-open impeller centrifugal and screw-type pumps are common. Many of these pumps handle semi-solids with more than 10% solids, but the high pipeline friction losses

usually make pumping these high-solids slurries impractical. Irrigation pumps work against fairly high pressures, especially with sprinklers. Sprinklers are usually the big gun-type with $\frac{3}{4}$ " and larger nozzles, requiring pressures of 80 psi or more, and pumping rates of 100 to 800 gpm.

Irrigation Pumps for Low Solids Wastes

Effluents from waste lagoons, feedlot runoff holding ponds, and milk houses (less than 3% solids content) can often be handled by conventional irrigation pumps and equipment. Single stage, standard closed impeller centrifugal pumps work well. Semi-open impeller pumps are sometimes desirable to reduce clogging. Screen out large solids at the pump inlet.

Smaller sprinkler nozzles handle these effluents because solids content is lower. There is little clogging at these low solids contents, so gated or perforated pipe distribution is practical, allowing lower pumping pressures.

Flushing and Recirculating Pumps

Size pumps that recirculate lagoon effluent to barn flushing systems large enough to fill the tanks in less than 30 min. Submersible sewage pumps designed for continuous duty work well. Install the pump and pipes so they drain completely when the pump shuts off. Pumps can be manually or timer controlled. Design the flush tank to overflow into the gutter when filled rather than using float valves.

A lagoon-to-flush tank pump can be on the lagoon bank in an insulated enclosure or in a dry well sunk in the bank, Fig 8-8. Protect the pump and pipes from freezing.

Put the intake at least 18" below the lagoon surface, with the intake several feet from the bank and as far away as practical from where wastes enter the lagoon.

Salts in lagoon water create numerous problems because they are corrosive and build up, especially on metal parts. It is best to avoid salt buildup through proper design and lagoon dilution.

- Avoid metal pipes and fittings in contact with the lagoon water. Ground metal pump housing to prevent an electrostatic charge from building up. Even if the pump is grounded through the electrical system, ground the pump with a cable from the pump housing to a ground rod driven into damp soil.
- Avoid sharp turns in the supply pipe, because they add to pressure drop and create turbulence conducive to salt buildup, especially in small pipes. Make the pump suction pipe one standard size larger than the pump discharge pipe. Minimum pipe diameter is $1\frac{1}{2}$ ".
- Locate the pump below or as close to the lagoon water level as possible to reduce the suction lift.
- Consider oversizing the pump and supply piping system, operating it on a timer, and allowing the system to drain when not in use. While more

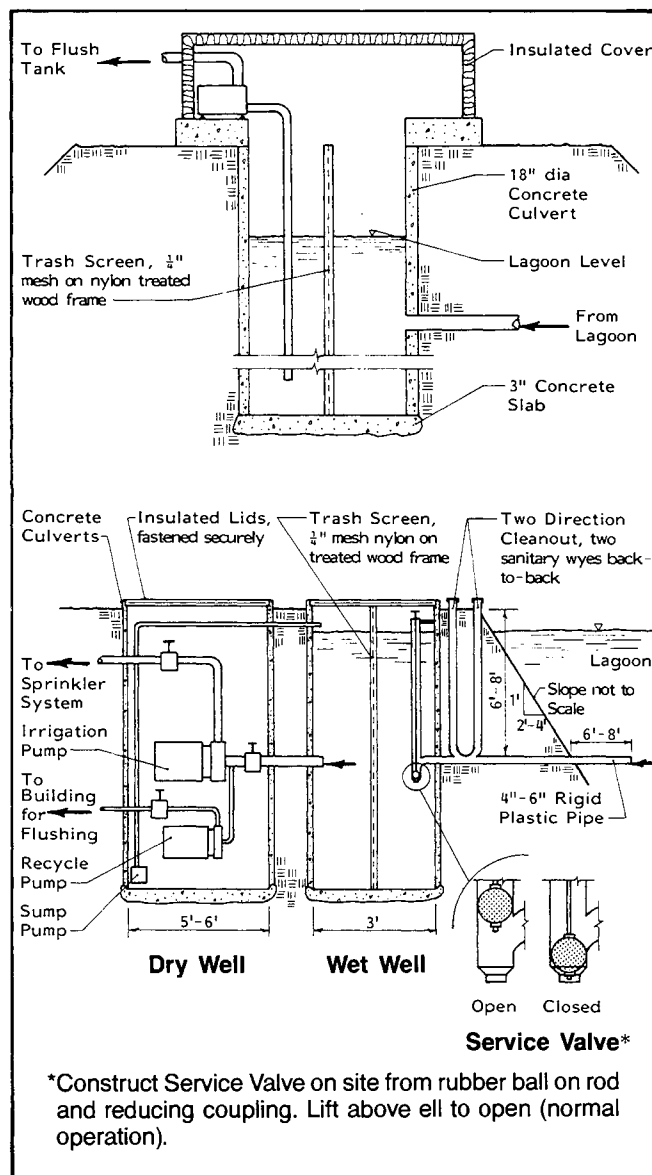


Fig 8-8. Lagoon-to-flush tank pump locations.
Use PVC plastic plumbing.

expensive to purchase, contact time between the pump and pipes and the lagoon water is greatly reduced.

- Add dilution water to the lagoon regularly and remove salts by irrigation.

Dilute acetic or hydrochloric (muriatic) acid can dissolve salt deposits in pumps and pipes. Muriatic acid is usually available in paint stores at 20% solution. Clean plastic pipe by filling the piping system with this undiluted 20% muriatic acid solution, letting it stand overnight, and then flushing the acid solution through the system into the lagoon. If the flush system has metal parts such as pump housing or metal pipes, dilute the acid (1 part acid to 12 parts water) to prevent damage to the metal. Mixing and using acid is hazardous and must be done with caution. **Do not add water to concentrated acid when making the dilution. Always add the concentrated acid to water—slowly.**

Sumps and Sump Pumps

Pumps in sumps handle livestock wastes where the fall is insufficient for gravity transport. Examples include raising flushed waste to storage and lifting waste to cut-and-fill (liquid above surface grade) lagoons. Select pump capacity and sump size together—with the same inflow, a larger pump is needed with a smaller sump, Table 8-3. For handling livestock wastes, pumps are usually designed to empty sumps in less than 5 min to prevent solids from settling out. The type of pump depends on the amount of solids in the liquid. They are usually low head pumps with a lift of 20'-30'.

To lift effluent from building to lagoon, use a commercial grade sewage lift pump activated with a mercury float switch. A 3" pump is satisfactory for most operations. Size the pipe that runs from pump to lagoon the same as the pump discharge to prevent solids from settling in the pipe. For flushing systems, size the sump no larger than the largest flush tank to avoid solids settling.

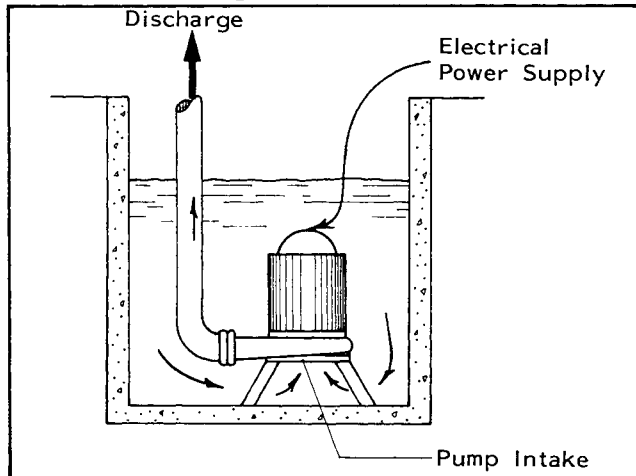


Fig 8-9. Sump with sewage lift pump.

Table 8-3. Round sump volumes.

Sump diameter, ft	Volume gal/ft of depth
1	6
1½	13
2	23
2½	37
3	53
3½	72
4	94
4½	119
5	147

Pump Controls

A float switch turns a pump motor on or off depending on liquid level. One type has a metal float and rod which moves up and down through guides to open and close contacts. Another has rubberized floats with mercury switches that open and close as the float tilts up and down with water level. Some pressure-sensing and float devices are built into the pump. Avoid pressure-sensing switches for livestock wastes because they can be affected by settled solids.

Pump and motor protection devices may also be required to protect pumps and power units against plugged pipes or nozzles, loss of prime, overheating, and lubricant loss. Match safety sensors and controls to pump, motor, and system types. Safety devices include temperature and pressure gauges, fuses, circuit breakers, and pressure switches. For internal combustion engines, consider safety cut-off gauges for coolant temperature, low oil pressures, and low system pressure. Protect electric motors from overload, lightning, and low system pressure.

Pressure surges in the discharge pipe (water hammer) are often a problem in starting irrigation pumps. Make sure a valve is open in the pipeline when pressurizing. Always increase the speed slowly with internal combustion engines.

Pump Power Supply

Power requirements:

Eq 8-1.

$$HP = (QG \times P) \div (3,960 \times PEFF)$$

HP = horsepower

QG = pump discharge, gpm

P = pressure, ft of water

PEFF = pump efficiency, %

or

Eq 8-2.

$$HP = (QF \times P) \div (8.8 \times PEFF)$$

QF = pump discharge, cfs

P = pressure, ft of water

PEFF = pump efficiency, %

Most centrifugal pumps are 60%-70% efficient if properly selected and operated. Pump head, capacity, and efficiency all decrease for viscous (thick) liquids. Table 8-4 lists power requirements.

Increase the size of power units rated for water capacity by at least 10% for increased friction losses and increased specific gravity of livestock wastes. Select pumps adequate for the flow and pressure of your system. Irrigation pumps can handle livestock wastes with only a few solids.

Table 8-4. Horsepower to pump water.

Pump efficiency assumed to be 65%. The table values are for power delivered to the pump shaft. Select engines rated at a higher horsepower. Multiply the table values by the following values to determine the required engine horsepower rating:

air-cooled gasoline, 1.54; liquid-cooled gasoline, 1.33; diesel, 1.18; electric motor, 1.00.

For example, a liquid-cooled gasoline engine pumping 300 gpm at 100 psi would have to be rated at least at:

$$27 \text{ hp} \times 1.33 = 36 \text{ hp}$$

Feet of water: lb/in ² (psi):	Pressure				
	115	172	230	287	345
Discharge gal/min (gpm)	50	75	100	125	150
100	4-5	6-7	8-9	11-12	13-14
200	8-9	13-14	17-18	22-23	27-28
300	13-14	20-21	26-27	33-34	40-41
400	18-19	27-28	35-36	44-45	53-54

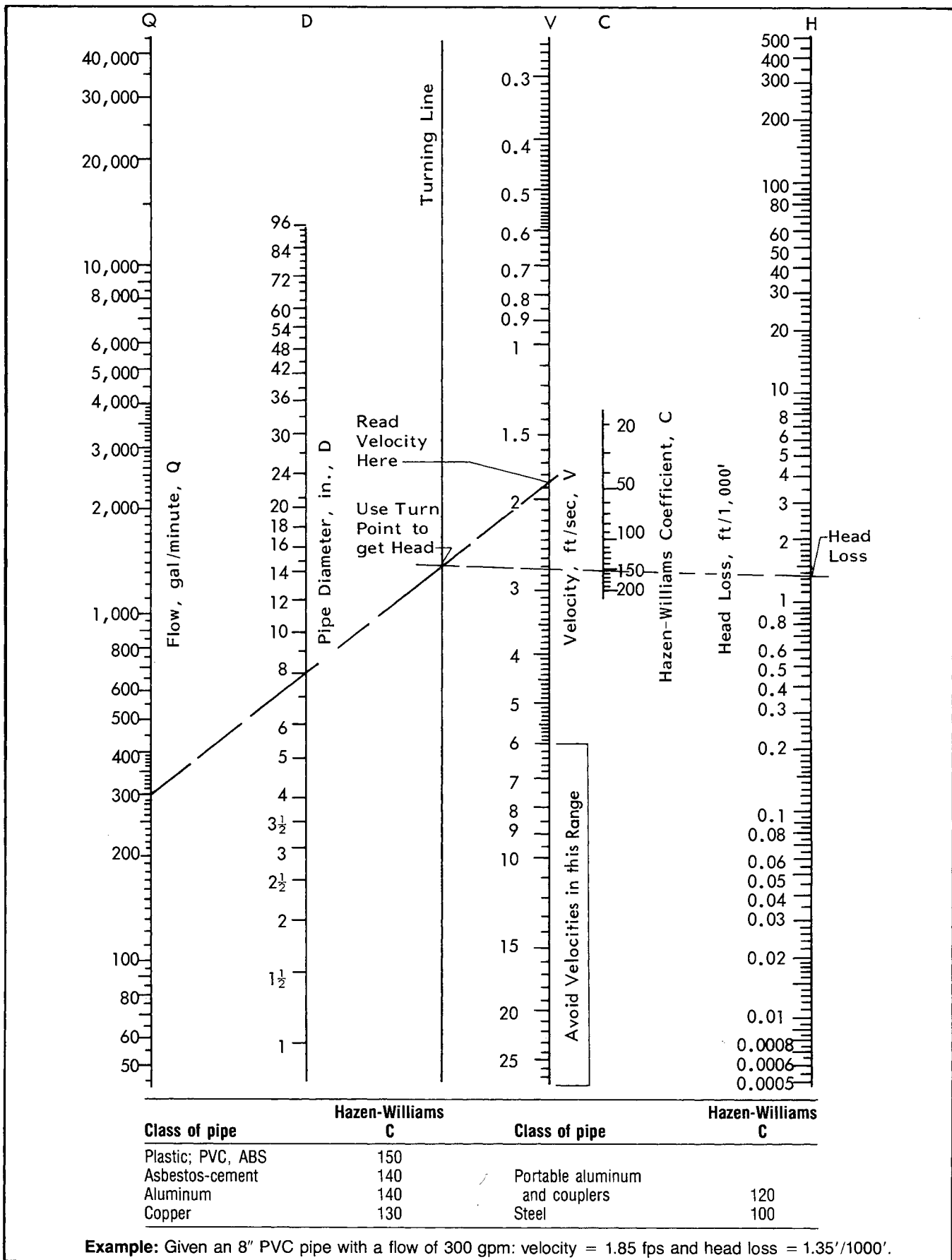


Fig 8-10. Pipe friction losses.

This chart is for water; friction is larger and flowrates smaller for manure.

Pump Bearings

Some pumps have replaceable lower wear plates. Some have oil reservoirs for the pump packing gland and shaft ball bearings. Rubber bearings are available and are suitable if the pump will never run dry or operate during freezing conditions. Although both cost about the same, oiled ball bearings usually last longer but cost more to replace than rubber.

Pipe

Small pipes in flushing systems carry dilution water to a flush tank and other low flow needs. Large pipe is for direct pump flushing of gutters, irrigation, roof and surface water control, conveying wastes to storage, and for other high flow needs.

Small pipe can be steel, copper, aluminum, or plastic. Large pipe is usually aluminum or plastic for irrigation, and steel, cast iron, plastic, or asbestos cement for culverts, drains, and other transport needs. Never bury aluminum pipe because it corrodes quickly. Exposure to ultraviolet sunlight rays make some plastic pipe brittle. Use plastic pipe from lagoon to flush tank. One continuous piece is preferred if possible. See Table 8-5 for sizing.

As water flows through a pipe, drag against the pipe wall reduces flow. The pressure needed to maintain flow is measured in feet—the pressure of a column of water of that height. Large pipe is more expensive, but has less friction per gallon and therefore uses less pumping energy. For friction loss of large diameter pipes, use Fig 8-10.

Table 8-5. Recommended pipe sizes.

For flushing and recirculating systems. Maximum flow velocity = 2.5 fps.

Pump capacity gal/min	Minimum pipe diameter in.
10	1.5
20	2.0
30	2.5
50	3.0
75	3.5
100	4.0
200	6.0
400	8.0
600	10.0
800	12.0
1,000	12.0

The pump must deliver the desired capacity against the total head. To determine total head, add friction losses due to pipe length, fittings, and orifices. Also add number of feet liquids are raised, or subtract number of feet discharge is below the inlet. If a pipe supplies nozzles, add the pressure required by the nozzle.

To convert total head in feet to pressure in psi:

$$\text{psi} = \text{ft} \times 0.434$$

Design for fluid velocities of 3 to 6 fps in pipes used for unsettled manure. At a velocity below 2 fps, solids may settle in low spots. If velocities are too high, friction loss and water hammer can be a problem. Limit velocities to 5 fps in pipe not buried or securely tied down. Flush pipelines with clean water to remove settled solids after pumping wastes.

9. LAND APPLICATION TECHNIQUES

Solid Waste

Wastes with 20% or more solids can usually be handled as a solid. Solid waste characteristics vary with the animal, ration, amount and type of bedding, time of year, and the amount of liquids separated from the solids. Manure collected in a settling basin can contain soil and debris.

Most solid waste spreaders are box-type. Others include flail-type spreaders, dump trucks, earth movers, or wagons. A spreader should distribute wastes uniformly. Front-end loaders, scrapers and blades, and several mechanical systems transport solid wastes but are not usually used for spreading.

Box-type spreaders are tractor-pulled or mounted on trucks. Pull-types have 90 to 650 ft³ capacities. On spreaders under 140 ft³ capacity, the spreading mechanism is either ground or PTO driven. Larger spreaders have PTO drives. Truck-mounted box spreaders hold 220 to 650 ft³. Spreader boxes are steel or wood and need to be watertight for road transport. Spreader mechanisms include paddles, flails, and augers. The feed apron, which moves the waste to the spreader, is often variable speed. Some spreaders have moving front-end gates that push the wastes to the spreading mechanism.

Flail-type spreaders are tanks with open tops and usually have a shaft mounted near the open top and parallel to the main axis of the tank. Chain flails on the shaft throw the wastes out the side of the spreader as the shaft turns.

Large spreader capacity reduces the number of trips to the field but can increase soil compaction. Calculate the number of trips from the amount of manure and spreader capacity.

Eg 9-1.

$$NT = MS \div SC$$

NT = number of trips

MS = manure to be spread, ft³
= AC x D

AC = area to be cleaned, ft²

D = depth of manure, ft

SC = spreader capacity, ft³

Liquid Waste

Wastes with up to about 4% solids can be handled as a liquid. From 4%-15% solids, waste is semi-liquid and can be handled as a liquid, but equipment needs differ. Fibrous materials, such as bedding, hair, or feed, can hinder pumping. Chopper pumps can cut fibrous materials for improved pumping. Piston pumps handle waste with bedding.

Liquids—Up to 4% Solids

If large quantities are handled, a pipeline may be preferred over tank wagons for transport. For example, to haul 325,000 gal (about one acre-foot of liquid)

it would take 216 trips with a 1,500 gal tank-wagon or about 12 hr of pumping plus time to and from the field. Prevent large solids such as ID tags, containers, lids, teeth, and hair from passing through the pump. Settle out solids if possible. For irrigation, provide a chopper ahead of the pump intake.

Required pump capacity is influenced by amount of wastes; time, labor, and power source available; labor and equipment costs; and for cropland disposal, the rate at which soil and crops can receive water. A small capacity pump is less expensive, but may require more labor and time than a larger pump.

See the discussion on irrigation in this section for more information.

Semi-Solids—4% to 15% Solids

Semi-solids with up to about 15% solids can be pumped. Solids and liquids separate in storage, so agitate wastes before pumping. Select power source and capacity for pumping semi-solids using the same criteria as for pumping liquids, particularly if pumping through pipes. Open impeller chopper pumps are often used to agitate semi-solids in storage.

Piston, helical rotor, submerged centrifugal, and positive displacement gear-type pumps handle heavy semi-solids against high pressures, but their performance is better if solids are below about 10%. They do not require priming and therefore adapt to automation. To pump heavy semi-solids against low pressures, use submerged centrifugal, piston, or auger pumps.

Custom Applicators

Custom applicators typically use large truck-mounted tanks with high volume vacuum agitation pumps. Most are outfitted to inject waste into the ground behind the truck. The trucks have large flotation tires to reduce soil compaction.

Custom application has the potential problem of the custom applicator not being available at precisely the time that the manure needs to be hauled. However, this is offset by the benefit of having good waste handling equipment available without the high investment and operating expenses involved in owning equipment that is used only a few days a year. While the rates charged by custom applicators vary with location, charges are usually about equal to the value of the nitrogen, phosphorus, and potassium fertilizer nutrient value contained in the waste.

Irrigation

Irrigation equipment disposes of wastes and also adds water and fertilizer to crops. Improved crop production from the water and the fertilizer value of manure can help pay for the waste disposal system. For relatively large amounts of wastes, irrigation systems are economical and labor saving.

Most irrigation systems can handle liquid wastes with up to 4% solids, which is typical of lot runoff and effluent from a lagoon, holding pond, or milkhouse. Flood irrigation and big guns can handle wastes with higher solids content.

Select a surface or sprinkler irrigation system adapted to your topography, soil, and crops. A well designed and managed system prevents runoff and erosion.

As with any waste management system, there are potential problems.

- Odor problems can be severe, depending on the waste and management.
- Application of strong wastes to crops may adversely affect plant growth or utilization.
- Fine-textured and tight soils may not have enough permeability to receive liquids rapidly.

Application Rate

Water irrigation systems apply up to 20 in/yr in at least three separate, smaller applications. The equipment is large enough to cover the entire area one set at a time and be back to the starting point before the plants are out of water.

Waste irrigation systems may apply only 1"-2" once a year, with crop water requirements not considered. Size is therefore much less critical and is more affected by the time the producer wants to spend spreading wastes. To spend 3 days instead of 3 weeks, buy bigger equipment; costs are roughly proportional to size.

To determine the in/acre applied for a given volume of waste:

Eq 9-2.

$$\text{in/ac} = \text{NG} \div (27,150 \times \text{NA})$$

in/ac = application quantity per acre, in/acre

NG = amount of waste applied, gal

NA = application land area, acres

The time required for a set (called the duration) is controlled by the application rate, soil intake rate, and the total amount of waste to be applied at that rate. A set is a strip of land as long as the lateral and as wide as the cover diameter of a particular irrigation system. For example, an application of 1.5" to a silt loam soil at 0.4 in/hr requires $1.5 \div 0.4 = 3.75$ hr duration for each set. Approximate soil intake rates for water are in Table 9-1. These may have to be reduced for some liquid wastes.

To avoid saturating the soil, estimate the percent of soil moisture content from Table 9-2. Then, from Table 9-3, estimate the maximum field capacity. For example, if capacity is 1", and you estimate the soil at 50% of field capacity, you can add ½" to the top foot of soil. Usually, waste spreading proceeds until ponding and/or runoff starts. Then discontinue in that area.

Once you have decided to irrigate for disposal and have an idea of the system you want, obtain additional help from the Extension Service, SCS, or consulting engineers. Irrigation equipment dealers and manufacturers usually provide free design service for their equipment.

Table 9-1. Maximum water application rates.

Soils usually absorb water at a faster rate if applied in light applications (¾"-1½") when soil is dry.

Soil characteristics	0%-5% slope	
	Cover	Bare
	- - - in/hr - - -	
Clay; very poorly drained	0.3	0.15
Silty surface; poorly drained clay and claypan subsoil	0.4	0.25
Medium textured surface soil; moderate to imperfectly drained profile	0.5	0.30
Silt loam, loam, and very sandy loam; well to moderately well drained	0.6	0.40
Loamy sand, sandy loam, or peat; well drained	0.9	0.60
Reduce application rates on sloping ground:		
Slope	Application rate reduction	
0%-5%	0%	
6%-8%	20%	
9%-12%	40%	
13%-20%	60%	
over 20%	75%	

Surface Irrigation

Surface spreading is an effective method of waste disposal, especially if you are already irrigating. Wastewater is delivered to the field through portable or stationary pipe and spread on fields with gated irrigation pipe, Fig 9-1a and Table 9-4, or through an open ditch with siphon tubes or turnout gates.

Surface irrigation is low cost and has low power requirements and few mechanical parts. However, it requires a high degree of management skill, is inflexible with respect to land area, and requires a moderate amount of labor. Surface systems require good design and management to avoid runoff and to get uniform distribution. Do not use them on land with greater than 2% slope. Before attempting surface spreading, contact a soil and water engineer to inspect the site and help you decide.

Dissolved nutrients enter the soil with the liquids, but solids tend to settle out or be filtered out by grass near the inlet to the field. More nutrients and somewhat more liquid are absorbed at the high end of the slope.

In **border irrigation**, an essentially level field is flooded with 3"-5" of water, which stands until it infiltrates. A small earth dike or berm borders the field. In **furrow irrigation**, the water is spread in furrows between row crops—downhill with slopes to 1% or along the contour for steeper slopes. In **corrugation irrigation**, shallow, closely spaced, V-shaped notches are tooled into a seedbed just before planting. Irregular and relatively steep land can be corrugation irrigated with grass or close growing crops, especially if the corrugations are contoured.

Table 9-2. Guide for determining soil moisture content.

Moisture condition	Percent of available moisture remaining in soil	Soil texture		
		Sand-sandy loam	Loam-silt loam	Clay loam-clay
Dry	0% Wilting point	Dry, loose, flows through fingers.	Powdery, sometimes slightly crusted but easily broken into powder. Forms a weak ball when squeezed but will not stick to tools.	Hard, baked, cracked; difficult to break into powder. Pliable, but not slick, balls under pressure. sticks to tools.
Low	50% or less	Loose, feels dry.		
Fair	50%-75%	Balls under pressure but seldom holds together when bounced in the hand.	Forms a ball somewhat plastic, sticks slightly with pressure. Does not stick to tools.	Forms a ball, ribbons out between thumb and forefinger, has a slick feeling.
Good	75%-100%	Forms a weak ball, breaks easily when bounced in the hand; can feel moistness.	Forms a ball, very pliable, slicks readily, clings slightly to tools.	Easily ribbons out between thumb and fore finger, has a slick feeling, very sticky.
Ideal	100% Field capacity	Soil mass clings together. Upon squeezing, outline of ball is left on hand.	Wet outline of ball is left on hand when soil is squeezed. Sticks to tools.	Wet outline of ball is left on hand when soil is squeezed. Sticky enough to cling to fingers.

Table 9-3. Soil moisture capacity.

Soil type	Moisture capacity in/ft of soil depth
Light sandy	1.00
Medium	1.69
Heavy	2.39

Wild flooding is more or less random. It has low initial cost, adapts to a wide range of irrigation flows, and can be used on close growing crops, rolling land, and shallow soils. However, wild flooding has a high labor requirement, uneven water and fertilizer distribution, and can cause water pollution unless carefully managed.

Gated pipelines

Design of a pipeline system includes selecting a spreading system, sizing transport pipes, and selecting a pump. The spreading system influences pump capacity and contributes to the pressure a pump works against. Pipe friction losses also contribute to the total system pressure. Total system pressure and pump capacity are calculated to complete the system design. A spreading system requiring little labor is desirable.

Sprinkler Irrigation

Sprinklers allow waste disposal on rolling and irregular land. Although initial and operating costs are generally higher for sprinklers than for surface systems, labor requirements are reduced, some systems can be automated, and application can be more uniform. Odors from sprinkled wastes can create nuisances. Avoid sprinkling on days with high humidity or when wind blows odors to areas of concern.

Select sprinklers and spacings to avoid runoff for the particular soil type, topography, crop, and application time. Select equipment to handle antici-

Table 9-4. Flowrate for gated pipe.

Maximum recommended flowrates per gate with openings spaced at 30"-40".

Q, gpm	40	25	16	12	10	5
Slope, %	0.2	0.4	0.6	0.8	1	2

pated waste particle sizes with minimum plugging and maintenance. Flushing the system with clean water after use prolongs equipment life by reducing corrosion.

Sprinkler nozzles

Sprinklers range in size up to large gun-type sprinklers with over 1" nozzles and over 1,000 gpm discharges. Discharge volume is controlled by nozzle size, number of nozzles, and operating pressure. Select a nozzle no smaller than the largest piece of waste to be discharged.

In this book, sprinkler systems generally have many smaller nozzles; big guns generally have only one larger nozzle especially designed for long throw distance.

Sprinklers have 1 to 3 nozzles. Single nozzle sprinklers perform better where wind is a problem. One large nozzle is less likely to plug than two smaller ones with the same capacity.

Table 9-5. Discharge of sprinkler nozzles.

Pressure psi	Nozzle diameter, in.				
	3/8"	1/2"	3/4"	1"	1 1/4"
	----- gpm -----				
70	33.2	—	—	—	—
80	35.7	61.6	154	264	416
100	40.7	68.9	173	296	462
120	—	—	189	324	511

Table 9-6. Discharge of big gun nozzles.

Taper bore nozzles have greatest stream integrity, longest throw distance, and minimum wind distortion. Ring nozzles have better stream breakup for lower pressure operation and delicate crops. Ring nozzles catch animal hair on the nozzle lip and plug more often than taper nozzles. Diameter is the size of the area irrigated; gpm is the application rate.

		Nozzle trajectory												
		24°						27°						
Taper bore:	0.6"	0.7"		0.9"		1.1"		1.3"		1.5"		1.75"		
Ring nozzle:	—	0.86"		1.08"		1.26"		1.41"		1.74"		1.93"		
Pressure psi	gpm	Dia. ft	gpm	Dia. ft	gpm	Dia. ft	gpm	Dia. ft	gpm	Dia. ft	gpm	Dia. ft	gpm	Dia. ft
50	74	225	100	250	165	290	255	330						
60	81	240	110	265	182	305	275	345	385	390	515	430	695	470
70	88	250	120	280	197	320	295	360	415	410	555	450	755	495
80	94	260	128	290	210	335	315	375	445	430	590	470	805	515
90	100	270	135	300	223	345	335	390	475	445	626	485	855	535
100	106	280	143	310	235	355	355	400	500	460	660	500	900	550
110	111	290	150	320	247	365	370	410	525	470	695	515	945	565
120			157	330	258	375	385	420	545	480	725	530	985	580
130									565	485	755	540	1,025	590

For approximate discharges from sprinklers with nozzle diameters from 1/8"-1 1/4", use the equation:

Eq 9-3.

$$ND = 29.84 \times d^2 \times P^{0.5}$$

ND = nozzle discharge, gpm

d = nozzle diameter, in.

P = pressure, psi

See Table 9-5 for typical discharges from sprinkler nozzles. See Table 9-6 for discharges from big gun nozzles.

Use Table 9-7 or the following equations to convert nozzle discharge to in/hr of irrigation:

Eq 9-4.

$$\text{in/hr} = ND \div (\text{acres} \times 453)$$

in/hr = application rate

ND = total nozzle discharge, gpm

acres = number of acres sprinkled

Table 9-7. Sprinkler application rate.

Sprinkler spacing ft	gpm from each full circle sprinkler						
	30	40	50	100	200	500	1,000
	----- in/hr -----						
60x60	0.80	1.07	1.34				
60x70	0.69	0.92	1.15				
60x80	0.60	0.80	1.00				
70x70	0.59	0.79	0.98	1.96			
70x80	0.52	0.69	0.86	1.72			
70x90	0.46	0.61	0.76	1.52			
80x80	0.45	0.60	0.75	1.50			
80x100	0.36	0.48	0.60	1.20			
100x100	0.29	0.39	0.48	0.96	1.93		
100x120	0.24	0.32	0.40	0.80	1.60		
150x150	0.13	0.17	0.21	0.43	0.85	2.14	
150x180	0.11	0.14	0.18	0.36	0.71	1.78	
200x200		0.10	0.12	0.24	0.48	1.20	
300x300				0.11	0.21	0.53	1.07
360x360					0.15	0.37	0.94

$$\text{in/hr} = 96 \times ND \div \text{ft}^2$$

ft² = number of ft² sprinkled

Eq 9-5.**Table 9-8. Labor and number of sets for 10 sprinkled acres.**

System	No. of sets/ 10 acres	Labor/set minutes	Labor/10 acres hr
Handmove ^a	5.5	70	6.4
Towline ^a	5.5	23	2.1
Stationary big gun ^b	4.5	70	5.2
Towed big gun ^b	4.5	23	1.7
Traveling big gun ^c	1.0	60	1.0

^a1/4 mile lateral with 60' between sets.

^b350' wetted diameter.

^c350' wetted diameter and 1/4 mile travel.

Handmove sprinklers

Handmove sprinklers have a mainline and one or more laterals, Fig 9-1b. The laterals are assembled from 20', 30', or 40' sections of aluminum pipe; sprinklers are 30' or 40' apart and cover 60'-80' circles.

As the pump runs, a strip is sprinkled as long as the lateral and as wide as the cover diameter of an individual sprinkler. That strip is one **set**. After that set is irrigated, the pump is shut off and the pipe is disassembled, moved to a new location, reassembled, and the new set is sprinkled.

With this system, a 1/4 mile lateral covers 1.8 acres with each 60' move; 32 sprinklers can discharge 10 gpm each for a total of 320 gpm pumped through 5" pipe. The application rate is 0.4 in/hr and the power requirement is about 20 hp.

Advantages:

- Low initial investment; consider a used system.
- Few mechanical parts to malfunction.
- Low power requirement (50 psi at the sprinklers).

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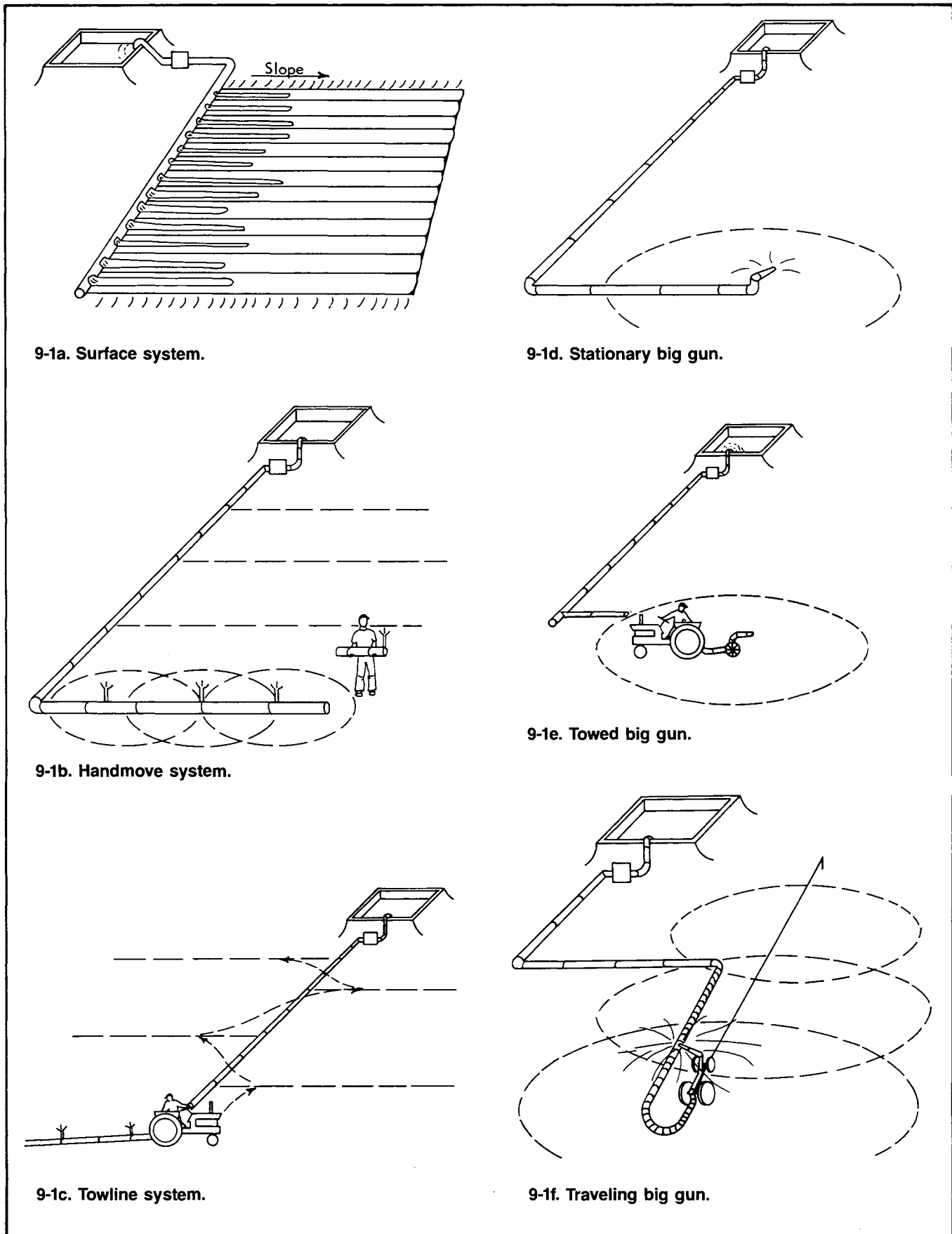


Fig 9-1. Irrigation systems.

- Adaptable to field shape. Different lengths can be set and run almost any direction to get to isolated corners.

Disadvantages:

- High labor requirement; individual pipe sections are moved, which can be a very unpleasant task with waste.
- Small sprinklers can plug.

Towline

Towlines are like handmove systems, except towlines have stronger, more permanent couplers between lateral pipe sections that are moved by tractor, Fig 9-1c.

Advantages:

- Low initial investment.
- Lower labor requirement than handmove; operator does not have to work in mud and manure to make moves.
- Few mechanical parts to malfunction.
- Low power requirement (50 psi at the sprinklers).

Disadvantages:

- Irregularly shaped fields can be a problem because of fixed lateral length.
- Small sprinklers can plug.
- Driving lanes for the tractor are required in tall row crops.

Table 9-9. Maximum spacing for low or medium pressure sprinklers.

For laterals perpendicular to the wind direction only.

Wind velocity, mph	Spacing in % of coverage diameter, ft	
	Along lateral %	Along main %
0	50	65
4 or less	45	60
4-8	40	50
8 or more	30	30

Example 9-1:

Compute spacing for three 0.6" sprinkler nozzles operating in a 5 mph wind.

Solution:

1. From Table 9-6, at 50 psi, dia = 225'.
2. From Table 9-9, space 40% along lateral and space 50% along main.
3. $0.40 \times 225' = 90'$; space nozzles 90' apart along lateral.
4. $0.50 \times 225' = 112'$; space laterals 120' apart, because pipe lengths are 20' or 30'.

Stationary big gun

This system is applicable to many waste disposal systems. A single large sprinkler is moved as in handmove systems, Fig 9-1d.

A big gun discharging 330 gpm sprinkles a 350' diameter circle (2.2 acres) at 0.33 in/hr and 90 psi. The power requirement is about 30 hp.

Advantages:

- Few mechanical parts to malfunction.
- Few plugging problems with large nozzle.
- Flexible with respect to land area.
- Pipe requirements are slightly less than with small sprinklers.
- Moderate labor requirement.

Disadvantages:

- Moderate to high initial investment.
- High power requirement (90 psi at the sprinkler).
- Uneven distribution in windy areas.

Towed big gun

This system is essentially a towline with the small sprinklers replaced by a big gun, Fig 9-1e. Or, it can be a stationary big gun with the pipe couplers replaced by towline couplers. It has the nonplugging advantage of the big gun and the lower labor advantage of the towline.

Advantages:

- Few mechanical parts to malfunction.
- Lower labor requirement than handmove or stationary gun systems.
- Few plugging problems with large nozzle.
- Pipe requirements are slightly less than with small sprinklers.

Disadvantages:

- High power requirement.
- Not as flexible with respect to land area.
- Driving lanes are required for tractor.

Traveling big gun

The traveling big gun is justifiable on large acreages irrigated several times a year. A single large nozzle is mounted on running gear that is pulled across the field by cable, Fig 9-1f. The gun is usually pulled by:

- A cable winch mounted on the running gear and powered by a small auxiliary gasoline engine or a water turbine in the irrigation line, which can plug with waste solids.
- A winch at the far end of the cable powered by an auxiliary gas engine.

Big guns travel either 660' ($\frac{1}{8}$ mile) or 1,320' ($\frac{1}{4}$ mile) on each set and have variable speeds to control application rates. They are fed by dragging a flexible hose behind them. The hose is relatively expensive and is much of the traveler cost.

Traveling guns are available in a wide range of sizes. A common size irrigates 10 acres per set compared with about 2 acres for a stationary gun.

Advantages:

- Lowest labor requirement of systems listed.
- No plugging problems with large nozzle.
- Flexible with respect to land area.

Disadvantages:

- Higher initial cost than the other systems.
- High power requirement.
- More mechanical parts than the other systems, especially with an auxiliary engine.

Table 9-10. Water applied by traveling big guns.

Average water depth applied, in. = $(1.605 \times \text{sprinkler gpm}) \div (\text{lane spacing, ft} \times \text{travel speed, ft/min})$. To convert table values to gal/acre, multiply by 27,150.

Sprinkler rate, gpm	Travel lane spacing ft	Travel speed, ft/min							
		0.4	0.5	1	2	4	6	8	10
		----- Water applied, in. -----							
50	105	1.9	1.5	0.76	0.38	0.19	0.13	0.096	0.076
	125	1.6	1.3	0.64	0.32	0.16	0.11	0.080	0.064
	155	1.3	1.0	0.52	0.26	0.13	0.09	0.065	0.052
60	110	2.2	1.8	0.88	0.44	0.22	0.15	0.109	0.088
	130	1.9	1.5	0.74	0.37	0.19	0.12	0.093	0.074
	160	1.5	1.2	0.60	0.30	0.15	0.10	0.075	0.060
70	115	2.4	2.0	0.98	0.49	0.24	0.16	0.122	0.098
	140	2.0	1.6	0.80	0.40	0.20	0.13	0.100	0.080
	170	1.7	1.3	0.66	0.33	0.17	0.11	0.083	0.066
80	120	2.7	2.1	1.07	0.54	0.27	0.18	0.134	0.107
	145	2.2	1.8	0.89	0.44	0.22	0.15	0.111	0.089
	180	1.8	1.4	0.71	0.36	0.18	0.12	0.089	0.071
90	125	2.9	2.3	1.16	0.58	0.29	0.19	0.144	0.116
	150	2.4	1.9	0.96	0.48	0.24	0.16	0.120	0.096
	185	2.0	1.6	0.78	0.39	0.20	0.13	0.098	0.078
100	165	2.4	1.9	0.97	0.49	0.24	0.16	0.12	0.10
	200	2.0	1.6	0.80	0.40	0.20	0.13	0.10	0.08
200	165	4.9	3.9	1.9	1.0	0.5	0.32	0.24	0.20
	200	4.0	3.2	1.6	0.8	0.4	0.27	0.20	0.16
300	200	6.0	4.8	2.4	1.2	0.6	0.40	0.30	0.24
	270	4.5	3.6	1.8	0.9	0.4	0.30	0.22	0.18
400	240	6.7	5.4	2.7	1.3	0.7	0.45	0.33	0.27
	300	5.4	4.3	2.1	1.1	0.5	0.36	0.27	0.21
500	270	7.4	5.9	3.0	1.5	0.7	0.50	0.37	0.30
	330	6.1	4.9	2.4	1.2	0.6	0.41	0.30	0.24
600	270	8.9	7.1	3.6	1.8	0.9	0.59	0.45	0.36
	330	7.3	5.8	2.9	1.5	0.7	0.49	0.37	0.29
700	270	10.4	8.3	4.2	2.1	1.0	0.69	0.52	0.42
	330	8.5	6.8	3.4	1.7	0.9	0.57	0.43	0.34
800	300	10.7	8.6	4.3	2.1	1.1	0.71	0.54	0.43
	360	8.9	7.1	3.6	1.8	0.9	0.59	0.45	0.36
900	300	12.0	9.6	4.8	2.4	1.2	0.80	0.60	0.5
	360	10.0	8.0	4.0	2.0	1.0	0.67	0.50	0.4
1,000	330	12.2	9.7	4.9	2.4	1.2	0.81	0.61	0.5
	400	10.0	8.0	4.0	2.0	1.0	0.67	0.50	0.4

Example 9-2:

Compute travel line separation for traveling big gun with a 1.5" taper nozzle at 100 psi in a 5 mph wind.

Solution:

1. From Table 9-6 at 100 psi, dia = 500'.
2. From Table 9-12, leave 350'-375' separation between lines.
3. Use 360' to fit 20' or 30' pipe lengths.

Other sprinkler systems

Some sprinkler irrigation systems are not common for waste disposal.

Center pivot systems, which move around in a circle like the spoke of a wheel, offer almost complete

Table 9-11. Acres irrigated per setting by traveling big guns.

For best watering uniformity, make lane spacing 50%-70% of the sprinkler wetted diameter.

Lane spacing ft	Travel distance	
	600'	1,000'
acres/set		
100	1.5	2.3
120	1.8	2.8
140	2.1	3.2
160	2.4	3.7
180	2.7	4.1
200	3.0	4.6
220	3.3	5.1
240	3.6	5.5
260	3.9	6.0
280	4.2	6.4
300	4.5	6.9
320	4.8	7.3
340	5.2	7.8
360	5.5	8.3
380	5.8	8.7
400	6.1	9.2

Table 9-12. Maximum lane spacing for traveling big guns.

Sprinkler wetted diameter, ft	% of wetted diameter						
	50 Wind over 10 mph	55 Wind over 10 mph	60 Wind up to 10 mph	65 Wind up to 10 mph	70 Wind up to 5 mph	75 Wind up to 5 mph	80 No wind
200	100	110	120	130	140	150	160
250	125	137	150	162	175	187	200
300	150	165	180	195	210	225	240
350	175	192	210	227	245	262	280
400	200	220	240	260	280	300	320
450	225	248	270	292	315	338	360
500	250	275	300	325	350	375	400
550	275	302	330	358	385	412	440
600	300	330	360	390	420	—	—

automation. They have many disadvantages: high cost, high power, small sprinklers, fixed land area covered, and mechanical maintenance problems.

Side roll systems, which move sideways across a rectangular field, are more adaptable than center pivot systems. They have small sprinklers, require rectangular fields, can have alignment problems, and have several mechanical devices to deal with.

Solid set systems, permanently installed throughout an entire field, are generally too expensive to install, except perhaps for small systems utilizing small diameter plastic pipe. The risers and sprinklers are always in place and must be avoided with machinery and protected from animals.

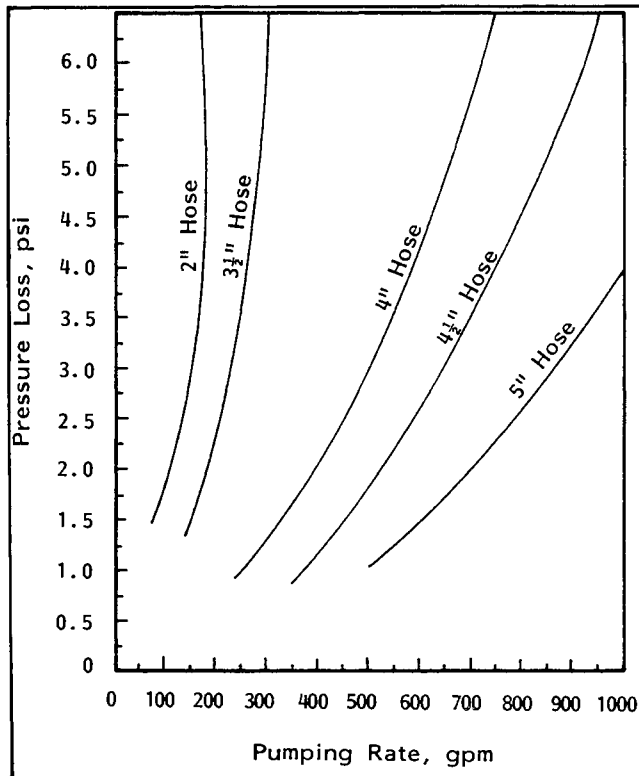


Fig 9-2. Irrigation hose pressure loss/100'.

Irrigating with Semi-Solids

Big gun sprinklers can spread wastes with high solids content. Pipeline design is similar to that for dilute wastes, except that each component is selected to handle more solids. Big guns handle any consistency up to that of thick milk. PVC plastic with adequate pressure rating is suitable for pipelines. Liquid may drain from irrigation pipe when the pump stops, leaving solids in the pipe that are hard to remove and can corrode aluminum pipe. Flush with fresh water after irrigating to remove these solids.

Manure solids can coat crop leaves, reducing photosynthesis and causing salt burns on leaves. Also, overapplication of a semi-solid waste or waste draining from the pipe when detached can kill the crop in that area. If possible, pump clean water for 10 to 15 min before moving the sprinkler to clean out the pipe, to rinse the pipe near the sprinkler, to wash solids off foliage, and to dilute drained liquid manure at the end. You may need to rinse-spray the crop with clean water about every hour if irrigating during the heat of the day.

Avoid applying semi-solid manure to a growing crop. If it is necessary, apply at minimal rates unless fresh water is also applied. For alfalfa, apply after hay cutting. For corn, do not apply when the plant is very young or during silking.

10. ANIMAL WASTE UTILIZATION

Most operators use wastes for an economic return, or at least to reduce costs. Animal manure is most commonly used as a fertilizer and soil conditioner.

Other established or potential practices include:

- Irrigation with waste effluent to supplement water needs for crop production.
- Reuse of liquids to flush and transport manure.
- Use of processed solids as bedding or litter.
- Use of processed solids for off-farm fertilizer, soil additive, or mulch.
- Salvage of energy from methane production.
- Reuse as feed ingredients for livestock, poultry, and aquatic life.

Land Application

Effects

Manure nutrients help build and maintain soil fertility. Manure also improves tilth, increases water-holding capacity, lessens wind and water erosion, improves aeration, and promotes beneficial organisms. When wastes include runoff or dilution water, they can supply water as well as nutrients to crops.

The economic value of manure fertilizer is calculated from its available N, P, and K at commercial fertilizer prices. These values change with the costs of fertilizer and handling practices.

Applying excess wastes can harm crop growth, contaminate soil, cause surface and groundwater pollution, and waste nutrients. While most soils have a tremendous capacity to absorb phosphorus, very high soil phosphorus levels can interfere with plant nutrition by inhibiting uptake of metallic trace elements such as iron, zinc, and copper. When plant residue or manure is added to soil, there is an immediate and marked drop in O_2 and an increase in CO_2 in the soil air, which can inhibit plant growth.

The carbon-nitrogen ratio (C/N) of applied wastes affects both microbial and plant growth. If a waste having a high C/N ratio, such as manure with a lot of bedding, is added to a soil, organisms decomposing the organic matter grow until available mineral and nitrogen become limiting. All the immediately available nitrogen is bound by the microorganisms. In the short run, nitrogen is unavailable for plant use and more chemical fertilizer may have to be added than before the waste application.

Heavy manure applications can increase soil salinity, especially in arid regions where little or no leaching occurs. Salts can inhibit plant growth and depress yields. If salinity becomes a problem, consult a crop specialist.

Sodium and potassium can alter soil structure and reduce water movement rates. Field equipment, such as heavy manure wagons, compacts wet soils, alters soil structure, and reduces water movement. Yield reduction can result.

Surface and Groundwater Quality

Several diseases that might infect both animals and man can be transmitted in waterborne livestock wastes. Land application can successfully interrupt infection cycles if water pollution is prevented.

Surface runoff contains pollutants, including plant nutrients, oxygen demanding material, and some infectious agents. Excessive nitrogen applications can cause nitrate pollution of water—the cause of infant cyanosis (blue babies) and perhaps chemical diarrhea.

Nitrogen in excess of crop requirements leaches through the soil once it is in the nitrate form. For local application rates to avoid groundwater pollution, consult your state extension crop and soil specialist or the SCS. Reducing excess nitrogen without pollution is difficult.

Excess nutrients in surface water can cause algae blooms, impaired fisheries, fish kills, odors, and increased turbidity. Nutrients in runoff from land where manure was applied and incorporated in the summer are less than in runoff where no manure was applied. But large nutrient losses can occur in spring runoff from land where manure was applied on frozen ground.

Nutrient Losses During Collection and Storage

Housing and waste handling systems affect the nutrient composition of wastes. Bedding and water dilute manure, resulting in less nutrient value per pound. Much nitrogen can be lost to the air as ammonia. Runoff and leaching in open lots can remove nitrogen. There is much less nitrogen loss from compost pits, liquid storage systems, or roofed feeding areas. See Table 10-1.

Phosphorus and potassium losses are negligible except for open lots or lagoons. About 20%-40% of the phosphorus and 30%-50% of the potassium can be lost by runoff and leaching in open lots. However, much of the P and K can be recovered by runoff control systems such as settling basins and holding ponds. Up to 80% of the phosphorus in lagoons can accumulate in bottom sludges and is not applied to land unless the sludge is removed.

Application

Manure is usually:

- Broadcast (top dressed) with plowdown or disking.
- Broadcast without plowdown or disking.
- Knifed (injected under the soil surface).
- Irrigated.

Table 10-2 shows average nitrogen losses by method of application.

The greatest nutrient response follows land application and immediate incorporation into the soil.

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Table 10-1. Nitrogen losses during handling and storage.

Typical losses between excretion and land application adjusted for dilution in the various systems. These values are in addition to land application losses, Table 10-2. Based on Purdue University data.

System	Nitrogen lost, %
Solid	
Daily scrape and haul	20-35
Manure pack	20-40
Open lot	40-55
Deep pit (poultry)	25-50
Litter	25-50
Liquid	
Anaerobic pit	15-30
Above-ground storage	10-30
Earth storage	20-40
Lagoon	70-85

Table 10-2. Nitrogen losses during land application.

Percent of nitrogen applied that is lost within 4 days of application. For handling and storage losses, see Table 10-1.

Application method	Type of waste	Nitrogen lost, %
Broadcast	Solid	15-30
	Liquid	10-25
Broadcast with immediate cultivation	Solid	1-5
	Liquid	1-5
Knifing	Liquid	0-2
Sprinkler irrigation	Liquid	15-40

Plow down solid manure as soon as possible to minimize nitrogen loss and to begin release of nutrients for plant use. Most losses occur in the first 24 hr after application, so incorporate manure into the soil as soon as possible. Injecting, chiseling, or knifing liquids into the soil minimizes odors and nutrient losses to the air and/or to runoff.

Nitrogen loss as ammonia from land is greater during dry, warm, windy days than during humid or cold days. Ammonia loss is generally greater during the spring and summer months.

Poultry and veal calf manures are highly alkaline, so ammonia losses are greater than from other manures. It is especially important that poultry and veal calf manure be incorporated into the soil as soon as possible. Uniform application prevents local concentrations of ammonium or inorganic salts that can reduce seed germination and yields.

Apply manure as near planting date as possible so more nutrients will be available to plants, especially in areas of high rainfall and with soils in which nitrate is lost by leaching or denitrification. Lowered germination and reduced seedling growth could occur, however, if planting takes place immediately after heavy manure applications, because of high salt concentrations near the soil surface.

As an alternative, late fall or winter applications may be desirable because of greater labor availability and better soil trafficability. Even though fall-winter applications may result in a 25%-50% total nitrogen loss (from leaching and denitrification), fall applica-

tions allow soil microorganisms time to more fully decompose manure and release nutrients for the following cropping season. This is especially advantageous for solid manure, which contains high levels of organic matter.

With liquid manure, much nitrogen loss by leaching or denitrification can be stopped with a nitrification inhibitor. These products inhibit the action of certain soil bacteria that convert ammonium nitrogen to nitrate nitrogen that can be easily leached by water movement through the soil or converted to nitrogen gas during denitrification. Thus, these products eliminate potential N losses from manure and/or commercial fertilizer, especially with fall applications.

Recent research has confirmed that the addition of a nitrification inhibitor to liquid swine manure reduced N losses and increased corn yields. This beneficial effect was more evident with fall manure applications than with spring applications, unless soil conditions were extremely wet in spring and favorable for denitrification.

Inhibitors can be added to manure:

- Through an open hatch prior to manure loading.
- Through a separate aspirator or gravity flow tube with vacuum systems.
- Into a manure pump at the time of loading.

Nitrification inhibitors work best when the rate of nitrogen added to the soil is equal to plant needs. Therefore, analyze manure samples to insure proper application of N. Nitrification inhibitors are volatile compounds, so immediate incorporation in the soil is vital.

Soil Characteristics

Light textured soils decompose organic matter faster than heavy textured ones because of better air and moisture movement and distribution. But heavier textured soils retain more nutrients in the upper soil profile.

Soil physical properties—water infiltration rate, holding capacity, texture, and total exchange capacity—affect waste application rates. For instance, heavy textured soils have slow water infiltration rates, so limit liquid waste applications to avoid runoff. Coarse textured soils, because of high permeability, accept higher liquid application rates without runoff. However, most coarse textured soils have very low exchange capacity, so if possible, apply animal wastes throughout the growing season to reduce nitrogen leaching.

Crop Nutrient Removal

Apply manure so nutrients added do not greatly exceed crop needs. See Table 10-3. Manure nutrients, especially nitrogen, are utilized more efficiently by grasses and cereals than by legumes. Legumes get most of their nitrogen from the air, so additional nitrogen is not usually needed.

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For the greatest return, apply manure first to corn and small cereal grains, then to sorghum and forages, and finally to pasture.

Before heavy manure applications, have your soil tested for fertilizer needs and nutrient imbalance. Adjust waste application rates for your soil conditions against soil tests for nitrogen, phosphorus, and potassium.

Example 10-1:

How much N, P₂O₅, and K₂O are utilized by a corn yield of 150 bu/acre?

Solution:

From Table 10-3, this crop uses 185 lb/acre of N, 80 lb/acre of P₂O₅, and 215 lb/acre of K₂O.

Table 10-3. Crop nutrient utilization.

Values are for the total above-ground portion of the plants. When only grain is removed, many nutrients are left in the residues but are temporarily tied up in them and are not readily available. Estimate nutrient requirements for one crop year by assuming complete crop removal. Alfalfa and soybeans get most of their N from the air, so additional N from manure is usually not needed. Source: Potash Phosphate Institute of America.

Boxed values refer to Examples 10-1, 10-2, and 10-3.

Crop	Yield	N	P ₂ O ₅	K ₂ O
lb/acre				
Corn	80 bu	121	42	77
	100 bu	160	60	120
	150 bu	185	80	215
	180 bu	240	100	240
Corn silage	16 tons	130	45	102
	32 tons	200	80	245
Soybeans	30 bu	123	32	52
	40 bu	180	45	80
	50 bu	257	48	120
	60 bu	336	65	145
Grain sorghum	4 tons	250	90	200
Wheat	40 bu	70	30	50
	60 bu	125	50	110
	80 bu	186	54	162
Oats	80 bu	75	35	95
	100 bu	150	55	150
Barley	65 bu	74	32	63
	100 bu	150	55	150
Alfalfa	4 tons	180	40	180
	8 tons	450	80	480
Orchardgrass	6 tons	300	100	375
Bromegrass	5 tons	166	66	254
Tall fescue	3.5 tons	135	65	185
Bluegrass	3 tons	200	55	180
Costal Bermuda grass	4 tons	225	40	160
	10 tons	535	145	410
Clover-grass	4.5 tons	185	60	175
	6 tons	300	90	360
Sugar beets	30 tons	275	85	550
Rice	2.25 tons	110	45	110
	3.5 tons	112	60	168
Timothy	4 tons	150	55	250
Pangola grass	12 tons	299	108	430
Sorghum-Sudan grass	8 tons	319	122	467

Nutrient Value per Animal Unit

The fertilizer value of manure depends upon livestock species and handling and disposal methods. Table 10-4 estimates the acres needed per 100 animal units for land application of manure. Table values consider nutrient losses from handling and disposal. Use Tables 10-3 and 10-4 to estimate the number of acres needed for a specific livestock and cropping operation.

Example 10-2:

A swine producer has a 50-sow farrow-to-finish operation. Liquid waste is stored in an anaerobic pit. The producer intends to broadcast and cultivate the liquid manure into the ground to produce 150 bu/ac corn. How many crop acres are needed?

Solution:

1. From Table 10-4, 152 ac are needed to apply 100 lb N/ac from 100 productive sows.

$$50 \text{ productive sows} \times (152 \text{ ac} \div 100 \text{ productive sows}) = 76 \text{ ac fertilized to } 100 \text{ lb N/ac}$$

2. From Table 10-3, 150 bu/ac corn requires 185 lb N/ac.

3. How many acres can be fertilized to 185 lb N/ac? Multiply the value from Step 1 by the ratio of 100 lb N/ac to the required lb N/ac.

$$76 \text{ ac} \times (100 \div 185 \text{ lb N/ac}) = 41.1 \text{ ac fertilized to } 185 \text{ lb N/ac}$$

4. Apply the liquid waste to 41.1 acres to fully utilize the N fertilizer value of the manure to meet N requirements more than adequately meets crop P₂O₅ and K₂O needs.

Nutrient Value for Crop Production

Tables 10-6 and 10-7 show estimated fertilizer compositions of waste applied to the land (wet basis). Nutrient contents vary widely, so these data are guidelines. For specific situations, have your manure analyzed. Conversion factors:

- Multiply P₂O₅ by 0.44 to convert to elemental P.
- Multiply K₂O by 0.83 to convert to elemental K.
- 27,150 gal = 1 acre-inch (a-in).

Available N is nitrogen the plant can use. Total N is mostly organic and ammonium nitrogen. Organic N is slow releasing N. Ammonium N is equivalent to commercial fertilizer and, except for that lost to the air, can be used by plants in the application year. Organic nitrogen must be released before plants can use it.

Variable amounts of organic nitrogen are released in a plant-available form during the first cropping year after application. Table 10-5 summarizes the percentages of organic nitrogen released (mineralized) during the first cropping season. Organic N released during the second, third, and fourth crop-

Table 10-4. Land application manure.

Values based on 100 lb of available N/ac-yr. To determine the land required for 200 lb N/ac-yr, divide the table value by 2. Manure nitrogen levels account for storage and application losses. Boxed value refers to Example 10-2.

Manure handling method	Animal units								
	Swine			Dairy cows mature	Beef feeders	Sheep	Broiler	Poultry Layer	Turkey
	Feeder pig production	Farrow to finish	Pigs fed 50-220 lb						
	Ac/100 productive sows ^a to yield 100 lb N/ac			----- (ac/100 animal units to yield 100 lb N/ac) -----					
Anaerobic pit									
Broadcast	13	129	9	89	17				
Broadcast/cultivate	16	152	10	105	20				
Injection	16	155	10	107	20				
Irrigation	12	113	8	78	15				
Deep pit									
Broadcast								0.4	
Broadcast/cultivate								0.5	
Open lot									
Broadcast	11	102	7	61	13				
Broadcast/cultivate	14	128	9	76	16				
Manure pack									
Broadcast	11	102	7	61	13	4	0.2		0.5
Broadcast/cultivate	14	128	9	76	16	6	0.3		0.6
Deep stack									
Broadcast						4			
Broadcast/cultivate						7			
Lagoon									
Irrigation	5	48	3	32	6				

^aBased on 16 pigs sold/productive sow-yr. Manure production per productive sow accounts for all animals in the operation such as boars, pigs in nursery, growing, etc.

Table 10-5. Mineralized organic nitrogen.

Amount mineralized (released to crops) during first cropping season after application of animal manure. Boxed value refers to Example 10-3.

Manure type	Manure handling	Mineralization factor
Swine	Fresh	0.50
	Anaerobic liquid	0.35
	Aerobic liquid	0.30
Beef	Solid without bedding	0.35
	Solid with bedding	0.25
	Anaerobic liquid	0.30
	Aerobic liquid	0.25
Dairy	Solid without bedding	0.35
	Solid with bedding	0.25
	Anaerobic liquid	0.30
	Aerobic liquid	0.25
Sheep	Solid	0.25
Poultry	Deep pit	0.60
	Solid with litter	0.60
	Solid without litter	0.60
Horses	Solid with bedding	0.20

ping years after initial application is usually about 50%, 25%, and 12.5%, respectively, of that mineralized during the first cropping season.

Nearly all of the phosphorus and potassium in animal wastes are available for plant use the year of application. After a few years of regular waste applications, the amounts available are about the same as one year's application.

Table 10-6. Nutrients in solid manure.

Approximate fertilizer value of manure from solid handling systems.

Species	Bedding or litter	Dry matter, %	Ammonium N	Total N	P ₂ O ₅	K ₂ O
lb/ton raw waste						
Swine	No	18	5	11	8	5
	Yes	18	4	9	7	7
Beef	No	15 ^a	4	11	7	10
	No	52 ^b	7	21	14	23
	Yes	50	8	21	18	26
Dairy	No	18	3	9	3	6
	Yes	21	4	9	3	6
Sheep	No	28	5	18	11	26
	Yes	28	5	14	9	25
Poultry	No	45	8	33	48	34
	Yes	75	10	47	48	30
	Deep pit	76	12	38	45	25
Turkey	No	20	8	20	40	17
	Yes	25	8	22	45	18
Horse	Yes	46	4	14	4	14

^aOpen concrete lot.

^bOpen dirt lot.

How Much Animal Waste Can Be Applied?

After determining crop fertilizer needs and manure nutrient value, estimate how much manure to apply and determine if additional commercial fertilizer is needed for efficient crop production. Also see the irrigation discussion in the land application techniques section for maximum liquid application.

Table 10-7. Nutrients in liquid manure.

Approximate fertilizer value of manure from liquid handling systems. Boxed values refer to Example 10-3.

Species	Waste handling	Dry matter, %	Ammonium N	Total N	P ₂ O ₅	K ₂ O
----- lb/1,000 gal raw waste -----						
Swine	Liquid pit	4	<u>24</u>	<u>36</u>	<u>25</u>	<u>22</u>
	Lagoon ^a	1	4	5	3	4
Beef	Liquid pit	9	10	29	18	26
	Lagoon ^a	1	2	4	3	4
Dairy	Liquid pit	8	7	31	15	19
	Lagoon ^a	1	2	4	3	4
Veal calf	Liquid pit	3	21	27	22	40
Poultry	Liquid pit	10	13	60	45	30

^aIncludes lot runoff water.

A worksheet is provided to help you find proper application rates. The procedure uses five sections:

- Manure composition and soil information.
- Nutrient needs of crop.

Table 10-8. Annual manure production.

Raw manure includes feces and urine. Boxed values refer to Example 10-3.

Animal	Raw manure production/ 1,000 lb animal weight	
	ton/yr	gal/yr
Dairy cow	15.7	3,787
Veal calf	11.3	2,730
Beef feeder	10.6	2,514
Beef cow	11.5	2,730
Swine feeder	15.3	<u>3,699</u>
Swine breeding herd	6.0	<u>1,453</u>
Sheep	7.3	1,706
Poultry layer	11.7	2,912
Poultry broiler	15.5	3,684
Turkey	8.6	2,037
Horse	9.3	2,210

- Annual rate of manure application.
- Amount of additional fertilizer needed.
- Amount of land required to dispose of annual manure production.

Worksheet to Determine Manure Application Rates and Disposal Area

Example 10-3:

A swine producer has a 1,500 head (one time capacity) farrow-to-finish operation (average weight 125 lb/market animal; 250 lb/breeding animal) in enclosed buildings. Manure is handled in liquid pits and injected into the soil. The area to be manured had received 6,000 gal/ac of manure last year.

To maximize the manure as fertilizer, what is the proper manure application rate, how much supplemental commercial fertilizer will be needed and how many acres of cropland can utilize the manure?

Calculations

Section A. Manure composition and soil information

1. Manure composition.

a. Values from chemical analysis of manure.

Composition ^a	Your farm
Total N	_____ %
Ammonium N	_____ %
Nitrate N	_____ %
P ₂ O ₅	_____ %
K ₂ O	_____ %

^aLaboratory data are often given in ppm. To convert ppm to %, divide by 10,000. If composition data are not available, use Table 10-6 or Table 10-7.

b. Determine the amount of each nutrient per ton of solid manure or per 1,000 gal of liquid manure. If nutrient contents are given in %:

% nutrient in manure × 20 = lb nutrients/ton;
or × 85 lb nutrients/1,000 gal (e.g. 0.5%
Total N = 10 lb/ton or 42.5 lb/1,000 gal)

Composition	Example (Table 10-7)	Your farm
Total N	<u>36</u> lb/1,000 gal	_____ lb/_____
Ammonium N	<u>24</u> lb/1,000 gal	_____ lb/_____
Nitrate N	_____ lb/_____	_____ lb/_____
P ₂ O ₅	<u>25</u> lb/1,000 gal	_____ lb/_____
K ₂ O	<u>22</u> lb/1,000 gal	_____ lb/_____

2. Soil information:

Soil information	Example	Your soil
Texture	<u>Silty Clay loam</u>	_____
Soil pH	<u>6.2</u>	_____
Available P	_____ lb/ac	_____ lb/ac
Exchangeable K	_____ lb/ac	_____ lb/ac

Section B. Nutrient needs of crop

	Example	Your crop
Crop to be grown	<u>Corn</u>	_____
Expected yield/acre	<u>150 bu</u>	_____
Nutrients required/ac	N = <u>185</u> lb/ac	_____ lb/ac
(based on soil test	P ₂ O ₅ = <u>80</u> lb/ac	_____ lb/ac
report or Table 10-3)	K ₂ O = <u>215</u> lb/ac	_____ lb/ac

Section C. Annual rate of manure application

1. Calculate amount of organic N in manure (either per ton or per 1,000 gal):

$$\text{lb total N} - (\text{lb ammonium N} + \text{lb nitrate N}) = \text{lb organic N}$$

Example:

$$36 - (24 + \text{---}) = 12 \text{ lb organic N/1,000 gal}$$

Your manure:

$$\text{---} - (\text{---} + \text{---}) = \text{---} \text{ lb organic N/---}$$

2. Calculate amount of organic N in manure made available the first year:

lb organic N/(ton or 1,000 gal) × mineralization factor, Table 10-5 = lb available organic N/(ton or 1,000 gal)

Example:

$$12 \times 0.35 = 4.2 \text{ lb available organic N/ } 1000 \text{ gal}$$

Your farm:

$$\underline{\hspace{1cm}} \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb available organic N/ } \underline{\hspace{1cm}}$$

3. Calculate amount of plant-available N in manure (use either a or b following):

- a. Incorporated application of manure:

Available organic N (Sec C.2) + Ammonium N (Sec A.1.b) + Nitrate N (Sec A.1.b) = lb plant available N/(ton or 1,000 gal)

Example:

$$4.2 + 24 + \underline{\hspace{1cm}} = 28.2 \text{ lb available N/ } 1000 \text{ gal}$$

Your farm:

$$\underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb available N/ } \underline{\hspace{1cm}}$$

- b. Surface application of manure (assumes $\frac{1}{3}$ of ammonium N lost by ammonia volatilization):

Available organic N (Sec C.2) + [Ammonium N (Sec A.1.b) × 0.66] + Nitrate N (Sec A.1.b) = lb plant-available N/(ton or 1,000 gal)

Your farm:

$$\underline{\hspace{1cm}} + [\underline{\hspace{1cm}} \times 0.66] + \underline{\hspace{1cm}} = \text{lb available N/ } \underline{\hspace{1cm}}$$

4. Adjust N fertilizer recommendation to account for residual N from manure applications in last 3 yr.

- a. Manure applied to field 1 yr ago (if none, proceed to b.):

lb organic N/(ton or 1,000 gal) of manure × (mineralization factor + 2) × tons or 1,000 gal applied/ac = lb residual N/ac

Example:

$$12 \div 1000 \text{ gal} \times (0.35 + 2) \times 6000 = 12.6 \text{ lb residual N/ac}$$

Your farm:

$$\underline{\hspace{1cm}} \times (\underline{\hspace{1cm}} + 2) \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb residual N/ac}$$

- b. Manure applied to field 2 yr ago (if none, proceed to c.):

lb organic N/(ton or 1,000 gal) of manure × (mineralization factor + 4) × tons or 1,000 gal applied/ac = lb residual N/ac

Your farm:

$$\underline{\hspace{1cm}} \times (\underline{\hspace{1cm}} + 4) \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb residual N/ac}$$

- c. Manure applied 3 yr ago (if none, go to d.):

lb organic N/(ton or 1,000 gal) of manure × (mineralization factor + 8) × tons or 1,000 gal applied/ac = lb residual N/ac

Your farm:

$$\underline{\hspace{1cm}} \times (\underline{\hspace{1cm}} + 8) \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb residual N/ac}$$

- d. Total residual N:

Sec C.4.a + Sec C.4.b + Sec C.4.c = total lb residual N/ac

Example:

$$12.6 + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = 12.6 \text{ total lb residual N/ac}$$

Your farm:

$$\underline{\hspace{1cm}} + \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ total lb residual N/ac}$$

- e. Adjust N requirement of crop:

lb N required by crop (Sec B) – lb residual N (Sec C.4.d) = lb N required/ac

Example:

$$185 - 12.6 = 172.4 \text{ lb N required/ac}$$

Your farm:

$$\underline{\hspace{1cm}} - \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ lb N required/ac}$$

5. Annual manure applications based on amount of N required by crop:

Adjusted N required (sec C.4.e) ÷ lb available N/(ton or 1,000 gal) (Sec C.3.a or C.3.b) = tons of manure/ac or number of 1,000 gal units of manure/ac

Example:

$$172.4 \div \frac{28.2 \text{ lb}}{1000 \text{ gal}} = 6113 \text{ gal/manure/ac}$$

Your farm:

$$\underline{\hspace{1cm}} \div \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ manure/ac}$$

6. Annual manure application based on amount of P_2O_5 required by crop:

P_2O_5 required by crop (Sec B) ÷ lb P_2O_5 ÷ (ton or 1,000 gal) (Sec A.1.b) = tons manure/ac or number of 1,000 gal units of manure/ac

Example:

$$80 \div \frac{25 \text{ lb}}{1000 \text{ gal}} = 3200 \text{ gal/manure/ac}$$

Your farm:

$$\underline{\hspace{1cm}} \div \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ manure/ac}$$

7. Select annual rate of manure to be applied. If manure is to supply all N and P_2O_5 needs of the crop, select the **higher** of the two values (Sec C.5 or Sec C.6) as your application rate per acre. If your aim is to maximize use of nutrients in animal manure, select the **lower** of the two values. Supplement with commercial fertilizer to supply the remainder of nutrients required by the crop.

Rate of manure to be applied is:

Example:

$$3200 \text{ gal/manure/ac}$$

Your farm:

$$\underline{\hspace{1cm}} \text{ manure/ac}$$

Section D. Additional fertilizer required

1. Nitrogen (do not complete if manure rate selected, Sec C.7, supplies the required N).

- a. Available N added in manure:

Tons or 1,000 gal units of manure added/ac
(Sec C.7) $\times$ lb available N/(ton or 1,000 gal).
(Sec C.3.a or C.3.b) = lb available N applied

Example:
 $3200 \text{ gal} \times \frac{28.2 \text{ lb}}{1000 \text{ gal}} = 90.2 \text{ lb available N applied}$

Your farm:

_____ $\times$ _____ = _____ available N applied

- b. Additional fertilizer N required:

Adjusted N requirements (Sec C.4.e) - lb N applied (Sec D.1.a) = lb fertilizer N required

Example:
 $172.4 - 90.2 = 82.2 \text{ lb fertilizer N}$

Your farm:

_____ - _____ = _____ lb fertilizer N

2. Phosphorus (do not complete if manure rate in Sec C.7 supplies the required amount of P_2O_5).

- a. P_2O_5 added in manure:

Tons or 1,000 gal units of manure/ac (Sec C.7)
 $\times$ lb P_2O_5 /(ton or 1,000 gal) (Sec A.1.b) = lb P_2O_5 applied

Your farm:

_____ $\times$ _____ = _____ lb P_2O_5 applied

- b. Additional fertilizer P_2O_5 required:

P_2O_5 required by crop (Sec B) - lb P_2O_5 applied
(Sec D.2.a) = lb fertilizer P_2O_5 required

Your farm:

_____ - _____ = _____ lb fertilizer P_2O_5 required

3. Potassium:

- a. K_2O added in manure:

Tons or 1,000 gal units of manure/ac (Sec C.7)
 $\times$ lb K_2O /(ton or 1,000 gal) (Sec A.1.b) = lb K_2O applied

Example:
 $3200 \text{ gal} \times \frac{22 \text{ lb}}{1000 \text{ gal}} = 70.4 \text{ lb } K_2O \text{ added}$

Your farm:

_____ $\times$ _____ = _____ lb K_2O added

- b. Additional K_2O required:

K_2O required by crop (Sec B) - lb K_2O applied
(Sec D.3.a) = lb fertilizer K_2O required

Example:
 $215 - 70.4 = 144.6 \text{ lb fertilizer } K_2O \text{ required}$

Your farm:

_____ - _____ = _____ lb fertilizer K_2O required

Section E. Land required to dispose of annual manure production

1. Determine average animal units (a.u.) per year, expressed as 1,000 pounds live weight, in the livestock enterprise:

Average weight per animal $\times$ average number of animals/yr

Example:

Breeding:

$(250 \text{ lb/animal} \times 300 \text{ animals}) \div 1,000 = 75 \text{ a.u.}$

Growing-finishing:

$(125 \text{ lb/animal} \times 1500 \text{ animals}) \div 1,000 = 187.5 \text{ a.u.}$

Your farm:

Breeding:

(_____ lb/animal $\times$ _____ animals) $\div$ 1,000 = _____ a.u.

Growing-finishing:

(_____ lb/animal $\times$ _____ animals) $\div$ 1,000 = _____ a.u.

2. Annual manure nutrient production per animal unit, expressed as pounds of nutrients per animal unit:

[manure (tons or 1,000 gal units) produced per a.u., Table 10-8, $\times$ nutrient content of manure (from Sec A.1.b and C.3.a or C.3.b)]

Example:

Breeding (75), Growing-Finishing (187.5)

$(1453)/\text{a.u.}$	$\times (28.2) \text{ lb available N}/(1000 \text{ gal})$	$= (41.0) \text{ lb available N/a.u.}$
$3699/\text{a.u.}$	$\times 28.2 \text{ lb available N}/1000 \text{ gal}$	$= 104.3 \text{ lb available N/a.u.}$
$(1453)/\text{a.u.}$	$\times (25.0) \text{ lb } P_2O_5/\text{a.u.}$	$= (36.3) \text{ lb } P_2O_5/\text{a.u.}$
$3699/\text{a.u.}$	$\times 25.0 \text{ lb } P_2O_5/\text{a.u.}/1000 \text{ gal}$	$= 92.5 \text{ lb } P_2O_5/\text{a.u.}$
$(1453)/\text{a.u.}$	$\times (22.0) \text{ lb } K_2O/\text{a.u.}/(1000 \text{ gal})$	$= (32.0) \text{ lb } K_2O/\text{a.u.}$
$3699/\text{a.u.}$	$\times 22.0 \text{ lb } K_2O/\text{a.u.}/1000 \text{ gal}$	$= 81.4 \text{ lb } K_2O/\text{a.u.}$

Your farm:

(____)/a.u.	$\times$ (____) lb available N/(____)	$=$ (____) lb available N/a.u.
____/a.u.	$\times$ _____ lb available N/_____	$=$ _____ lb available N/a.u.
(____)/a.u.	$\times$ (____) lb P_2O_5 /(____)	$=$ (____) lb P_2O_5 /a.u.
____/a.u.	$\times$ _____ lb P_2O_5 /_____	$=$ _____ lb P_2O_5 /a.u.
(____)/a.u.	$\times$ (____) lb K_2O /(____)	$=$ (____) lb K_2O /a.u.
____/a.u.	$\times$ _____ lb K_2O /_____	$=$ _____ lb K_2O /a.u.

3. Calculate annual manure nutrient production,
lb/yr:

[animal units (Sec E.1) × lb nutrient/a.u. (from
Sec E.2)]

Example:

Breeding (75), Growing-Finishing (187.5)

			Total
(75)/a.u.	× 41.0 lb available N/a.u.	= (3075) lb available N/yr	
188/a.u.	× 104.3 lb available N/a.u.	= 19,608 lb available N/yr	22,683
(75)/a.u.	× 36.3 lb P ₂ O ₅ /a.u.	= (2723) lb P ₂ O ₅ /yr	
188/a.u.	× 92.5 lb P ₂ O ₅ /a.u.	= 17,390 lb P ₂ O ₅ /yr	20,113
(75)/a.u.	× 32.0 lb K ₂ O/a.u.	= (2400) lb K ₂ O/yr	
188/a.u.	× 81.4 lb K ₂ O/a.u.	= 15,303 lb K ₂ O/yr	17,703

Your farm:

			Total
()/a.u.	× () lb available N/a.u.	= () lb available N/yr	
____/a.u.	× ____ lb available N/a.u.	= ____ lb available N/yr	_____
()/a.u.	× () lb P ₂ O ₅ /a.u.	= () lb P ₂ O ₅ /yr	
____/a.u.	× ____ lb P ₂ O ₅ /a.u.	= ____ lb P ₂ O ₅ /yr	_____
()/a.u.	× () lb K ₂ O/a.u.	= () lb K ₂ O/yr	
____/a.u.	× ____ lb K ₂ O/a.u.	= ____ lb K ₂ O/yr	_____

4. Total cropland required for manure application,
ac/yr:

[nutrients generated/yr (Sec E.3) + nutrients
required for crop (Sec B or Sec C.4.e)]

Example:

22,683 available N/yr + 172.4 lb N/ac (Sec C.4.e) =
131.6 ac/yr

20,113 lb available P₂O₅/yr + 80 lb N/ac (Sec B)
= 251.4 ac/yr

Your farm:

____ lb available N/yr + ____ lb N/ac (Sec C.4.e)
= ____ ac/yr

____ lb available P₂O₅/yr + ____ lb N/ac (Sec B) =
____ ac/yr

If you are basing manure application rate on the
crop's nitrogen needs, the number of acres for manure
disposal is given in the first line above. The second
line gives the number of acres required if manure
application rate is based on the P₂O₅ needs of the crop.

Estimating the fertilizer value of manure

Calculating manure fertilizer value produced an-
nually on your farm is important if you are planning

a new operation of your present one. In Sec E.3 you
calculated the amounts of N, P₂O₅ and K₂O produced
annually in your livestock operation. The value of the
nutrients in the manure can be estimated by multi-
plying the pounds of nutrients produced per year by
the price per pound of commercial fertilizer nutrients.

Example:

	lb/yr (Sec E.3)	Price (\$/lb)	Value (\$)
Available N	22,683	× 0.20	= \$4,537
P ₂ O ₅	20,113	× 0.30	= \$6,034
K ₂ O	17,703	× 0.13	= \$2,301
Total			\$12,872

Your farm:

Available N	_____	× _____	= \$ _____
P ₂ O ₅	_____	× _____	= \$ _____
K ₂ O	_____	× _____	= \$ _____
Total			\$ _____

The total value is the estimated gross value of the
manure nutrients and does not include cost of labor,
equipment, maintenance and management of the ma-
nure system. However, these costs would still be
incurred for manure disposal regardless of whether
or not the manure is used for fertilizer.

Management Considerations:

- Check state and local regulations concerning land application times and rates.
- Surface apply animal wastes at least 100' from streams, ponds, open ditches, and inlets to tile lines.
- While ground is frozen, apply animal wastes to relatively level land remote from surface water.
- Avoid spreading liquid manure on water saturated soils where runoff is likely.
- For odor control, spread raw animal wastes frequently, especially during the summer; spread early in the day as the air is warming up and rising rather than late when the air is cooling and settling; and avoid days when the wind is blowing toward populated areas or when the air is still and seems to hang.
- Agitate or mix liquid wastes for removal of settled solids and uniform waste nutrient application to the land.
- Use good safety measures when removing manure from tanks or pits. Remove animals or increase ventilation to maximum in slatted floor animal areas located over manure pits during agitation because of oxygen deficiency or toxic gas accumulation. If animals are left in buildings during agitation, monitor animal behavior carefully. Do not enter manure storage structures without life support equipment.
- Consider irrigating dilute manures (lagoon or runoff liquids) during dry weather to apply needed water and nutrients to growing crops.
- When irrigating manure on growing crops, avoid application during the heat of the day and rinse with clean water after manure application to wash the plants off to avoid leaf burn.
- In arid regions, the salt content of manure is of potential concern. Sufficient water must be applied sometime during the year to avoid soluble ion accumulation in the root zone.

Refeeding

Livestock waste may be more valuable as a feed ingredient than as a source of plant nutrients. Raw

manure can be directly refed, as when swine follow cattle to obtain nourishment from their droppings. Ruminants (cattle, sheep, goats) have microorganisms in the rumen that can utilize fiber and nonprotein nitrogenous compounds (NPN) to a greater extent than nonruminants.

Some grain and forage pass through an animal without being digested. If it can be recovered, it is essentially the same as "new" feed. Whole and cracked corn kernels and larger partially digested waste solids can be reclaimed with liquid-solid separation techniques. The liquid portion is then typically handled as liquid manure. See section on liquid-solid separation.

Dried manure is easier to handle and store and readily mixes with other feed ingredients. Although expensive, it avoids some of the problems and uncertainties of biological conversion processes.

The nutrients in animal manure can be converted biologically to enhance their usefulness as feed ingredients. Ensiling makes the material more palatable but does not really change its nature. Some processes degrade the waste to a molecular form, and then form new microbial, plant, or animal matter. Bacterial production of single cell protein is one example. In a sense, the production of corn from land where manure was applied is another example.

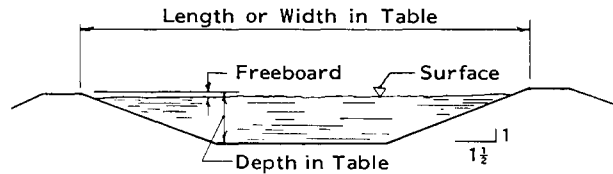
Ensiling livestock waste mixed with whole, chopped corn plants changes the nutritive composition of the silage. All types of livestock wastes seem to ensile well, with the order of quality, based on fermentation characteristics, being poultry-swine-cattle. Dry matter digestibility was increased 12% in tests by adding poultry waste, 6% by swine waste, and 0% by cattle waste. Recycling beef manure at rates up to 50% has been projected as safe. Ensiling also reduces the risk of transmitting pathogenic bacteria.

Pretreating feedlot waste with hydrogen peroxide and ferrous sulfate may improve the conversion of indigestible cellulose for microbial biomass production. At least one commercial process is now retailing this type of pretreatment system for refeeding livestock waste.

11. APPENDIX

Table 11-1. Earth basin, holding pond, and lagoon capacities.

Bank slope = 1.5:1. Volume allows for 2' of freeboard. All dimensions are in feet.

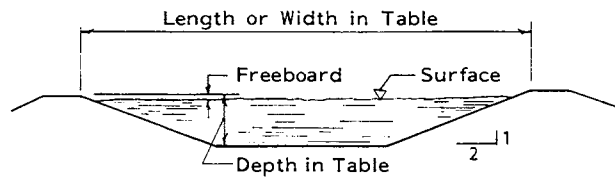


Volume, thousands of ft ³	Depth																			
	8					10					12					15				
	Interior width					Interior width					Interior width					Interior width				
	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200
	----- Interior length, ft -----																			
4	33	26	-	-	-	32	-	-	-	-	32	-	-	-	-	33	-	-	-	-
6	43	31	-	-	-	40	-	-	-	-	39	-	-	-	-	39	-	-	-	-
8	52	37	-	-	-	48	35	-	-	-	46	-	-	-	-	45	-	-	-	-
10	62	42	-	-	-	56	39	-	-	-	53	-	-	-	-	52	-	-	-	-
15	86	56	44	-	-	75	50	-	-	-	70	47	-	-	-	67	46	-	-	-
20	109	70	54	-	-	95	61	48	-	-	87	57	-	-	-	83	54	-	-	-
30	157	98	74	52	-	134	83	63	-	-	122	75	58	-	-	115	70	55	-	-
40	205	126	93	64	-	173	105	78	56	-	156	94	71	-	-	146	85	65	-	-
50	252	153	113	77	-	212	127	94	65	-	191	112	83	-	-	177	101	75	-	-
60	300	181	132	89	69	251	149	109	74	-	225	131	96	67	-	209	116	86	-	-
70	348	209	152	101	78	290	171	124	84	66	260	149	109	75	-	240	132	96	68	-
80	395	237	172	114	87	329	193	139	93	73	294	168	121	82	-	272	147	106	74	-
90	443	265	191	126	96	368	215	155	103	80	329	186	134	90	71	303	163	117	80	-
100	490	292	211	138	105	407	236	170	112	86	363	205	147	98	76	334	178	127	86	69
110	538	320	230	151	114	446	258	185	122	93	398	223	159	106	82	366	194	137	92	73
120	586	348	250	163	123	485	280	200	131	100	432	242	172	113	88	397	209	148	99	78
130	633	376	270	175	132	524	302	216	141	107	467	260	185	121	93	428	225	158	105	82
140	681	403	289	188	141	563	324	231	150	114	501	279	197	129	99	460	240	168	111	86
150	729	431	309	200	150	602	346	246	160	121	536	297	210	137	104	491	256	179	117	91
160	776	459	328	212	159	642	368	261	169	128	570	316	223	144	110	523	272	189	123	95
170	824	487	348	225	168	681	390	277	179	134	605	334	235	152	116	554	287	199	130	100
180	871	515	368	237	177	720	412	292	188	141	639	353	248	160	121	585	303	210	136	104
190	-	542	387	249	186	-	434	307	198	148	674	371	261	168	127	617	318	220	142	109
200	-	570	407	262	195	-	456	322	207	155	708	390	273	175	132	648	334	230	148	113
225	-	640	456	293	218	-	511	360	231	172	794	436	305	195	146	727	373	256	163	124
250	-	709	505	323	240	-	565	399	254	189	880	483	337	214	160	805	411	282	179	135
275	-	778	554	354	263	-	620	437	278	207	967	529	368	234	174	884	450	308	194	146

	Depth																			
	10					15					20					25				
	Interior width					Interior width					Interior width					Interior width				
	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400
	----- Interior length, ft -----																			
300	475	302	224	151	116	334	210	157	109	-	278	173	131	-	-	253	156	120	-	-
325	513	325	241	162	124	359	225	168	116	-	299	185	140	100	-	271	166	127	-	-
350	551	349	258	173	132	385	241	179	123	-	320	197	148	105	-	290	176	133	-	-
375	589	373	275	184	141	411	256	190	130	-	340	209	156	110	-	308	186	140	102	-
400	627	396	292	195	149	437	272	201	137	107	361	221	165	115	-	326	196	147	106	-
425	665	420	310	206	157	463	287	212	144	112	382	233	173	121	-	344	206	154	110	-
450	703	444	327	217	165	488	303	223	151	118	403	245	181	126	-	363	216	161	114	-
475	742	467	344	228	173	514	318	234	158	123	423	256	190	131	104	381	225	167	119	-
500	780	491	361	239	181	540	333	245	165	128	444	268	198	136	108	399	235	174	123	100
600	932	586	430	284	214	643	395	289	193	148	527	316	231	157	123	472	275	202	139	112
700	1084	681	499	328	247	747	457	333	221	169	610	363	264	178	138	545	315	229	156	124
800	-	775	567	372	280	850	519	377	249	189	693	411	298	199	153	618	355	256	173	136
900	-	870	636	417	312	953	581	422	277	210	776	458	331	219	169	691	394	283	190	148
1000	-	965	705	461	345	1056	642	466	305	231	859	506	364	240	184	765	434	311	207	160

Table 11-2. Earth basin, holding pond, and lagoon capacities.

Bank slope = 2:1. Volume allows for 2' of freeboard. All dimensions are in feet.

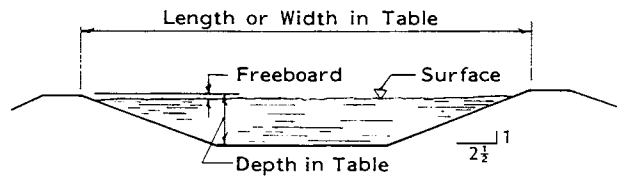


Volume, thousands of ft ³	Depth																			
	8					10					12					15				
	Interior width					Interior width					Interior width					Interior width				
	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200
	----- Interior length, ft -----																			
4	41	31	-	-	-	40	32	-	-	-	40	34	-	-	-	39	-	-	-	-
6	52	37	32	-	-	50	37	-	-	-	49	38	-	-	-	49	40	-	-	-
8	63	43	36	-	-	59	42	-	-	-	58	42	37	-	-	58	44	-	-	-
10	74	49	40	-	-	69	47	-	-	-	67	46	40	-	-	68	47	42	-	-
15	102	65	51	-	-	93	59	48	-	-	90	57	47	-	-	92	57	48	-	-
20	130	80	61	45	-	117	71	56	-	-	113	68	54	-	-	116	66	54	-	-
30	185	110	82	58	-	165	96	72	-	-	158	89	68	51	-	164	85	66	52	-
40	241	140	103	71	-	213	120	89	63	-	204	110	82	60	-	212	104	77	59	-
50	296	171	124	84	66	261	145	105	73	-	249	132	96	68	-	260	122	89	65	-
60	352	201	144	97	75	309	169	122	83	66	295	153	109	76	62	308	141	101	72	-
70	407	231	165	109	85	357	194	138	93	73	340	174	123	84	68	356	160	112	78	65
80	463	262	186	122	94	405	218	154	103	80	386	195	137	92	74	405	179	124	85	70
90	518	292	207	135	103	453	243	171	113	87	431	217	151	101	80	453	197	135	92	74
100	574	322	228	148	112	501	267	187	123	95	476	238	165	109	85	501	216	147	98	79
110	630	352	249	161	122	550	292	204	132	102	522	259	179	117	91	549	235	159	105	84
120	685	383	269	173	131	598	316	220	142	109	567	280	193	125	97	597	254	170	112	88
130	741	413	290	186	140	646	341	237	152	116	613	302	207	133	103	645	272	182	118	93
140	796	443	311	199	149	694	365	253	162	123	658	323	221	142	109	693	291	194	125	98
150	852	474	332	212	159	742	390	270	172	130	704	344	234	150	114	741	310	205	132	102
160	907	504	353	225	168	790	414	286	182	137	749	366	248	158	120	789	329	217	138	107
170	-	534	374	238	177	838	439	302	192	144	795	387	262	166	126	837	347	229	145	111
180	-	565	394	250	186	886	464	319	202	151	840	408	276	174	132	885	366	240	151	116
190	-	595	415	263	196	934	488	335	212	158	886	429	290	183	138	933	385	252	158	121
200	-	625	436	276	205	982	513	352	222	166	931	451	304	191	144	981	404	264	165	125
225	-	701	488	308	228	-	574	393	247	183	-	504	339	211	158	-	451	293	181	137
250	-	777	540	340	251	-	635	434	271	201	-	557	373	232	173	-	498	322	198	148
275	-	852	592	372	274	-	696	475	296	219	-	610	408	252	187	-	544	351	214	160

	Depth																			
	10					15					20					25				
	Interior width					Interior width					Interior width					Interior width				
	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400
	----- Interior length, ft -----																			
300	516	321	237	160	124	380	231	172	120	-	334	197	148	-	-	322	183	139	-	-
325	557	346	254	171	132	409	248	183	127	-	359	210	157	113	-	346	194	146	109	-
350	599	371	272	182	140	439	264	195	134	-	384	223	166	118	-	369	205	153	113	-
375	640	395	290	194	148	468	281	206	142	112	408	236	175	124	-	393	216	161	117	-
400	681	420	308	205	157	497	297	218	149	117	433	250	184	129	105	417	228	168	122	-
425	722	445	325	216	165	526	314	230	156	123	458	263	193	135	109	440	239	176	126	105
450	763	470	343	227	173	555	330	241	163	128	483	276	201	140	113	464	250	183	131	109
475	804	495	361	239	182	584	347	253	171	133	508	289	210	145	117	488	262	191	135	112
500	845	519	379	250	190	613	364	264	178	138	532	302	219	151	121	511	273	198	140	115
600	1010	619	450	295	223	730	430	311	207	159	632	354	255	173	136	606	318	228	157	127
700	-	718	521	341	256	846	496	357	236	181	731	407	291	194	152	700	364	258	175	140
800	-	817	592	386	290	963	563	403	265	202	830	459	326	216	168	795	409	287	193	152
900	-	916	663	431	323	1080	629	450	293	223	929	512	362	238	183	889	454	317	210	165
1000	-	1015	734	477	356	-	695	496	322	244	1028	564	397	259	199	984	500	347	228	178

Table 11-3. Earth basin, holding pond, and lagoon capacities.

Bank slope = 2.5:1. Volume allows for 2' of freeboard. All dimensions are in feet.



Volume, thousands of ft ³	Depth																			
	8					10					12					15				
	Interior width					Interior width					Interior width					Interior width				
	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200	50	75	100	150	200
	Interior length, ft																			
4	49	37	-	-	-	48	38	-	-	-	48	-	-	-	-	37	-	-	-	-
6	62	44	-	-	-	61	44	-	-	-	61	45	-	-	-	57	46	-	-	-
8	75	50	42	-	-	73	49	42	-	-	74	50	-	-	-	78	51	-	-	-
10	89	57	46	-	-	86	55	46	-	-	88	55	-	-	-	98	55	-	-	-
15	122	74	57	-	-	117	69	55	-	-	121	67	-	-	-	149	67	56	-	-
20	155	90	68	51	-	148	83	64	50	-	154	80	63	-	-	201	79	63	-	-
30	222	124	91	64	-	211	110	82	60	-	221	105	78	-	-	303	103	77	-	-
40	289	157	113	78	63	273	138	100	71	-	288	130	93	68	-	406	126	90	68	-
50	355	190	135	91	72	336	166	117	81	66	354	155	109	77	-	508	150	103	75	-
60	422	224	157	104	82	398	194	135	91	73	421	180	124	85	70	611	174	117	82	70
70	489	257	180	118	91	461	221	153	102	81	488	205	139	94	76	714	197	130	89	74
80	555	290	202	131	101	523	249	171	112	88	554	230	155	103	82	816	221	143	96	79
90	622	324	224	144	110	586	277	189	123	95	621	255	170	111	88	919	245	157	104	84
100	689	357	246	158	120	648	305	207	133	103	688	280	186	120	94	-	268	170	111	89
110	755	390	268	171	129	711	333	225	143	110	754	305	201	129	100	-	292	184	118	94
120	822	424	291	184	139	773	360	242	154	117	821	330	216	138	106	-	316	197	125	99
130	889	457	313	198	148	836	388	260	164	125	888	355	232	146	113	-	339	210	132	104
140	955	490	335	211	158	898	416	278	175	132	954	380	247	155	119	-	363	224	139	109
150	-	524	357	224	167	961	444	296	185	140	-	405	263	164	125	-	387	237	147	114
160	-	557	380	238	177	-	471	314	196	147	-	430	278	172	131	-	410	250	154	118
170	-	590	402	251	186	-	499	332	206	154	-	455	293	181	137	-	434	264	161	123
180	-	624	424	264	196	-	527	350	216	162	-	480	309	190	143	-	458	277	168	128
190	-	657	446	278	206	-	555	367	227	169	-	505	324	198	149	-	481	291	175	133
200	-	690	468	291	215	-	583	385	237	176	-	530	339	207	155	-	505	304	182	138
225	-	774	524	324	239	-	652	430	263	195	-	592	378	229	170	-	564	337	200	150
250	-	857	580	358	263	-	721	475	289	213	-	655	416	251	185	-	623	371	218	162
275	-	940	635	391	286	-	791	519	315	231	-	717	455	272	200	-	683	404	236	175

	Depth																			
	10					15					20					25				
	Interior width					Interior width					Interior width					Interior width				
	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400	100	150	200	300	400
	Interior length, ft																			
300	564	341	250	168	131	438	254	187	131	106	410	223	165	120	101	435	212	158	119	103
325	608	367	268	180	139	471	272	199	138	111	441	238	175	126	105	468	225	166	124	107
350	653	393	287	192	148	505	290	211	146	117	472	253	184	132	109	502	239	174	128	110
375	698	420	305	203	156	538	308	223	153	122	503	267	194	137	113	535	252	182	133	113
400	742	446	323	215	165	571	325	236	161	128	534	282	204	143	117	569	265	190	138	116
425	787	472	342	226	173	605	343	248	168	133	565	296	213	149	121	602	278	199	142	120
450	832	498	360	238	182	638	361	260	176	138	596	311	223	154	126	636	291	207	147	123
475	876	524	378	249	190	672	379	272	183	144	626	326	232	160	130	669	304	215	152	126
500	921	550	397	261	199	705	397	284	190	149	657	340	242	166	134	702	318	223	156	130
600	1100	654	470	307	232	839	469	333	220	171	781	399	280	188	150	836	370	256	175	143
700	-	758	544	354	266	973	540	382	250	192	904	457	319	211	166	970	423	289	194	156
800	-	862	617	400	300	1107	612	431	280	214	1028	516	357	234	182	1104	476	322	212	169
900	-	966	691	446	334	1240	683	480	310	235	-	574	395	256	198	-	528	355	231	182
1000	-	1071	765	492	367	1374	755	529	340	257	-	633	433	279	214	-	581	387	250	195

Livestock Weights

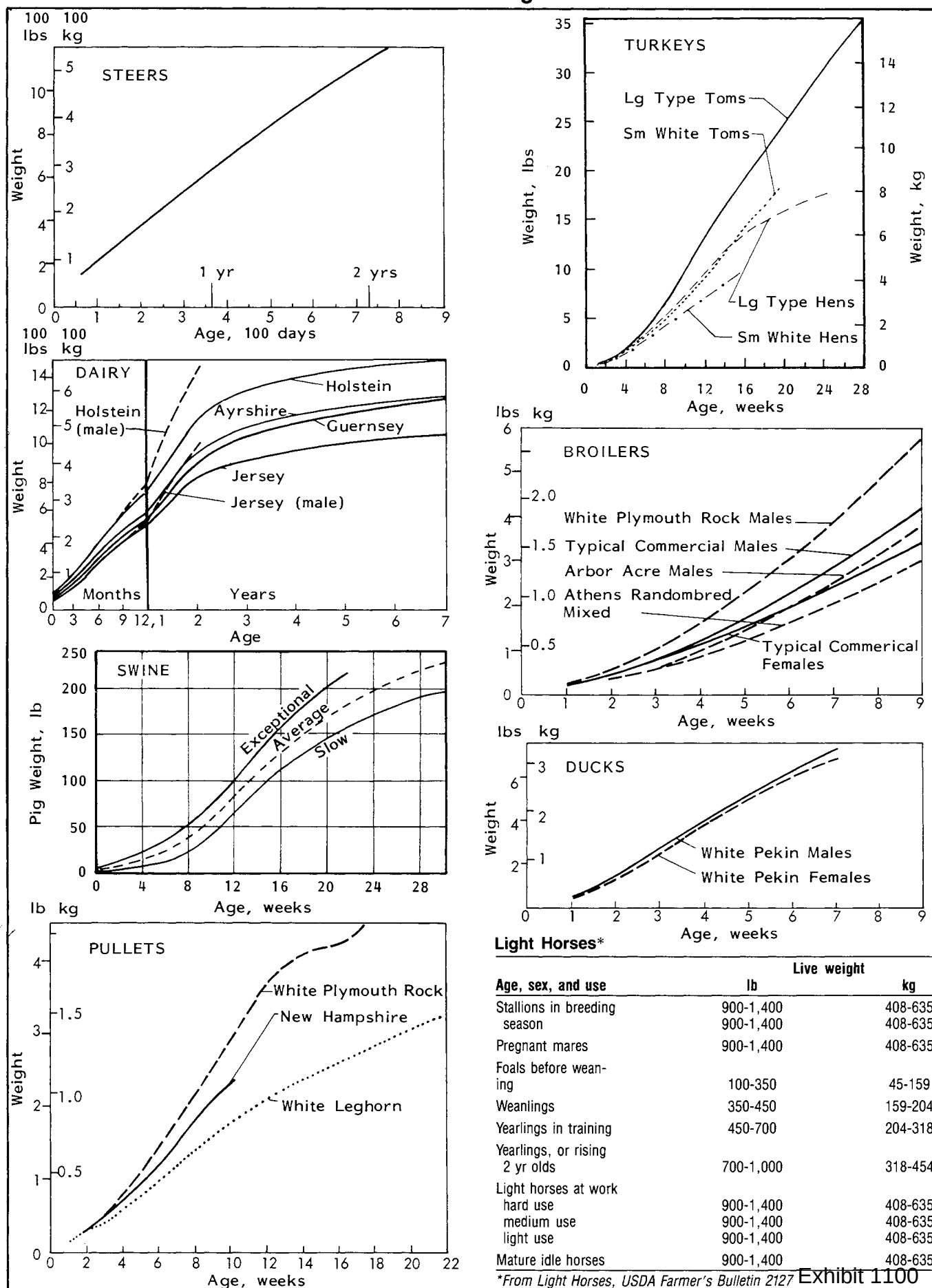


Fig 11-1. Weight vs. age of livestock.

From 1983 Agricultural Engineers Yearbook unless otherwise noted.

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The climate data in Figs 11-2 through 11-14 are from or adapted from the following sources: *Climate*

Atlas of the U.S., 1968 Dept. Commerce—ESSA; and *Technical Papers 25, 37, 41, and 49*, U.S. Dept. Commerce—ESSA.

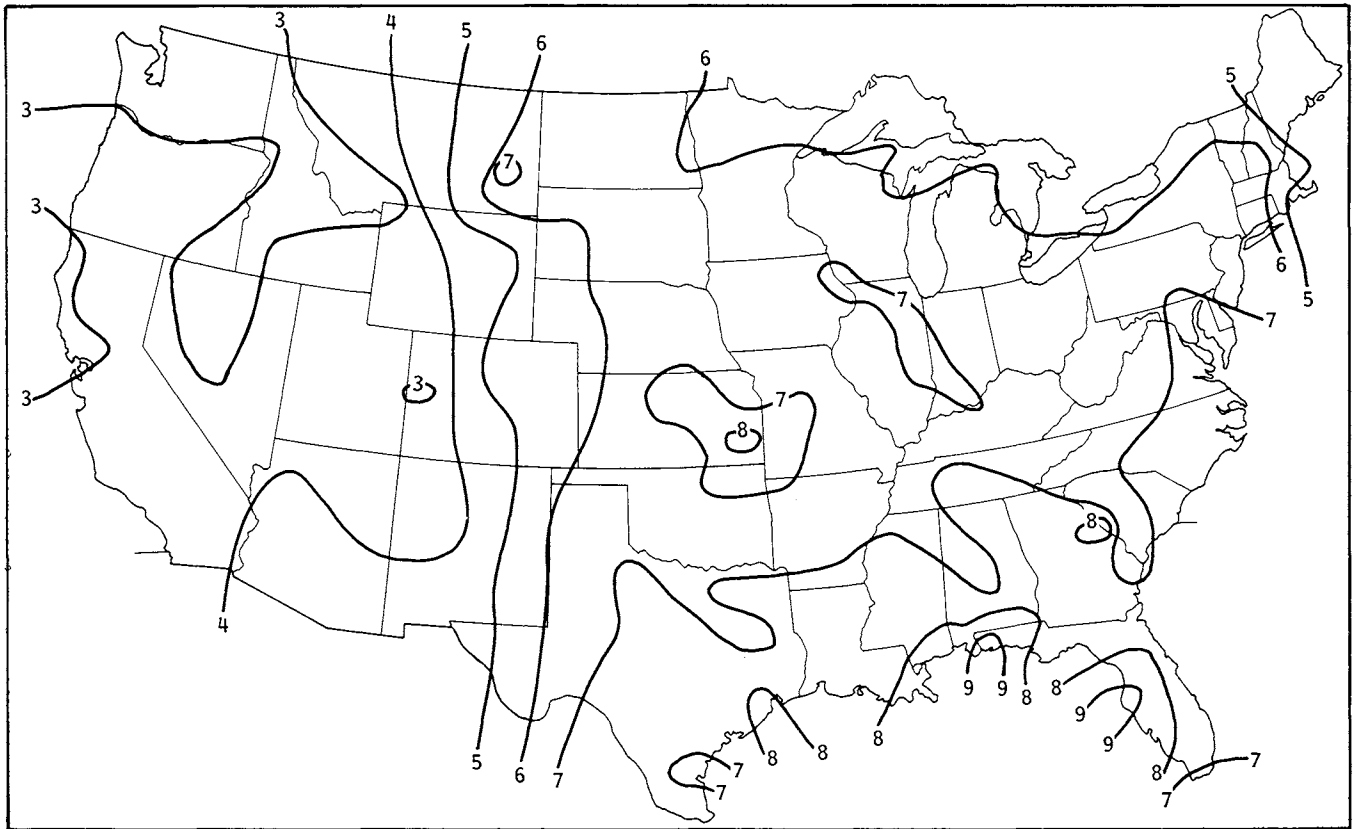


Fig 11-2. 10-yr, 5-min rainfall intensity, in/hr.



Fig 11-3. 25-yr, 5-min rainfall intensity, in/hr.

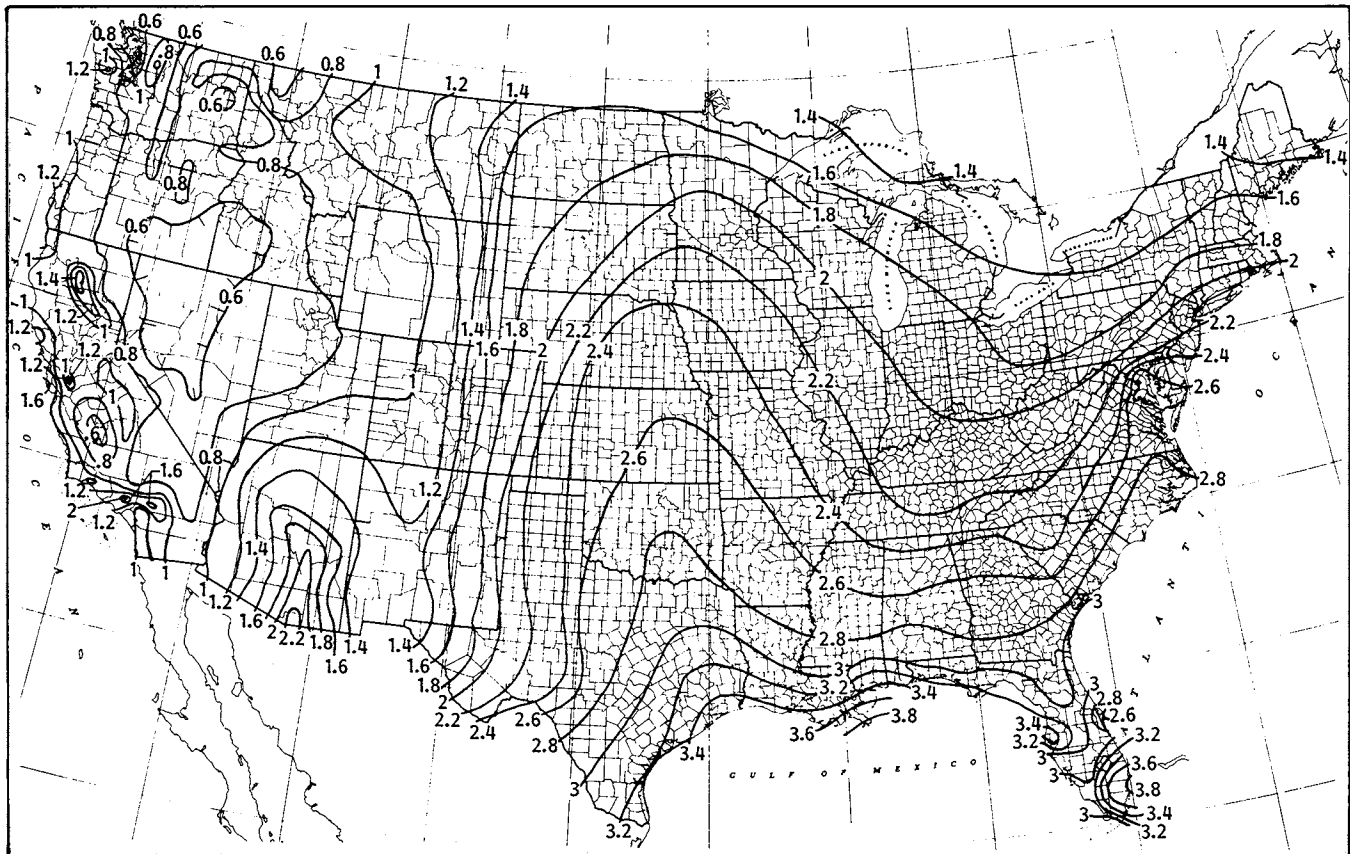


Fig 11-4. 10-yr, 1-hr rainfall intensity, in/hr.

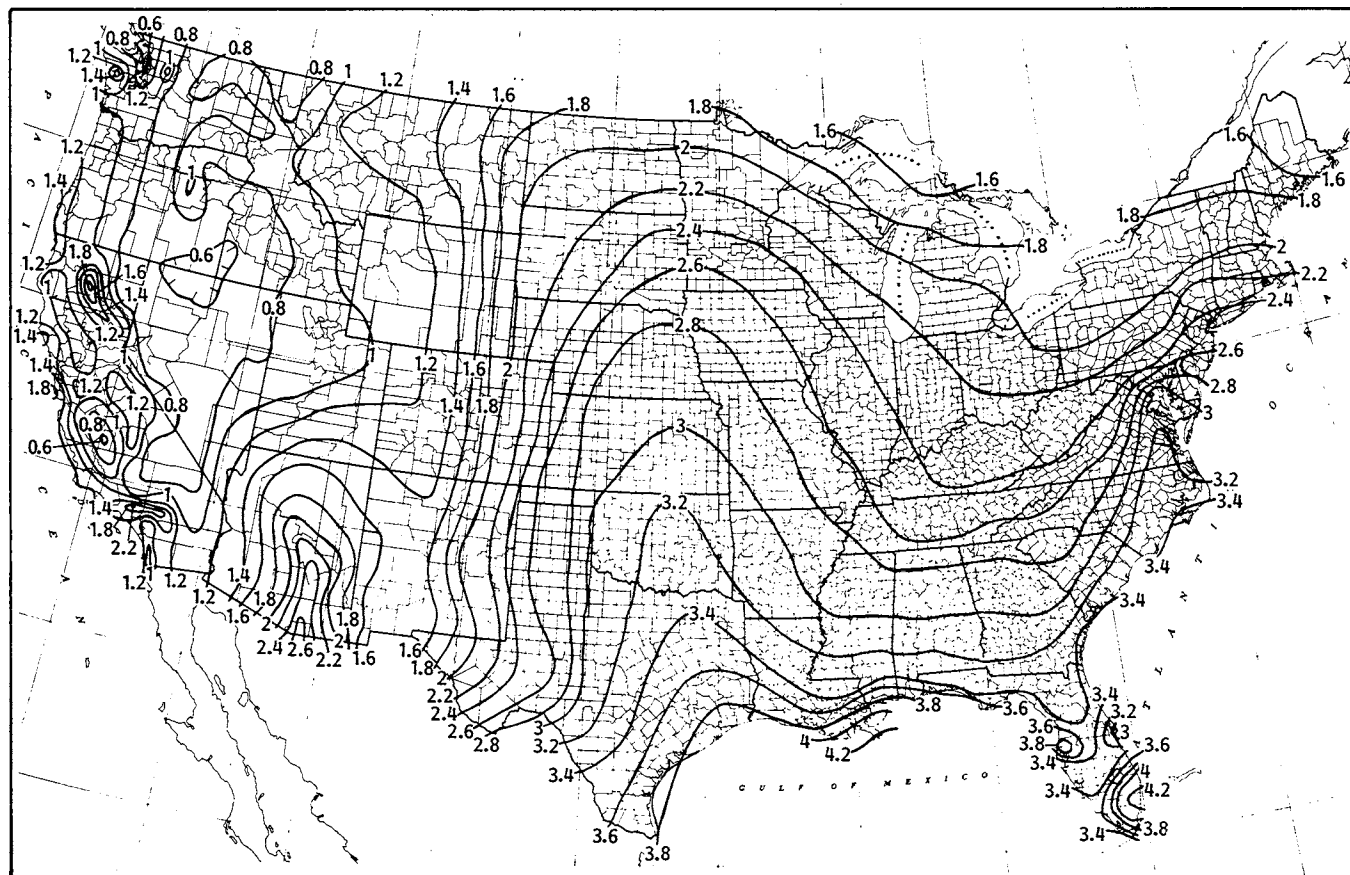


Fig 11-5. 25-yr, 1-hr rainfall intensity, in/hr.

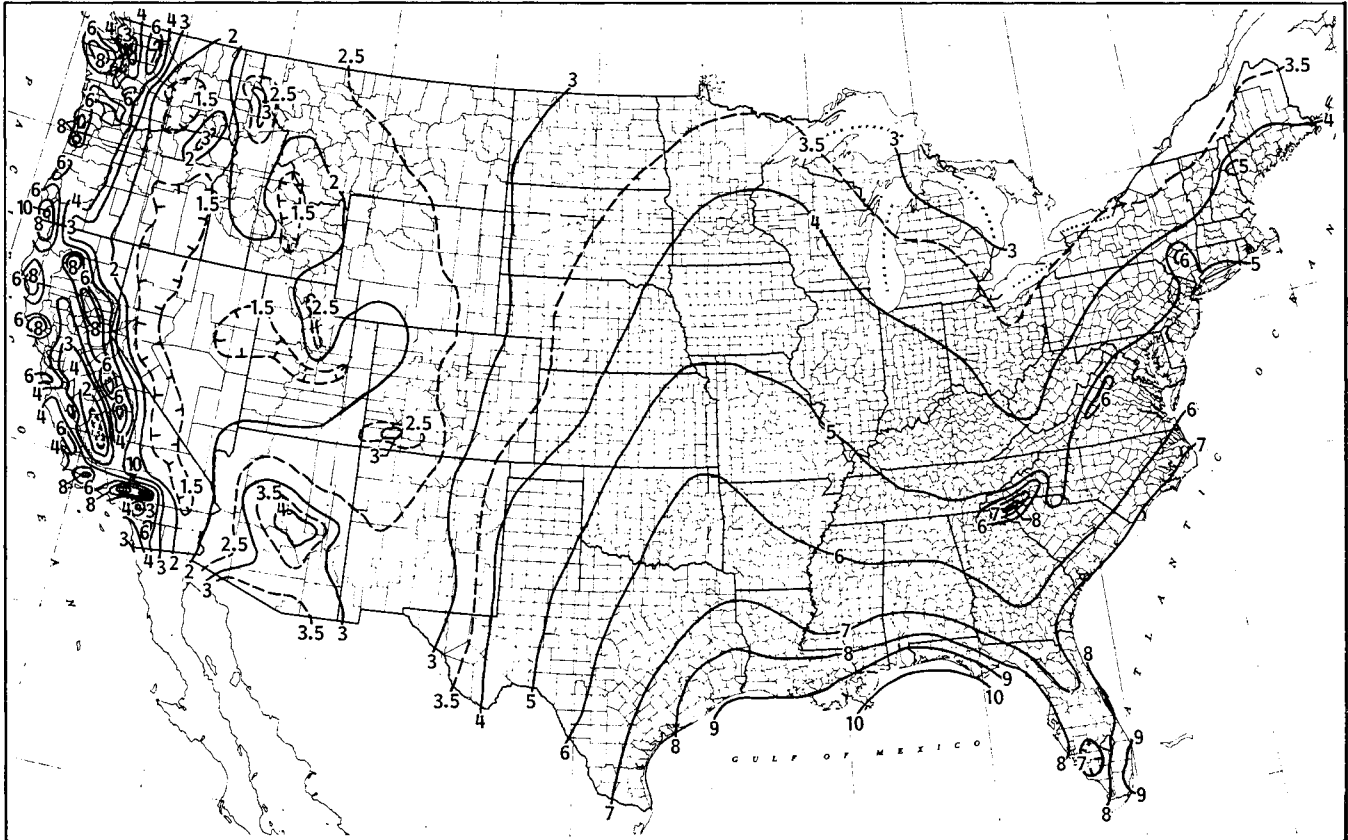


Fig 11-6. 10-yr, 24-hr rainfall, in.

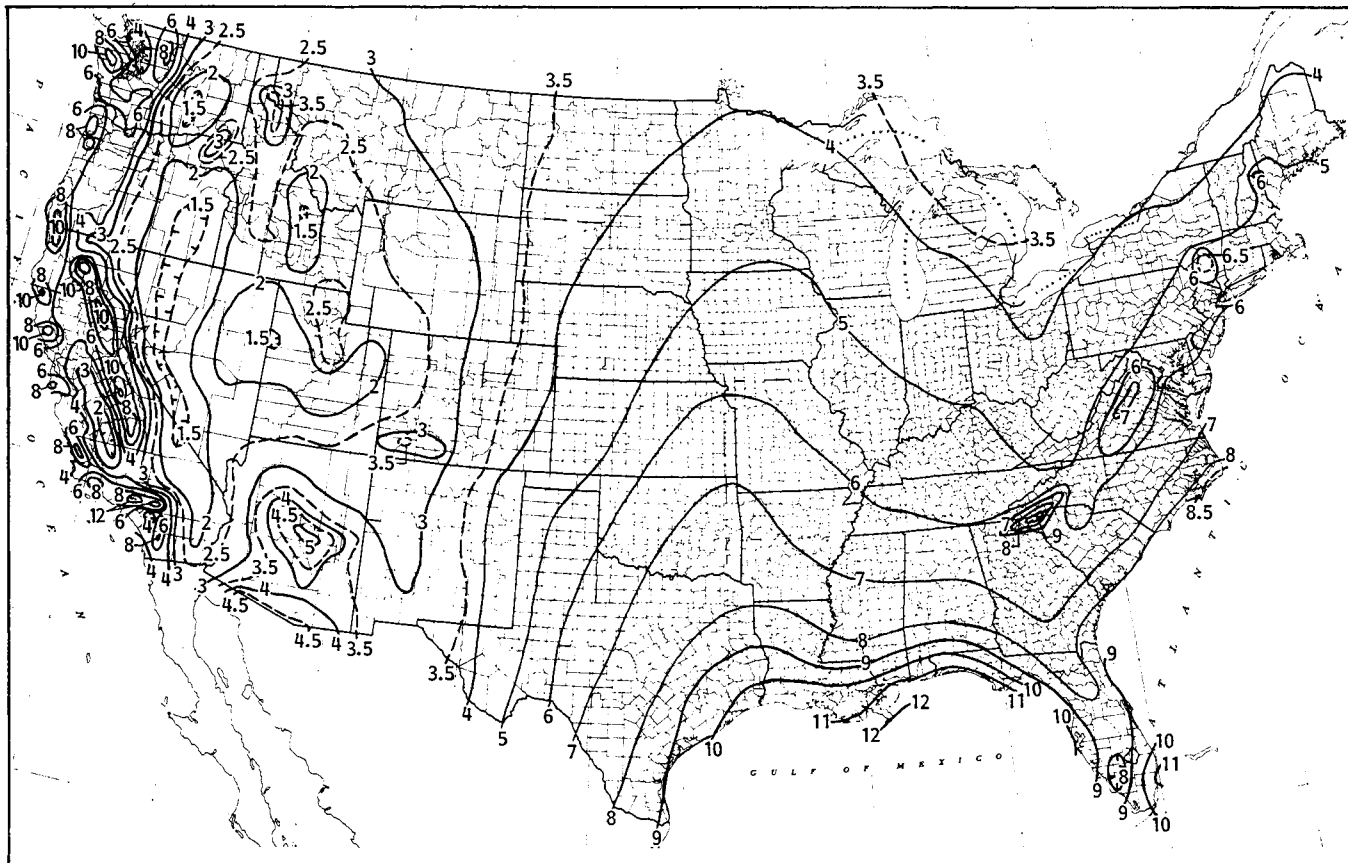


Fig 11-7. 25-yr, 24-hr rainfall, in.

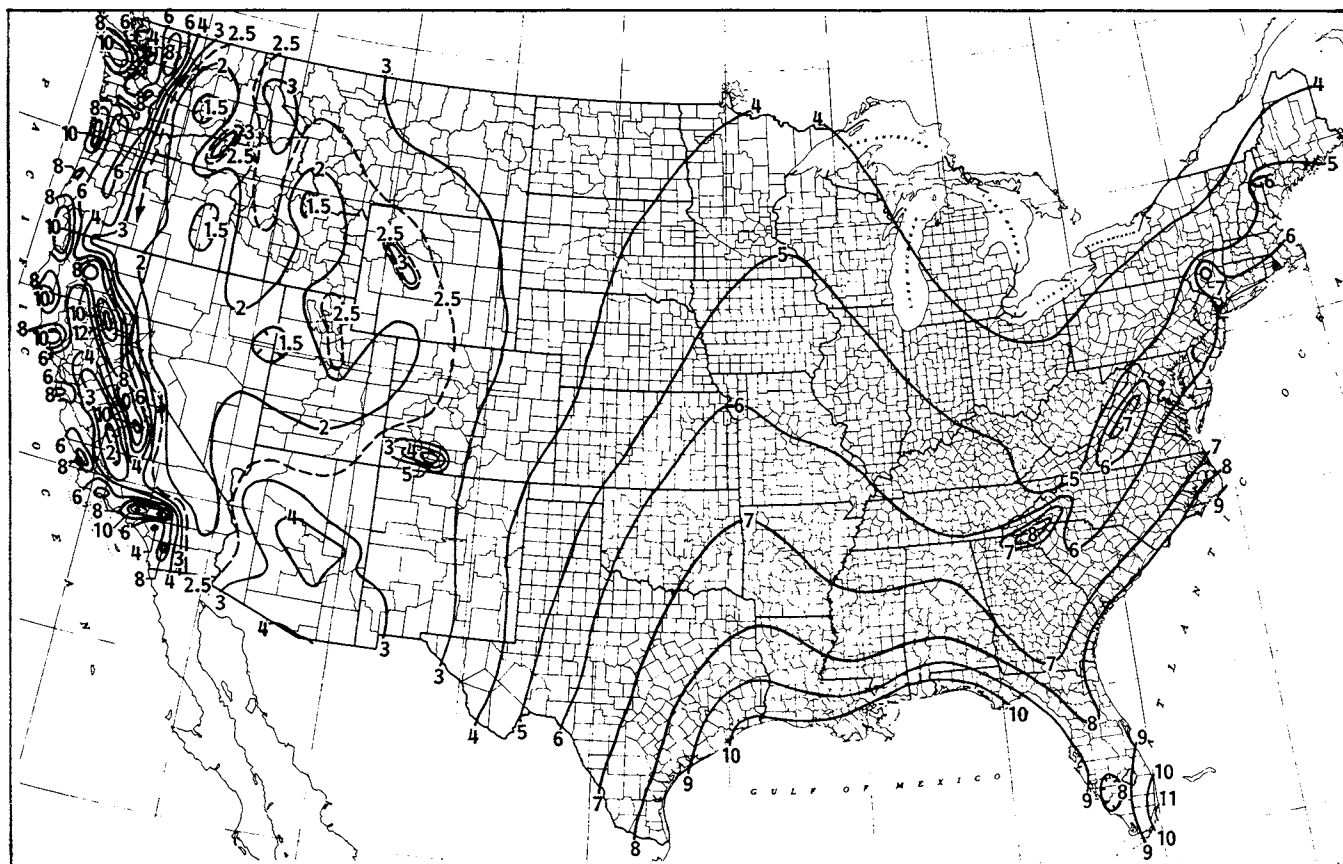


Fig 11-8. 10-yr, 2-day rainfall, in.

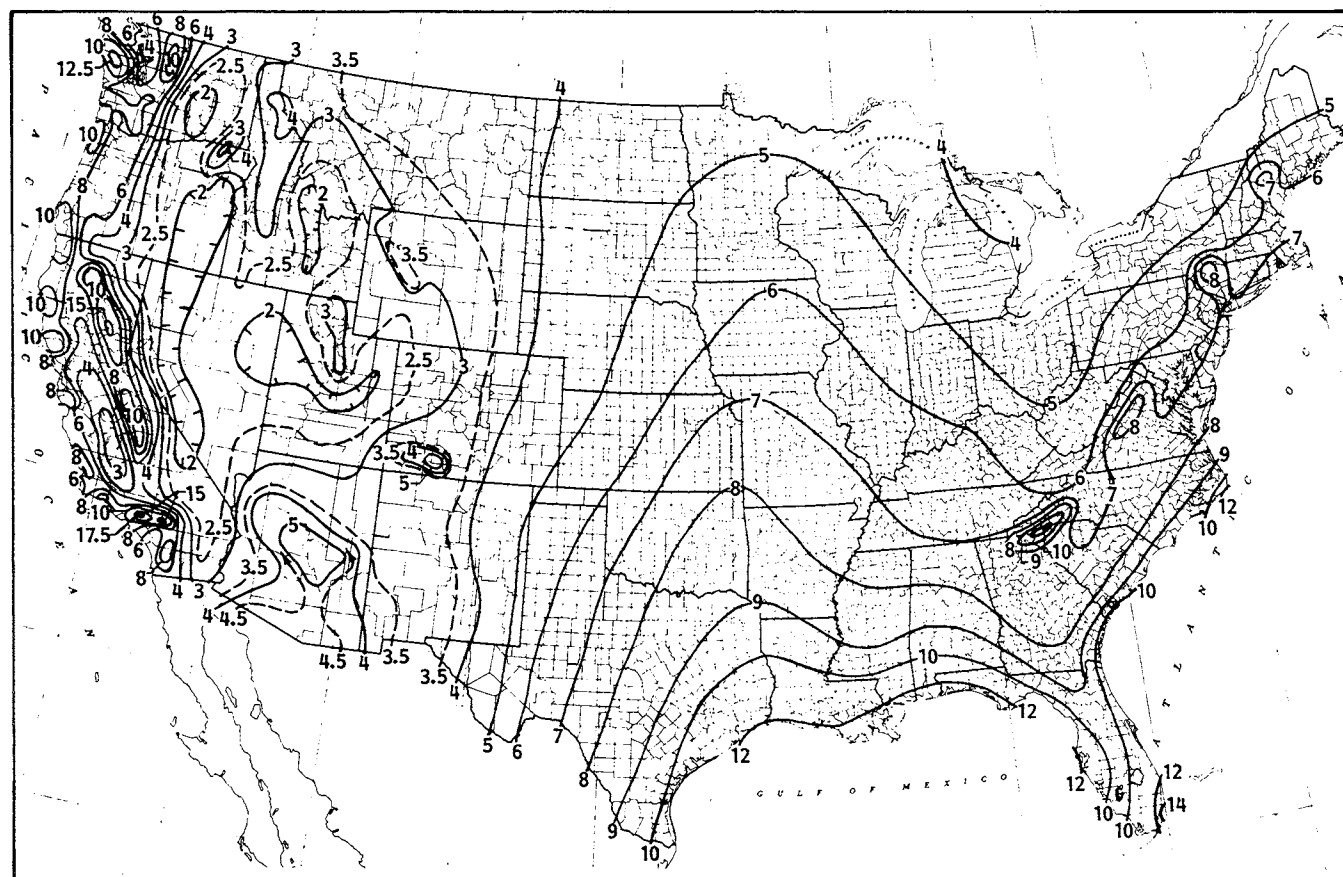


Fig 11-9. 25-yr, 2-day rainfall, in.

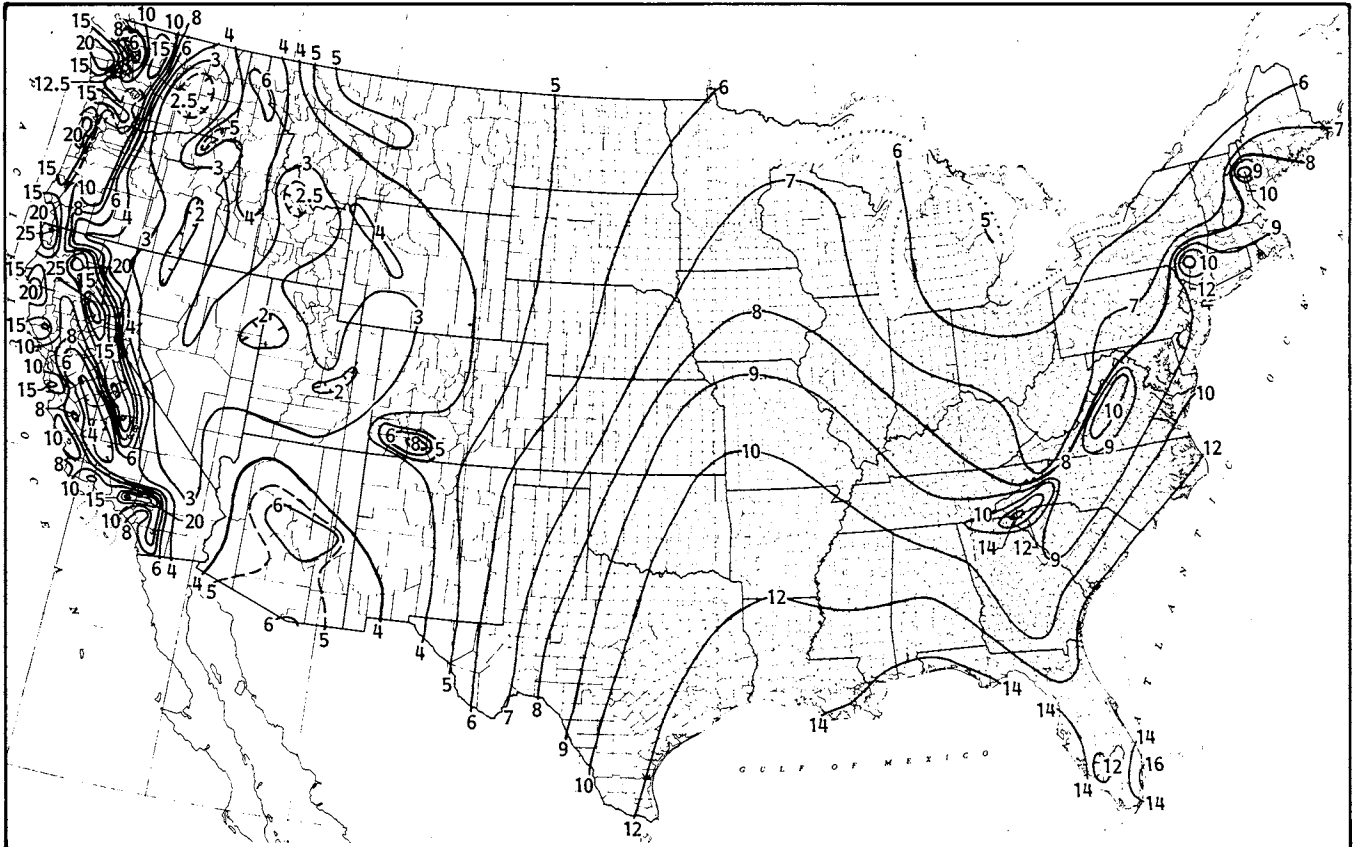


Fig 11-10. 10-yr, 10-day rainfall, in.

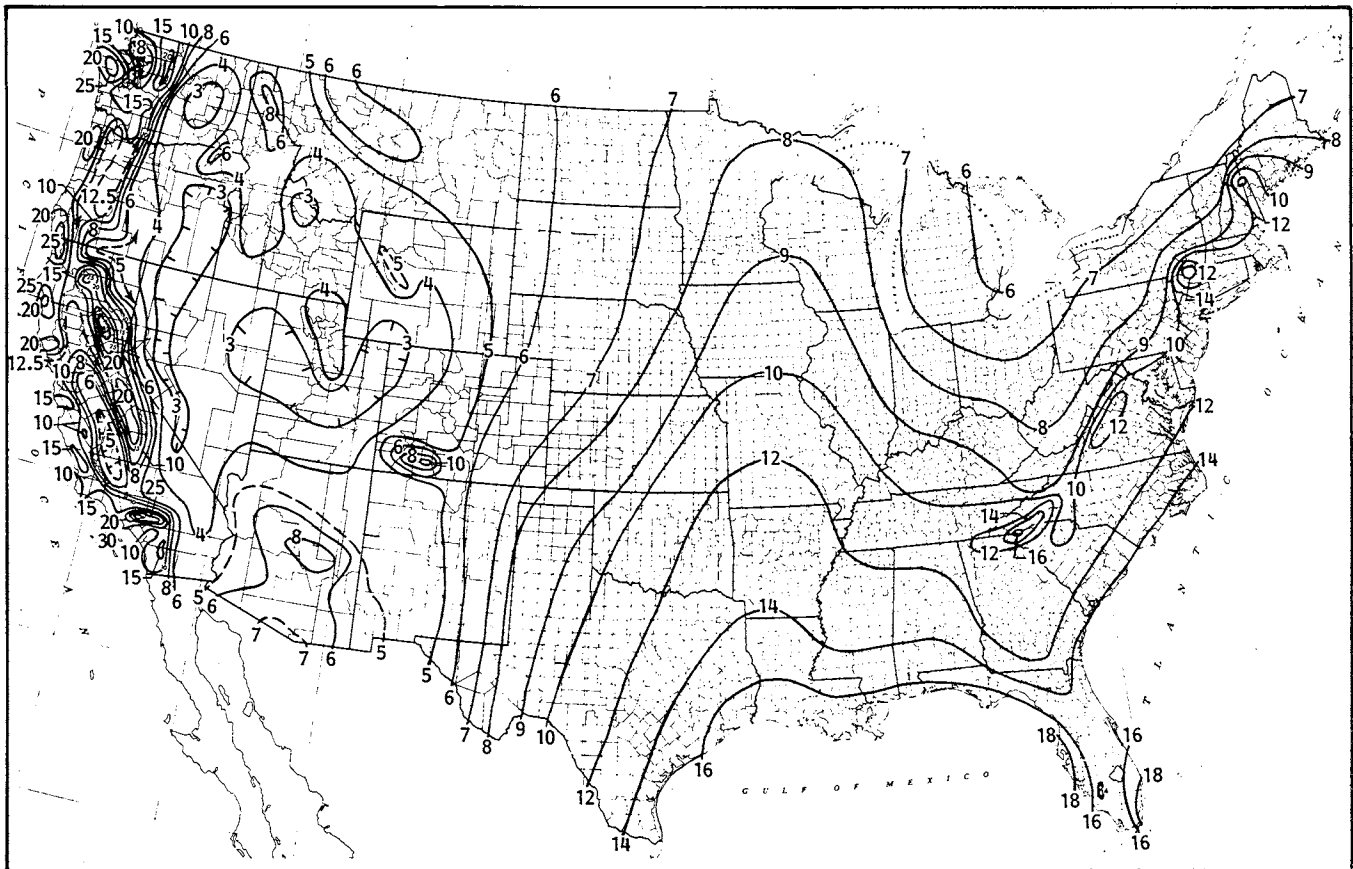


Fig 11-11. 25-yr, 10-day rainfall, in.

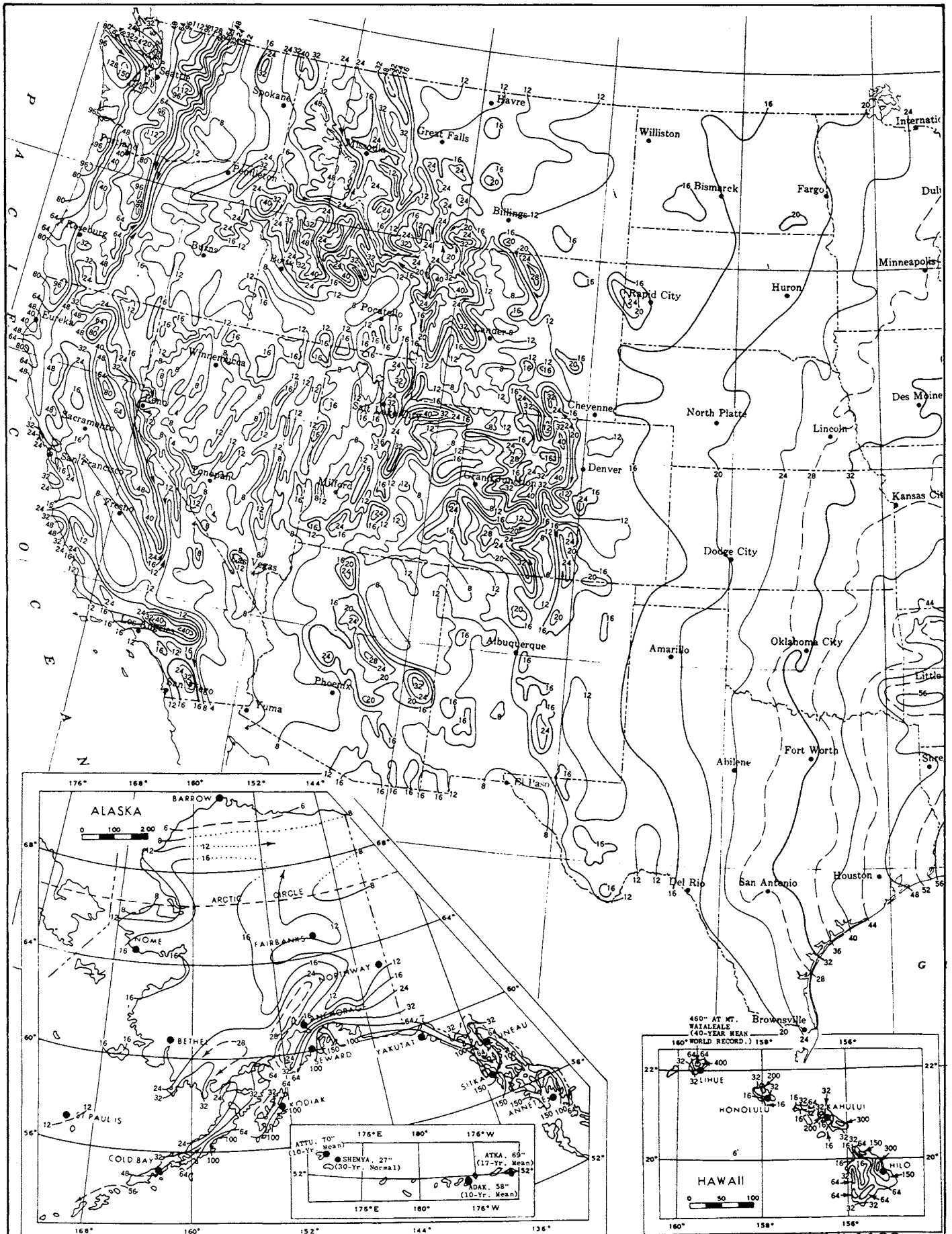
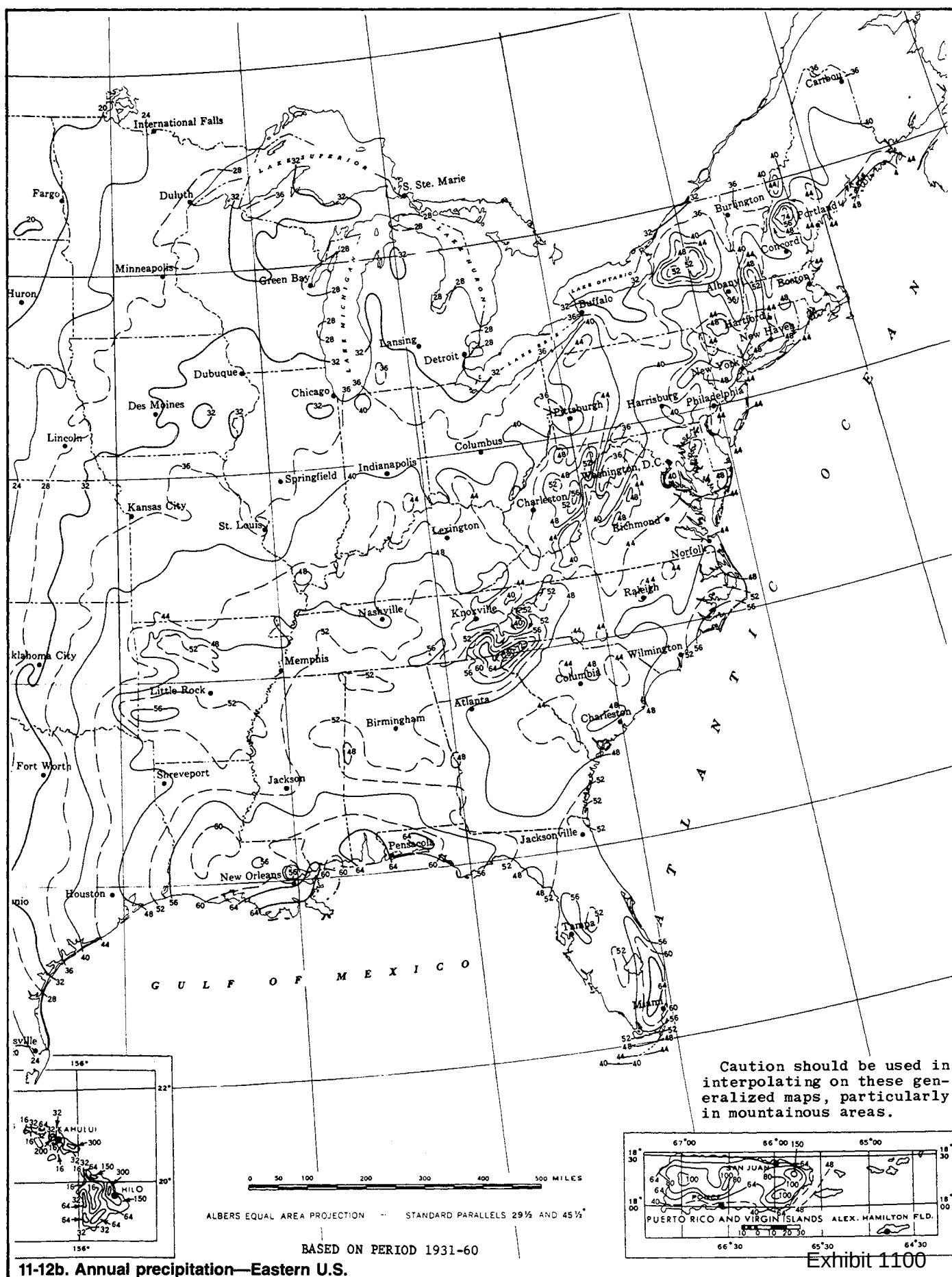


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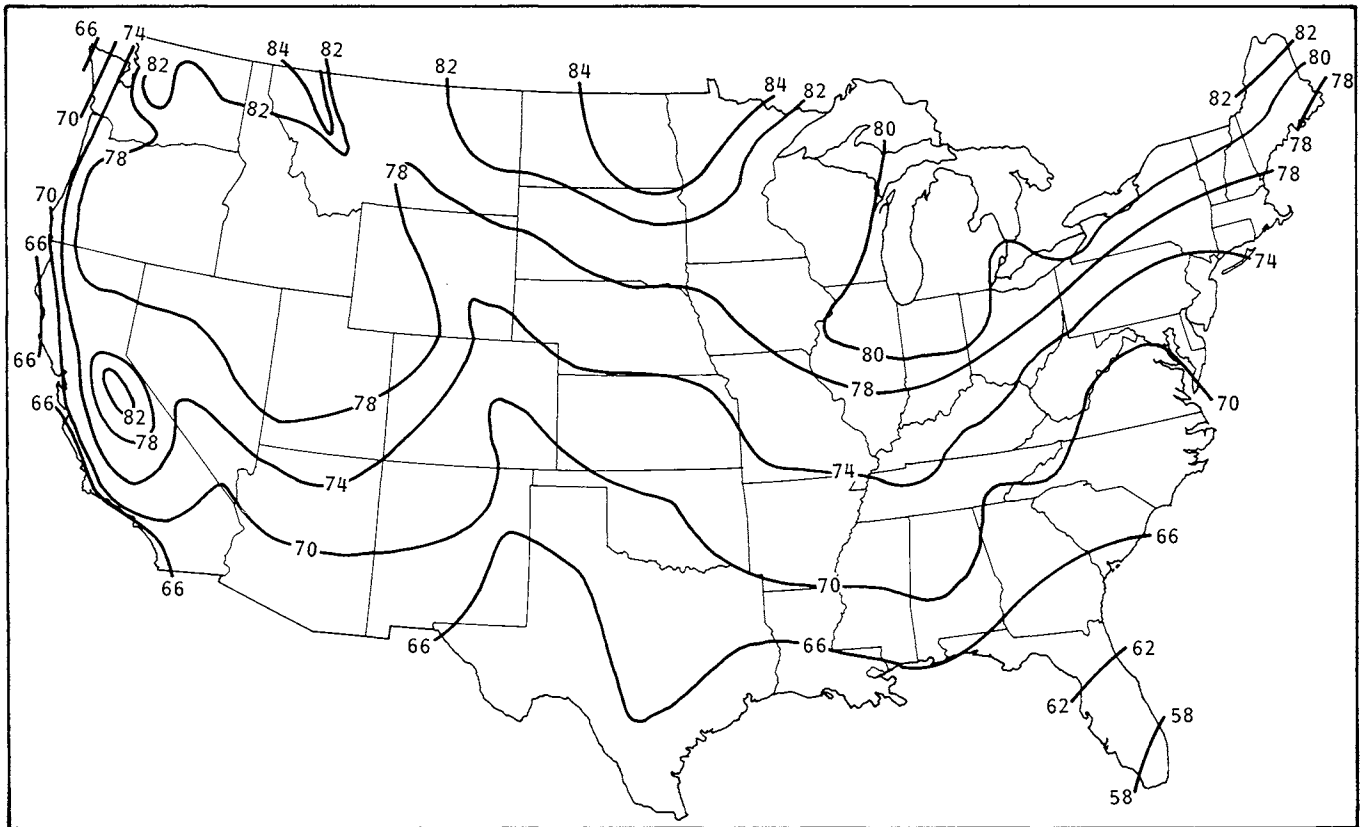


Fig 11-13. Mean May-October evaporation in percent of total.

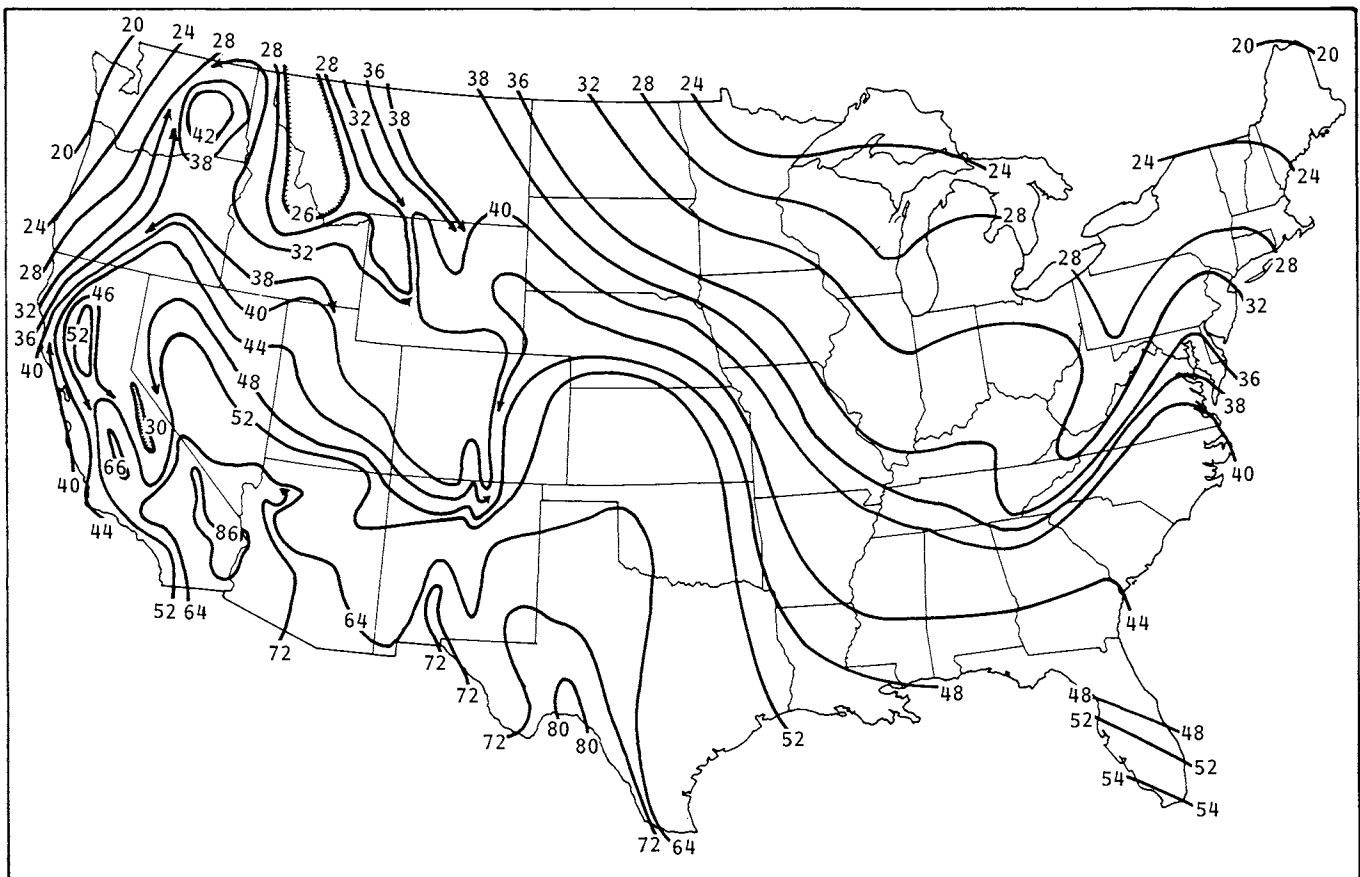


Fig 11-14. Mean annual lake evaporation, in.

12. GLOSSARY

(based on ASAE R292.1)

Aerobic bacteria. Bacteria that require free elemental oxygen for their growth. Oxygen in chemical combination will not support aerobic organisms.

Aerobic lagoon (see lagoon)

Aeration. Creating contact between air and a liquid by spraying the liquid in the air, bubbling air through the liquid, or agitating the liquid to promote surface absorption.

Agitation. The remixing of liquid and settled solids.

Anaerobic bacteria. Bacteria not requiring the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered by dissolved oxygen and sometimes by highly oxidized substances, such as sodium nitrates, nitrites, and perhaps sulfates.

Bacteria. A group of essentially one cell microscopic organisms lacking chlorophyll. Bacteria are usually regarded as plants.

Biochemical oxygen demand (BOD). The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. A standard test used in assessing wastewater strength.

Biodegradation. The destruction or mineralization of natural or synthetic organic materials by microorganisms.

Carbon-nitrogen ratio (C/N). The weight ratio of carbon to nitrogen.

Composting. The aerobic decomposition of organic wastes to a relatively stable humus subject to further, slower decay but sufficiently stable not to reheat or cause odor or fly problems.

Denitrification. The reduction of nitrates with nitrogen gas evolved as an end product.

Digestion. Commonly, the anaerobic breakdown of organic matter in water solution or suspension into simpler or more biologically stable compounds, or both. Organic matter may be decomposed to soluble organic acids or alcohols and then to gases such as methane and carbon dioxide. Bacterial action alone cannot complete destruction of organic solid materials.

Effluent. A liquid leaving a container or process.

Facultative bacteria. Bacteria that can grow in the presence, as well as in the absence, of oxygen.

Fertilizer value. The potential worth of the plant nutrients in the wastes and available to plants when applied to soil. It is the cost of obtaining the same nutrients commercially.

Filtration. The process of passing a liquid through a filter to remove suspended matter.

Holding pond. A storage, usually earthen, where lot runoff, lagoon effluent, and other dilute wastes are stored before final disposal. It is not designed for treatment.

Humus. The dark, high carbon residue from plant decomposition. Similar residues are in composted manure and well-digested sludges.

Infiltration. The process of water entering soil through the surface.

Infiltration rate. The rate at which water enters soil under a given condition, expressed as depth of water per unit time, usually inches per hour.

Influent. A liquid entering a container or process.

Lagoon. A treatment structure for agricultural wastes. Lagoons can be aerobic, anaerobic, or facultative depending on their loading and design, and can be used in series to produce a higher quality effluent.

Leaching. The removal of soluble constituents from soils or other material by water.

Livestock wastes. Manure with added bedding, rain or other water, soil, etc. It also includes wastes such as milkhouse or washing wastes not particularly associated with manure. It also includes hair, feathers, and other debris.

Lot. Any paved or unpaved outdoor animal area—feedlot, handling area, resting areas, etc.

Manure. The fecal and urinary defecations of livestock and poultry. Manure does not include spilled feed, bedding, or additional water or runoff.

Milkhouse wastes. Wastewater from milkhouse operations.

Organic matter. Chemical substances of animal or vegetable origin containing carbon.

pH. A measure of the hydrogen-ion concentration. A pH of 7 is neutral; pH = 0-7 is acidic; pH = 7-14 is alkaline.

Pollutant. A resource out of place; a resource is anything useful.

Settleable solids. Matter in wastewater that either settles to the bottom or floats to the top during a preselected settling period.

Settling tank. A tank in which settleable solids are removed by gravity.

Slotted flooring. The floor surface of a building that has open spaces or grooves to allow material to drop below the floor surface.

Solids content. The residue remaining after water is evaporated from a sample at a specified temperature, usually about 215 F (103 C).

Total solids. The sum of dissolved and undissolved solids in water or wastewater, usually stated in milligrams per liter.

Exhibit 1100

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