Section 6 Vegetative Treatment Area Design

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Topics

VTA design recommendations for:

- Size
- Encouraging sheet flow
- Plant materials
- Slope limitations
- Options for reducing discharge

Purpose

VTA is a fairly simple technology having modest design requirements. However, for a VTA to function properly and minimize the potential for release of polluted runoff, several fundamental design requirements must be considered including sizing, maintenance of sheet flow, and selection of plant materials. These few, but critical considerations, must be carefully evaluated to ensure that the environment is protected. This section reviews those critical design considerations for a properly functioning VTA.

Past research has documented that contaminants contained by feedlot runoff is too concentrated, even after treatment by a VTA, to be discharged into surface waters. It should also be recognized, that the NPDES permit granted to a CAFO will require equal or better performance for a VTA as compared to a conventional holding pond and land application. A properly designed VTA is critical to limiting VTA runoff and protecting surface and ground water. Proper design must address:

- Minimum size requirements
- Distribution of flow and nutrients within the VTA
- Proper selection of forage or grass
- Recognizing VTA slope limitations

VTA definition

A VTA is an area of planted or indigenous vegetation situated downslope of animal production facilities that provides localized erosion protection and contaminant reduction. Planted or indigenous vegetation preferably includes perennial vegetation including forages, grasses, or pasture. These crops are used to treat runoff through evapotranspiration, adsorption, settling, and infiltration. Thus, the word treatment in the term describes an important function of these soil- and plant-based systems. VTS refers to a collection of treatment components, including at least one component based upon vegetation treatment that is used to manage the runoff from an open lot production system or other process waters.

A summary of the treatment performance of these systems is included in Section 9, Literature Review. This technology has received significant research evaluation and development with more than 30 research applications of VTAs to manure or runoff from animal agriculture applications.

Four alternative types of soil- and plant-based runoff treatment components have been used to treat animal manures, open lot runoff, or other process waters:

- *VTAs*—Perennial grass and forage filters can be applied to lower sloping land (sec. 6). Woody plants, trees, and annual forages may provide alternative plant materials for VTA, although there is less experience with these plant materials. Proper sizing, plant selection, and creating and maintaining sheet flow of runoff are critical design considerations for optimum performing VTAs.
- *Terraced VTAs* have been used to contain runoff on sloped areas. Both overflow and sepentine terraces have been used. Overflow terraces move runoff from one terrace to a second by cascading of runoff over the terrace top or by plastic tile drains. Serpentine terraces move runoff back and forth across the face of a slope. In both situations, the upper terrace is typically used for solids settling with succeeding terraces intended to encourage infiltration of liquids into the soil. Terraced systems are considered a subcategory of VTAs and may provide an optional approach for open lot systems located in steeper terrain.
- *VIBs* have many similarities to VTAs with the exception that they include subsurface collection and drainage and complete enclosure by a berm designed to prevent surface discharges. Runoff from an open lot is allowed to infiltrate through a soil system within 30 to 72 hours. Section 7 focuses on the design of VIBs.
- *Constructed wetlands* have been utilized to treat open lot runoff. Design and management is challenged by intermittent flow from open lots with resulting difficulty in maintaining wetlands function. Seasonal open lots used for winter livestock housing and empty during the summer may be a preferred system for constructed wetlands. Constructed wetlands are recognized as an alternative, but are not described in detail in this publication. For additional information on constructed wetland application to animal effluents, see Payne 1992 and Gulf of Mexico Program 1997.

VTA sizing

Proper VTA sizing is essential to:

- Minimizing excess nutrient accumulation and leaching within a VTA
- Limiting the potential for an unplanned release of runoff from the VTA

Two approaches are currently used for sizing the area required by a VTA. One approach is based upon a balance between the nutrients contained within the runoff with the nutrients harvested by the forage or grass grown within the VTA. A second approach is based upon a water balance, matching the rate of runoff water collected from an open lot and additional drainage area with the water infiltration rates of the land area used for the VTA. The following discussion examines these two sizing procedures in greater detail and reviews their strengths and weaknesses.

Sizing of a VTA based upon a water balance method offers several environmental advantages:

- Infiltration of feedlot runoff into the VTA for most storm events, thus, minimizing the potential for contaminated runoff from the VTA
- The limited potential for release of runoff from a VTA and the presence of perennial vegetation results in minimum potential contamination of surface water from soil, phosphorus, and pathogen movement. This advantage is most distinct when compared to baseline systems based upon row crop production.

Sizing of a VTA based upon a nitrogen balance method should produce the same advantages as one based upon a water balance with one additional environmental benefit:

- Reduced nitrogen leaching to ground water resulting from a rough balance between nitrogen applied and nitrogen harvested within a VTA. Because of the non-uniform infiltration of runoff and the associated nitrogen into the VTA soils, nitrogen leaching remains a potential concern within some areas of a VTA.

Alternative sizing procedures target runoff contact time with vegetation in the VTA and/or flow depth at the entrance to the VTA. These alternative design methods may be adequate for AFOs that have modest risk of being classified as a CAFO, but should only be used as design refinements for VTAs on CAFOs to assure distribution throughout the VTA. Sizing methods that assure infiltration of feedlot runoff for most precipitation events are critical for CAFOs.

The Iowa State University VTA performance model discussed in section 2 uses a comprehensive water balance method for estimating VTA size. It allows factors such as multiple soil layers, shallow ground water tables, timing of runoff release into the VTA, and other factors to be considered in a robust water balance estimate of performance. This performance model estimates surface water releases of water and the four required contaminants, but currently makes no prediction of nitrate movement to ground water.

VTA sizing by nutrient balance

To design a VTA that minimizes release of feedlot runoff nutrients to surface and ground water, four critical questions must be answered. This section provides information for answering those questions.

What is the volume of runoff from the feedlot?

The volume of runoff from a feedlot for a given storm is commonly estimated using the NRCS curve number method and a selected storm event. This method is described in the NRCS National Engineering Handbook, Part 630, chapter 10. A summary of this procedure along with an example problem is provided in appendix B.

What is the mass of nutrients in the feedlot runoff?

VTAs are usually designed to retain nitrogen. This method is primarily intended to limit potential leaching of nitrate to ground water. Additional considerations to protect ground water are discussed in section 3 on site selection and section 8 on management to protect ground water.

Nitrogen is generally the limiting nutrient in VTA design for feedlot runoff. Limited movement of phosphorus with runoff and settling of significant portions of the phosphorus in the settling basin limits the phosphorus risk. It is further assumed phosphorus that is not attached to the settleable solids will become adsorbed in the soil profile or utilized by the crop once the runoff water infiltrates the soils of the VTA. VTAs with perennial vegetation should have minimal risk associated with phosphorus buildup and runoff. Regular harvesting of VTA vegetation will help keep phosphorus levels in check. Soil phosphorus levels should be monitored regularly (sec. 8) for confirming that assumption.

Three methods are used to estimate the mass of nitrogen leaving a feedlot through runoff:

Method 1 requires a runoff nitrogen concentration from similar paved and unpaved feedlots and assumes these concentrations will be representative of the runoff from the feedlot under consideration for a VTA. Annual runoff volume can be determined from figures B–2 and B–3 of appendix B.

As illustrated in table 5–1 (sec. 5), considerable variation exists in nitrogen concentration in runoff. It is best to use numbers from the feedlot for which a VTA is being designed or numbers collected from the region in which the feedlot is located. Precipitation rates and patterns influence the concentration of nutrients in runoff and regionally specific runoff nutrient concentrations should be used. *If no local data on feedlot runoff nutrient concentration is available, this method may not be acceptable.*

Method 2 is described in lesson 22 of the Mid-West Plan Service Livestock and Poultry Environmental Stewardship Program. This method uses a relationship between annual runoff and annual rainfall as represented in figure 6–1.

Method 1

$$\text{Annual N leaving feedlot} = \text{Annual runoff volume} \times \text{N concentration in runoff}$$

Method 3 is based upon standard values for as excreted nitrogen in manure and estimates of nitrogen in runoff and availability of nitrogen to the crop. Section 9 summarizes the research literature basis for these estimates. This method assumes that:

- Nitrogen leaving the lot as runoff represents 5 percent of the annual excreted nitrogen
- Nitrogen entering the VTA after solids removal represents 50 percent of the nitrogen in runoff (the remaining 50 percent is retained as settled solids in a settling basin or comparable solids removal treatment)
- Nitrogen available for crop uptake is 50 percent of nitrogen entering VTA (losses due to ammonia volatilization and denitrification)

These estimates are adequate to design systems that utilize open lot runoff. When in operation, the stored runoff should be sampled to determine the actual nitrogen concentration and the wastewater applied accordingly. Runoff application rates to the VTA may not be adjustable. However, record keeping on rainfall events (which can be used to approximate application rate), runoff nutrient concentration and other indicators of N management (section 8) should be used in adjustment of any additional nitrogen fertilizer application to the grass or forage system (table 6–1).

Some systems based upon a VTA may include additional pre-treatment in advance of the VTA. For example, VTS option 3 described in section 3 includes both solids removal and VIB in advance of the VTA. Based upon past research and experience, the VIB will consistently remove at least 75 percent of the nitrogen in advance of the VTA. Thus, for VTS option 3, reduce the previous estimates for N reaching the VTA by 75 percent to account for the additional pre-treatment resulting from both the solids removal and VIB.

Figure 6–1 Method 2 estimate of annual N released from paved and earthen feedlot surfaces. Refer to figure B–2 appendix B, for value for annual runoff percent to enter on x-axis.

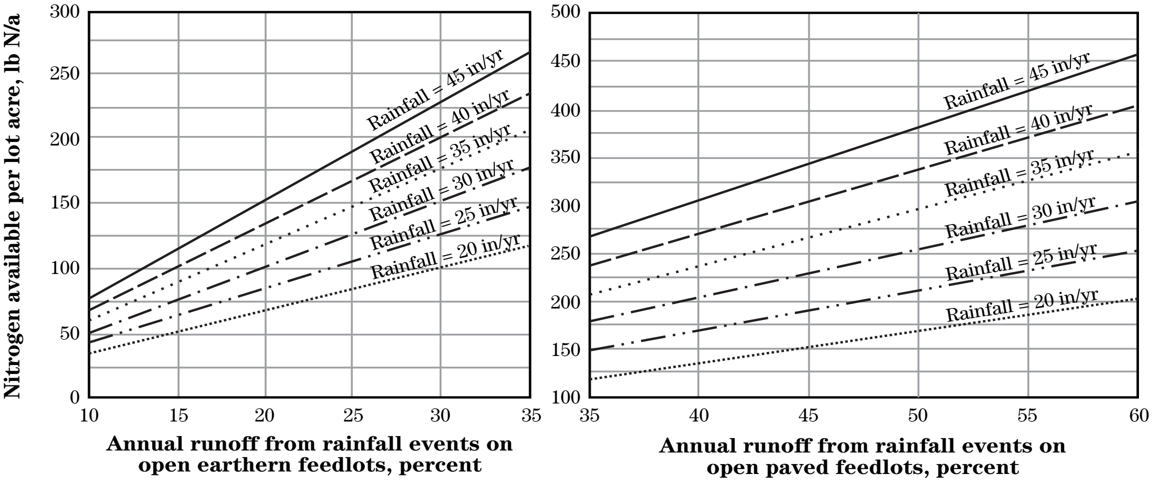

Table 6–1 Method 3 for estimating nitrogen in runoff

Species	Typical nitrogen excretion	N in runoff from open lot [1]	Plant available N [2]
		lb N/finished animal	
Beef finish cattle	55	2.8	0.69
		lb N/finished animal	
Beef – Cow	0.42	0.021	0.0053
Beef – Growing calf	0.29	0.015	0.0036
Dairy – Lactating cow	0.98	0.049	0.012
Dairy – Dry cow	0.50	0.025	0.0063
Dairy – Calf (330 lb)	0.14	0.0070	0.0018
Dairy – Heifer (970 lb)	0.26	0.013	0.0033
Horse – Sedentary (1,100 lb)	0.20	0.010	0.0025
Horse – Intense exercise (1,100 lb)	0.34	0.017	0.043

[1] Assumes 5% of excreted N is runoff

[2] Assumes 50% of N in runoff is retained after solids separation and 50% of retained N is plant available

Example: Estimate the N in runoff using the three methods for a 2,000 head capacity dirt feedlot located in central Iowa. The feedlot is 11.5 acres in area with an additional 8 acres of roads, drainage ditches, feed storage and preparation areas, and compost site draining into the settling basin. The settling basin's surface area is 123,000 square feet. Annual precipitation is 34 inches. A nearby feedlot has observed an average concentration of 25 pounds total N/acre-inch in runoff samples collected after solids settling. See examples in appendix B for additional information.

Method 1

Total volume to VTA (a-in) = Annual runoff from eedlot and contributing area +
(area of settling basin x annual rainfall)
= 240 a-in (from app. B example problem) +
($123{,}000 \text{ ft}^2 \div 43{,}560 \text{ ft}^2/\text{a}$) x 34 in
= 336 a-in/yr

Using a runoff sample from a nearby feedlot (25 lb N/a-in), total N in runoff is:
25 lb N/a-in x 336 a-in = 8,400 lb total N from feedlot per yr
Plant available N (50% of total N) is:
8,400 lb total N x 0.5 = 4,200 lb plant available N/yr

Discussion: Is the concentrations of N in runoff from a nearby feedlot representative of this feedlot? The amount of dilution water from contributing areas can significantly change the N concentration between feedlots. Our example feedlot has significant runoff from the 8 acres of contributing area outside of the feedlot.

Method 2

From figure 6–1 with 23 percent annual runoff[1], 140 pounds of N in runoff per acre of feedlot area from the 11.5 acres of feedlot (assume N runoff from 8 acres additional contributing area is minimal):
140 lb N/a of drainage area x 11.5 a = 1,610 lb N

Method 3

From table 6-1, assuming 5 percent of N is in runoff and 25 percent of that nitrogen will become crop available:
0.69 lb N/finished animal x 4,000 head finished = 2,800 lb plant available N

Discussion: Large volume of dilution water (150 a-in of runoff from roads and other contributing areas and 96 a-in from rainfall on settling basin) make method 1 suspect. No reason was found to reject methods 2 and 3. Select larger estimate of methods 2 and 3 or 2,800 pounds plant available N from feedlot.

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[1] 23% annual runoff estimate is from appendix B, figure B–2 for Earthen open lot runoff (CN=90)

How large will the VTA need to be to capture these nutrients?

If the designer is able to make an appropriate estimate of the pounds of nitrogen that will be applied to the VTA on an annual basis, the minimum size of the VTA can be computed by dividing the nitrogen to be applied to the VTA on an annual basis by the annual nitrogen uptake of the vegetation in the VTA. State or local agronomy guides should be used to determine reasonable crop yields and nitrogen uptake values. In many cases, VTA yield will exceed typical non-irrigated yields in the same locality. In the absence of localized data, use table 6–2 for nitrogen uptake.

For conventional holding ponds and spray irrigation systems, 1 acre of feedlot requires approximately 1 acre of land application area to manage the nitrogen. Similar and possibly slightly larger VTA areas might be needed for a VTA due to a smaller nitrogen volatilization rate during storage and land application. As a result, a land area of between 1 and 1.5 acres VTA per acre of feedlot might be a reasonable starting point for estimating VTA size based upon nitrogen.

How will the nutrient loading of the VTA be timed to match the nutrient uptake of the vegetation?

Timing of the application of the nutrients to a VTA is typically driven by the rainfall and runoff events that carry nutrients to the VTA. In most Corn Belt and High Plains regions, runoff is greatest in spring and early summer which is timed well to the nutrient requirements of most grasses and forages (late spring through fall). Due to the moisture utilization by perennial forages, most excess nitrogen will be stored in the soil during the growing season until it is utilized by the vegetation, minimizing the leaching of nitrogen beyond the root zone.

This may not be a valid assumption where a substantial amount of nutrients are carried to the VTA in early fall if a crop is not continuing to use nutrients. Grass and forages with long growing seasons would be preferable to row crops, such as corn, for utilizing nutrients from early fall runoff events. Late fall and winter application of runoff will add ammonium and some organic nitrogen to the VTA, both of which are immobile in most soils. However, these forms of nitrogen are unlikely to be converted to mobile nitrate nitrogen until the soil warms in the spring. Perennial grasses and forages with long growing seasons should allow removal of mobile nitrate nitrogen during an extended period of the year when nitrogen in this form is available.

Under frozen soil conditions, the ability of a VTA to manage runoff should be reviewed. In many Midwest locations, the fraction of rainfall that exits a dirt lot as runoff is typically very small (for Ames, IA: 10%, <10%, and 15% of monthly rainfall exits as runoff in Jan., Feb., and Mar., respectively). Precipitation is also low during these periods of time (for Ames, IA: 0.76, 0.74, and 2.06 in for Jan., Feb., and Mar., respectively). Frozen soil conditions in a VTA may present minimal environmental risk because of low total runoff from dirt lots during the same period (for Ames, IA:

Table 6–2 Plant nitrogen uptake by forages removed with the harvested part of the crop

Crop	Nitrogen uptake	Crop	Nitrogen uptake
Alfalfa	45 lb/ton	Lespedeza	47 lb/ton
Alfalfa haylage	28 lb/ton	Little bluestem	22 lb/ton
Bahiagrass	25 lb/ton	Orchardgrass	29 lb/ton
Big bluestem	20 lb/ton	Panagolagrass	26 lb/ton
Birdsfoot trefoil	50 lb/ton	Paragrass	16 lb/ton
Bluegrass	58 lb/ton	Red clover	40 lb/ton
Bromegrass	39 lb/ton	Reed canarygrass	27 lb/ton
Clover-grass	30 lb/ton	Ryegrass	33 lb/ton
Dallisgrass	38 lb/ton	Switchgrass	23 lb/ton
Guineagrass	25 lb/ton	Tall fescue	39 lb/ton
Bermudagrass	38 lb/ton	Timothy	24 lb/ton
Indianagrass	20 lb/ton	Wheatgrass	28 lb/ton

0.08, 0.07, and 0.30 in of runoff in Jan., Feb., and Mar., respectively). Runoff from paved lots is significantly higher during winter conditions and may produce a greater risk for frozen soil conditions in a VTA.

Critical assumptions the producer should check

Any design involves several critical assumptions that influence a planner's recommendations for VTA size. To ensure that a design based upon a nitrogen balance will perform as expected, the producer should quiz the planner about the following critical assumptions:

- What estimate was made of nitrogen runoff from the feedlot, nitrogen removal by the solids settling facility, and the crop availability for of nitrogen reaching the VTA? Compare those assumptions with estimates shown.
- What assumptions were made for nitrogen removal by the perennial forage or grass including the planned yield? Do yields match local experience with growing similar forages or grasses?
- What design features were included to maintain relative uniform distribution of nitrogen and water within the VTA?

Draw upon the expertise of a local crop consultant, land grant university extension specialist, or NRCS staff to review the validity of the assumptions made by the planner.

Example: Tall fescue is harvested at 5 ton/a from the VTA on our 2,000 head feedlot. Based upon nutrient removal rates from table 6–2, the amount of land required would be approximately:

Method 2: 1,610 lb N ÷ (39 lb N/ton x 5 ton/a) = 8.3 a

Method 3: 2,800 lb N ÷ (39 lb N/ton x 5 ton/a) = 14 a

VTA sizing by water balance

A water balance is used to design a VTA to minimize release of feedlot runoff nutrients to surface water. It focuses on hydraulic loading rates and limits of a VTA. A water balance approach compares the release rate of runoff from a design storm to the infiltration rate of the soil. Typically, the runoff volume is a function of a 25-year, 24-hour storm event (fig. B–1, app. B), drainage area, and type of surface. Procedures for estimating runoff are illustrated in appendix B.

The water balance procedure described in this section assumes that the runoff release from the solids removal component to the VTA is controlled so that limited runoff is added to the VTA during the storm event. For systems that do not control the release of liquid to the VTA (a settling bench), the intensity of the storm and the more rapid addition of water to the VTA must also be addressed in the design.

The ability of the soil to assimilate the runoff from the storm event is dependent upon three factors:

- The saturated soil infiltration rate (a safety factor for infiltration rate can be included assuming that sheet flow of runoff water does not cover the entire VTA) from the county soil survey.
- The time over which the settling basin is allowed to drain. Typically 30 to 72 hours is allowed for the settling basin to drain to the VTA.
- VTA area

Using these procedures, a ratio of VTA area to drainage area (assuming all precipitation runs off) is reported in table 6–3.

This method does not address deep percolation of runoff water into or below the soil profile. With a VTA/feedlot area ratio of 0.5, and assuming uniform application on the VTA, a 5.5-inch design storm will result in 9 to 11 inches of additional water applied to the VTA (see table B–1 for storm event runoff). If the soil within the crop rooting depth cannot (in most cases will not) assimilate this depth of water, deep percolation may be a concern. A larger VTA may be needed to address this issue.

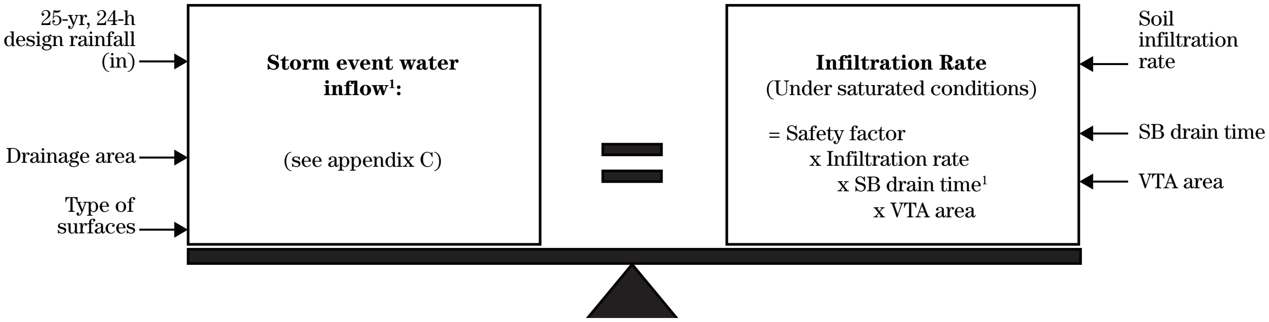
In summary, a water balance can serve as one option for estimating the minimum size requirement for a VTA. This estimate should be compared against an estimate based upon nutrient balance methods. Generally, the nitrogen-based balance will produce the larger VTA design. However, for systems involving additional runoff pre-treatment (solids settling and VIB in advance of VTA), the water balance method may be the more conservative procedure (fig. 6–2). A model for predicting performance using site-specific weather data (ISU VTA Model described in sec. 2) should now be used to estimate performance of the selected VTA size.

Critical assumptions the producer should check

A water balance design involves several critical assumptions that influence a planner's recommendations for VTA size. To assure that a design based upon a water balance will perform as expected, the producer should review with the planner the following critical assumptions:

- What assumptions were made about soil infiltration rate? Was it assumed to remain constant or change during the storm event?

Figure 6–2 Water balance method for VTA



1 Settling basin drain time: Design time for draining 25-yr, 24-h storm from settling basin

Table 6–3 Ratio of VTA area/drainage area for three saturated soil infiltration rates and three settling basin drain times

Design storm event (in)	Infiltration rate (in/h)								
	0.2 in/h settling basin drain time (h)			0.6 in/h settling basin drain time (h)			1.0 in/h settling basin drain time (h)		
	30	48	72	30	48	72	30	48	72
Earthen feedlot surface									
3	0.7	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
3.5	0.8	0.5	0.3	0.3	0.2	0.1	0.2	0.1	0.1
4	1.0	0.6	0.4	0.3	0.2	0.1	0.2	0.1	0.1
4.5	1.1	0.7	0.5	0.4	0.2	0.2	0.2	0.1	0.1
5	1.3	0.8	0.5	0.4	0.3	0.2	0.3	0.2	0.1
5.5	1.5	0.9	0.6	0.5	0.3	0.2	0.3	0.2	0.1
6	1.6	1.0	0.7	0.5	0.3	0.2	0.3	0.2	0.1
6.5	1.8	1.1	0.7	0.6	0.4	0.2	0.4	0.2	0.1
7	1.9	1.2	0.8	0.6	0.4	0.3	0.4	0.2	0.2
Concrete feedlot surface									
3	0.9	0.6	0.4	0.3	0.2	0.1	0.2	0.1	0.1
3.5	1.1	0.7	0.5	0.4	0.2	0.2	0.2	0.1	0.1
4	1.3	0.8	0.5	0.4	0.3	0.2	0.3	0.2	0.1
4.5	1.4	0.9	0.6	0.5	0.3	0.2	0.3	0.2	0.1
5	1.6	1.0	0.7	0.5	0.3	0.2	0.3	0.2	0.1
5.5	1.8	1.1	0.7	0.6	0.4	0.2	0.4	0.2	0.1
6	1.9	1.2	0.8	0.6	0.4	0.3	0.4	0.2	0.2
6.5	2.1	1.3	0.9	0.7	0.4	0.3	0.4	0.3	0.2
7	2.3	1.4	0.9	0.8	0.5	0.3	0.5	0.3	0.2
Medium texture cropland									
3	0.32	0.20	0.13	0.11	0.07	0.04	0.06	0.04	0.03
3.5	0.43	0.27	0.18	0.14	0.09	0.06	0.09	0.05	0.04
4	0.56	0.35	0.23	0.19	0.12	0.08	0.11	0.07	0.05
4.5	0.68	0.43	0.28	0.23	0.14	0.09	0.14	0.09	0.06
5	0.82	0.51	0.34	0.27	0.17	0.11	0.16	0.10	0.07
5.5	0.95	0.60	0.40	0.32	0.20	0.13	0.19	0.12	0.08
6	1.1	0.68	0.46	0.36	0.23	0.15	0.22	0.14	0.09
6.5	1.2	0.77	0.52	0.41	0.26	0.17	0.25	0.15	0.10
7	1.4	0.86	0.58	0.46	0.29	0.19	0.28	0.17	0.12
Medium texture grassland									
3	0.24	0.15	0.10	0.08	0.05	0.03	0.05	0.03	0.02
3.5	0.34	0.21	0.14	0.11	0.07	0.05	0.07	0.04	0.03
4	0.44	0.28	0.18	0.15	0.09	0.06	0.09	0.06	0.04
4.5	0.56	0.35	0.23	0.19	0.12	0.08	0.11	0.07	0.05
5	0.68	0.42	0.28	0.23	0.14	0.09	0.14	0.08	0.06
5.5	0.80	0.50	0.34	0.27	0.17	0.11	0.16	0.10	0.07
6	0.94	0.58	0.39	0.31	0.19	0.13	0.19	0.12	0.08
6.5	1.1	0.67	0.45	0.36	0.22	0.15	0.21	0.13	0.09
7	1.2	0.75	0.50	0.40	0.25	0.17	0.24	0.15	0.10

1 Safety factor of 0.5 was assumed for area of VTA coverage by sheetflow

- Did the infiltration rate consider a shallow water table, if present? Shallow ground water tables will reduce the total infiltration that a site is capable of managing.
- What fraction of the VTA is assumed covered by runoff during a storm event and thus contributing to the total infiltration of runoff? It will be difficult to assure that the entire VTA is uniformly covered with runoff water and thus contributing to runoff infiltration. What design features were included to maintain relative uniform distribution of water within the VTA?

Use the expertise of your local Soil and Water Conservation District or NRCS office to review the validity of the assumptions made by the planner.

Example: Estimate the VTA size for the 2,000 head Central Iowa earthen feedlot (drainage area includes 11.5 acres of feedlot and an additional 8 acres of roads, drainage ditches, feed storage and preparation areas, and compost site) using the water balance. The 25-year, 24-hour design storm is 5.5 inches. The soil survey suggests that the soils at the selected site have an infiltration rate of 0.6 to 2.0 inches per hour. Assume that the settling basin outlet pipe will drain the basin in 48 hours.

From table 6–3, the VTA would need to be:

$$(0.3 \times 11.5 \text{ feedlot a}) + (0.4 \times 8 \text{ additional a}) = 7 \text{ acres}$$

Estimate assumes that additional drainage area would have runoff similar to concrete lot, a conservative assumption.

Estimate also assumes that lower infiltration rate from soil survey will be used.

Discussion: This compares to our earlier estimates of 8 and 14 acres for the VTA based upon two nutrient balance methods. Since the nitrogen balance method suggests a larger VTA size, the vulnerability of local ground water to nitrate leaching may be critical to determining which sizing estimate to accept.

Sheet flow considerations

For VTAs to provide maximum benefit for water quality protection, flow should be uniformly distributed across the treatment area. Uniform flow reduces flow velocity and encourages settling of suspended particles, thus improving treatment efficiency. In addition, uniform flow maximizes infiltration, reducing the potential for a discharge. Dickey and Vanderholm (1981) estimated that it would require flow distances at least 10 times greater for channel flow treatment as compared to treatment from sheet flow through a vegetative filter.

Poor distribution of nutrients is probably the most significant environmental challenge for a VTA. To minimize this problem, the following considerations are essential:

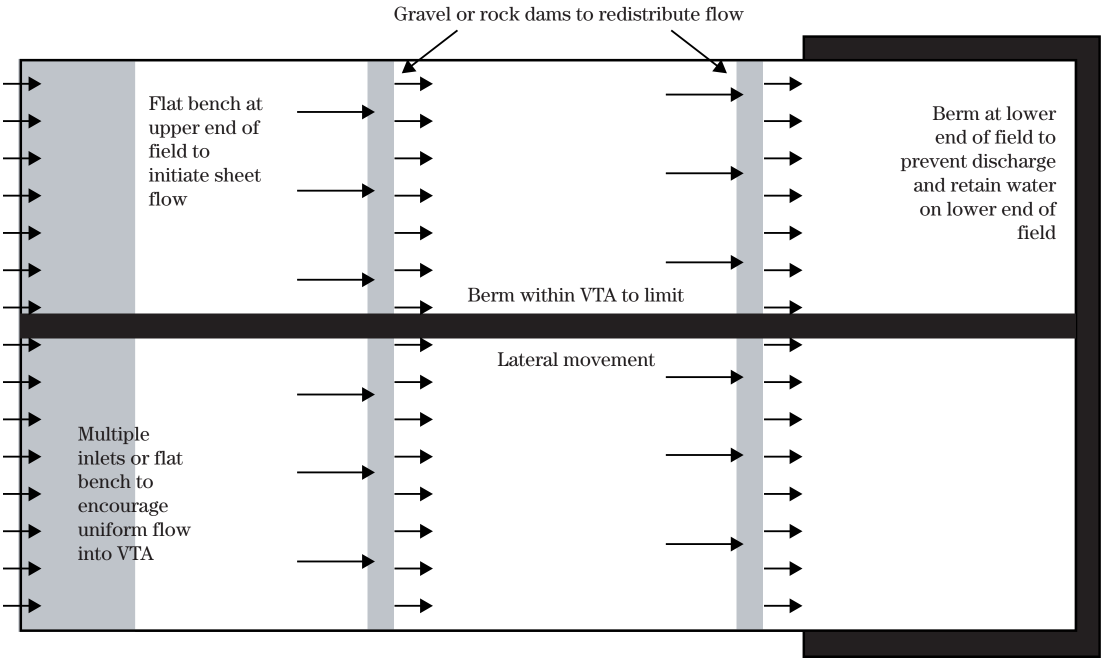
- Uniform distribution of runoff at the entrance
- Flow may converge within the VTA, and in field measures should be considered to redistribute flow within the VTA
- VTA management must monitor and maintain conditions to encourage sheet flow (sec. 8).
- A soil and/or forage nutrient monitoring program is necessary identify potential developing nutrient excess concentrations.

Initial runoff distribution

To maximize VTA performance, it is important that inflow to the system be distributed to initially create shallow sheet flow less than 1 inch deep (by definition) across the entrance to the system (fig. 6–3). To encourage uniform distribution from a settling basin into the VTA, the following options should be considered:

- A concrete distribution lip constructed as part of the settling basin or separately can be used with long, narrow VTAs. It is critical that the lip be at a constant elevation and long enough to span the width of the VTA. The one disadvantage to this approach is the inability to control the flow rate to allow the settling basin to drain over a 30- to 72-hour period.
- Gated irrigation pipe placed on a pre-determined constant contour elevation to allow equal flow at all outlets.
- A flat, land-graded bench can be created over the first 30 to 50 feet of the VTA will encourage uniform spreading of the flow.
- A gravel or rock dam across the upper end of the VTA immediately following the runoff release from the settling basin.
- Multiple pipe outlets from the settling basin can be spaced at 20- to 50-foot intervals with the entrance to each outlet placed at the exact same

Figure 6–3 Options for creating and maintaining sheet flow within a VTA



elevation. Each pipe must be placed on a concrete pad (base of which is below the frost line) to minimize settling. The final height of each inlet must also be adjustable to offset modest irregular settling that cannot be prevented with the concrete pads. The outlet should have a specifically sized orifice designed to produce the 30- to 72-hour settling basin drain period.

In all these cases, the inlet structure (often the outlet from settling basin) should be designed such that periodically the inlet can be re-calibrated to maximize uniform flow distribution. Design and construction for multiple pipe outlets need to include mechanisms for periodic adjustments so each pipe inlet is at a consistent elevation. The gravel and rock structures should be designed and constructed such that they can effectively be re-leveled without significant disturbance to the system. If gated pipe distributes the runoff, uniform distribution can be achieved if pipe flow is operated “full” and gates are adjustable to full pipe flow under most conditions. Placing gated pipe on the contour (constant elevation) is also critical. Screening of debris is also necessary for most inlets to avoid plugging of gates or orifices.

The inlet structure should be such that erosion features will not develop that could reduce the effectiveness of the flow distribution system. Earthen embankments should not be used for flow distribution due to erosion risk. High flow rates at the inlet (a pipe from settling basin) to the VTA should also be avoided because of the erosion potential. A graded flat bench over the first 50 feet of the VTA offers value for erosion control.

Distribution within VTA

The runoff from a feedlot can be introduced to a VTA evenly across the upper end of a VTA and still experience uneven distribution of nutrients over the length of the VTA. The portion of the VTA immediately below the settling basin will be more frequently loaded as a result of smaller storm events producing uneven distribution of nutrients and water. This creates a concern for nitrate leaching to ground water. Three possible solutions to improving distribution over the length of a VTA include:

- The runoff should be distributed to multiple outlets distributed down the length the VTA (one outlet at the headlands and a second halfway between the headlands and the end of the VTA). This option should be used with caution. Outlets not placed at the upper end of the field should include a control valve so they can be shut down during higher intensity storms.
- The runoff could be stored and distributed onto the VTA through sprinkler irrigation or other pressure dosing system such as a pump or siphon to a gated pipe.
- A shallow berm could be built around the lower end of the VTA and excess runoff is stored within the VTA. This does nothing to facilitate flow distribution, although it is useful where concentrated flow occurs despite previous measures and the potential for release from the VTA must be minimized.

Overland flow will tend to converge as it flows through the VTA. Maintenance of sheet flow for more than 200 feet is difficult without some sort of intervention. Level grading of the VTA across its width promotes sheet flow. Spreaders may be constructed as rock or gravel berms or wood and concrete sills. These spreaders should extend above the ground surface only a few inches to allow for flow spreading without extensive ponding of flow. The design and operation and maintenance plan for these spreaders should include provisions for periodic re-leveling.

Constructed spreaders would not need to be as structurally significant as might be required for the inlet distribution system, but they still should be able to remain structurally intact under high flow conditions (fig. 6–3). In addition, periodic maintenance may be required if erosion features would develop in the spreader. As such, the spreaders shall be inspected periodically (not less than annually) to confirm the level and functionality of the spreader.

Since some of the VTA systems may be relatively wide (perpendicular to the direction of predominant flow), limiting the width of the VTA will assist with sheet flow. A maximum width of a VTA should be 200 feet (table 6–4). Wider VTAs should include use of borders or berms parallel to the direction of flow spaced at 200-foot intervals similar to those used in some flood irrigation applications.

Table 6–4 Level spreader spacing recommended by IA NRCS

Slope (%)	Maximum spacing (ft)
<2	200
2–5	100
>5	50

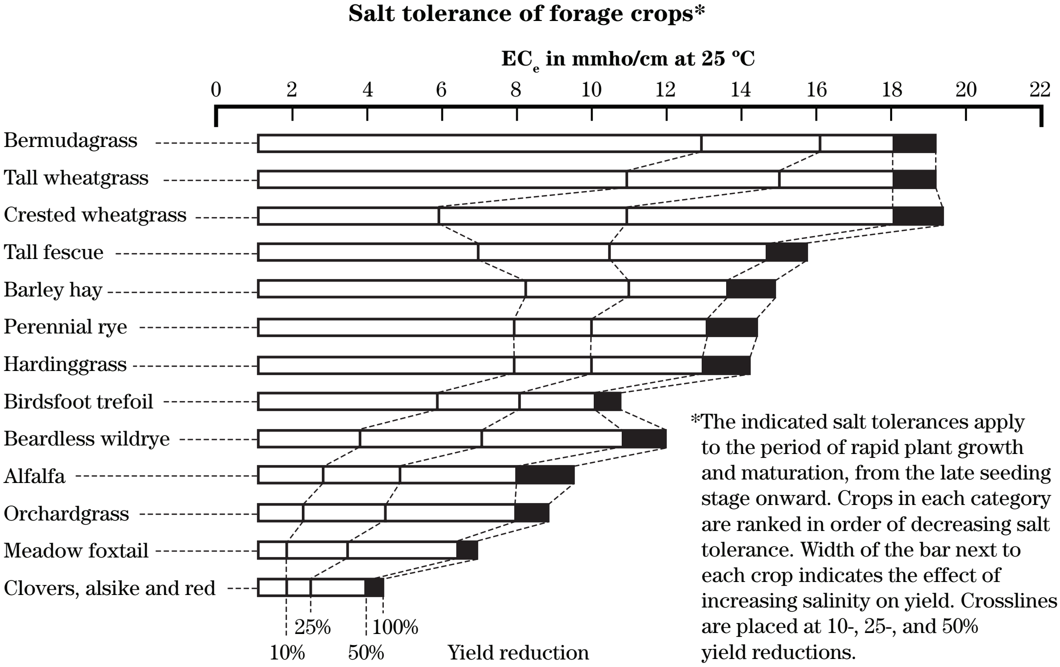
Plant materials selection

Appropriate forages or other crops should be selected based on the following considerations:

- *Tolerance to local climate*—Tolerance to temperature extremes, rainfall, and drought conditions specific to location is a first consideration.
- *Tolerance to flooding and saturated soil conditions* for extended periods—A bermed VTA will collect a diluted runoff from the open lot. Forages or other crops maintained in a bermed VTA will need to withstand flooding and saturated conditions over an extended time period. In addition, a VTA receiving liquid from a settling basin over an extended period (30 to 72 hours) may also deserve special consideration for the plant materials ability to withstand extended periods of saturated soil conditions.
- *Tolerance to salts*—Runoff associated with rainfall events is the primary source of water volume that will be collected by an infiltration basin. Average reported electrical conductivity (EC) levels range from 3.2 millimhos per centimeter (mmho/cm, a standard English measure of electrical conductivity. Some measures are reported in dS/m, which is the metric measurement. The two measures are equal, and no conversion is needed between mmho/cm and dS/m for eastern NE to 8.6 mmho/cm for central CO). Drier climates typically produce the higher average EC levels. Smaller, less intense precipitation events typically produce higher salt concentration in runoff. For example, a central Kansas study observed EC levels ranging from 2 to 13 millimhos per centimeter. Winter runoff is also likely to produce higher EC levels. A Nebraska study suggests EC levels were approximately three times greater for winter runoff as compared to rainstorm runoff.

The research literature has not observed salt tolerance problems in most applications. Dilution of runoff with rainfall falling on the settling basin and VTA plus the leaching of the salts through the soil profile may prevent most concerns. However, selection of an appropriate forage or grass should consider its salt tolerance, and low tolerance plant materials should be avoided. A separate grass or forage species may be preferable for the first 50 feet of the VTA where solids settling and infiltration of runoff will be greatest within the VTA. Figure 6–4 provides an indication of crops tolerance to higher EC levels. Salt tolerance of locally specific crops should be available by contacting your local county cooperative extension program or the local NRCS office.

Figure 6–4 Effect of soil salinity on growth of selected forage crops (Soil Conservation Service, Agricultural Waste Management Field Handbook, ch. 6)



*The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50% yield reductions.

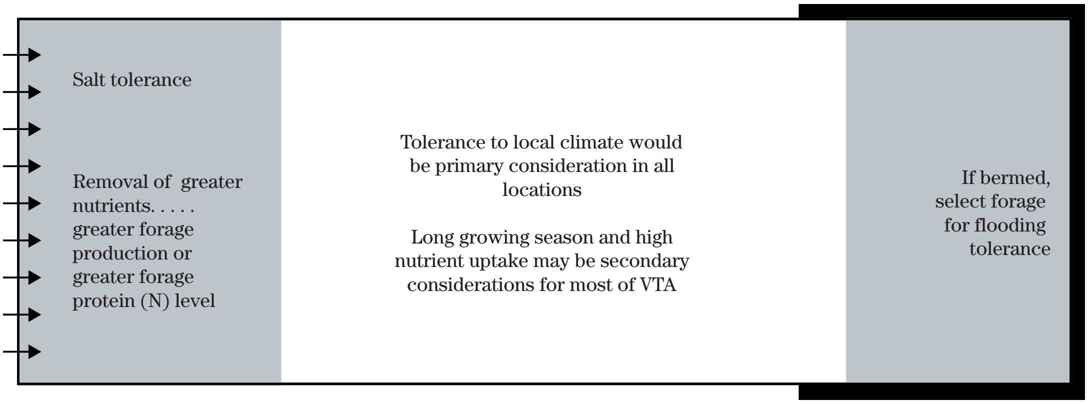
- *Tolerance to ammonia*—Many plants cannot tolerate high concentrations of ammonia. Influent concentrations should be 200 milligrams per liter or less. Typical feedlot runoff may contain higher ammonia concentrations (400–700 mg/L) than the plants can tolerate, although, actual concentrations may vary significantly. Higher concentrations are expected from densely stocked lots, and infrequently scraped lots. If higher ammonia concentrations enter the VTA than the plants can tolerate vegetation will be lost. If high concentrations are anticipated, pre-treat by blending the settling basin effluent with outside clean water to lower the influent concentration. Blending will result in a larger VTA.

In addition to the crop's tolerance to the controlling or limiting conditions discussed previously, a preferred crop for an infiltration basin should have some of the following characteristics:

- *High nutrient uptake*—Forages that harvest high levels of nitrogen are beneficial for infiltration basins. Phosphorus may be of concern. However, open lot runoff tends to be low in phosphorus, especially after moving through a settling basin.
- *Value as animal feed*—VTA forage growth will need to be harvested regularly. It is preferable to select forages that will be of value as an animal feed so as to gain some value for the land committed to a VTA. If harvested forage cannot be used for animal feed, alternative uses (bedding or carbon source for composting) are preferable to stock piling undesirable forage.
- *High evapotranspiration rates*—VTAs can reduce the total water volume if a forage or grass is selected for its high evapotranspiration rates.
- *Long growing season crops* offer advantages for nutrient uptake and evapotranspiration.
- *Perennials*—Infiltration basins should utilize perennial vegetation that provides growing plants from early spring into late fall for maximum nutrient uptake and water evapotranspiration. Grass and forages with long growing seasons would be preferable to row crops, such as corn, for utilizing nutrients from early spring through mid-fall runoff events. Combinations of warm- and cool-season grasses can create a long growing season in many applications. Late fall and winter application of runoff will add ammonium and some organic nitrogen to the VTA, both of which are immobile in most soils. These forms of nitrogen are unlikely to be converted to mobile nitrate nitrogen until the soil warms in the spring. Perennial grasses and forages with long growing seasons should allow removal of mobile nitrate nitrogen during an extended period of the year when nitrogen in this form is available.
- *Large root mass and surface area* provides an environment that encourages microbial activity. Aerobic decompositions of organic solids and mineralization and nitrification of nitrogen in runoff require active biological environments. Plants with large root mass contribute to an active biological environment. Plants that produce large tap roots are undesirable, increasing the potential for preferential flow.
- *Sod-forming grasses* are preferable to bunch-forming grasses as a means to maintaining uniform cover and facilitating sheet flow conditions.

Another intensive vegetation management strategy would be to employ vegetative zones designed similar to those used by some constructed wetlands (fig. 6–5).

Figure 6–5 Considerations for forage selection in different VTA locations



Salt accumulation is typical near the inlet of the runoff to the vegetative area. Planting crops that are salt tolerant near this inlet area would improve sustainability. Also, crops that use greater amounts of nitrogen and phosphorus near this inlet would minimize nutrient build-up. A VTA with a berm to control runoff on the lower end may require plant materials at the lower end that is flood tolerant.

Characteristics of common grasses and forages are summarized in appendix E. Additional suggested resources include:

- USDA Conservation Plants Pocket Guide at *http://plant-materials.nrcs.usda.gov/pubs/mopmcpuidguide.pdf*
- USDA VegSpec Web site at *http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm*
- USDA Crop Nutrient Tool, which provides estimates of nutrient removal by crops, based upon nutrient percentages that reflect national averages. It can be found at *http://npk.nrcs.usda.gov/*

Slope considerations

Preferred slopes for effective VTA function are dependent on several factors such as soil infiltration rate and vegetation type and condition. Additionally, the primary function of the VTA, whether plant uptake, soil infiltration or vegetative filtration, should also be considered for determining the appropriate slope. Research for VTAs has been conducted on a range of topographic slopes from 0.25 to 10 percent. According to the EPA Process Design Manual for Land Treatment of Municipal Wastewater 1982, VTAs have been effectively used on slopes of less than 1 percent and up to 12 percent with the optimum range being 2 to 8 percent. Some reports have suggested that slopes less than 3 percent can produce ponding and poor distribution. However, it is the collective judgment of the authors that slopes between 1 and 5 percent are recommended with special considerations given to slopes outside this range.

Minimum slope—While attempting to maximize contact time, special precautions should be taken for lower slopes, generally less than 1 percent, to ensure that ponding and/or front end nutrient loading does not occur. Saturated soil conditions are not conducive to rigorous vegetative growth, which is necessary for effectively treating feedlot runoff. Without feedlot runoff moving down slope, the upper reach of the VTA has the potential of becoming overloaded with nutrients and possible contaminants. Excessive nutrient loadings would also negatively affect vegetative growth. Additional monitoring or soil sampling may be necessary in the upper reaches of the VTA to ensure proper functionality.

Maximum slop—Slopes greater than 5 percent have a greater likelihood of channelized and possibly gullying conditions uniform vegetative cover is established prior to using the VTA. Additional efforts to redistribute flow such as additional in-field spreaders (see table 6–4) or application of terraced VTA must be considered for steeper slopes. Reduced performance and potential failure of a VTA is possible due to erosion and/or reduced utilization of nutrients and contaminants. Greater slopes may also require larger treatment areas for equivalent performance.

Additional options for reducing VTA runoff release

Several options can be employed to reduce potential for an unplanned release from a VTA. Systems designed to reduce this risk are described in section 3. Some additional VTA design strategies can also be used to reduce discharge. A brief description for each of these is listed below.

Runoff volume reduction—Current regulations require CAFOs to collect any runoff originating from the unroofed animal confinement (feedlot, exercise lots, or loafing areas), the feed storage and preparation area, and on-site manure storage or composting areas. It is important to divert clean runoff coming from crop production areas, roadways (not used for animal traffic), or roofed buildings (animal housing, feed storage, equipment storage) to reduce the runoff volume collected. Reducing runoff volume will directly impact the risk of a discharge from the VTA.

Storage prior to VTA—Storage size (typically the settling basin) impacts the risk of a discharge. Reducing the size of the temporary runoff storage facility increases the potential for untreated runoff to pass over the vegetated area and be released from the VTA. A smaller storage volume prior to the VTA will require a VTA with a larger area to minimize releases. A storage volume capable of handling a 25-year, 24-hour storm is important to minimizing an uncontrolled discharge.

Controlling discharge to VTA—Timing of the release of liquids from a settling basin to the VTA is critical to reducing discharges from the VTA. During chronic rainy periods, the VTA soil profile is saturated lending itself to solute transport to ground water and discharges from the VTA. Two management options exist for reducing these risks. Controlling the release of runoff from the settling basin until after the storm event (active producer management of release) reduces the surface water risk. This also requires close management of the release during chronic wet periods to prevent overflows from the settling basin. High rate discharges from the settling basin are possible if an actively managed system is not closely observed in a chronic wet period.

A passively managed release strategy is based upon a carefully designed release rate for liquids in the settling basin. Extended periods for releasing the collected runoff from the settling basin to the VTA minimizes the addition of contaminated runoff to the VTA during the storm event and extends the opportunity for infiltration into the soil after the storm event. A release time of 30 hours is considered a minimum for the designed storage volume with a 72-hour design period being preferred. This approach minimizes the risk to the basin structure. Both options are discussed in greater details in sections 3 and 8.

Both the actively and passively designed release of liquids from the settling basin should include a fail-safe method for releasing liquids under storm events that exceed the basin's design capacity (an emergency spillway).

Contact time—Strategies that increase infiltration also improve contact time between potential contaminants in the runoff and the soil biological components, which aid in remediation. Soil biological components include plant roots, rodents, worms, insects, and microorganisms. One of the most important biological components for utilizing nutrients contained in feedlot runoff is the symbiotic zone surrounding plant roots called the rhizosphere. Generally, pore spaces in this rhizosphere are small, and as a result, nutrient transport is diffusion dependent. Increasing contact time of runoff nutrients in the rhizosphere will improve transport into these small pore spaces. Improving nutrient movement (extending periods for infiltration and matching VTA area to expected nutrients in runoff) into the rhizosphere will effectively increase nutrient utilization by the microorganisms and plant systems.

Containment dikes—Installing containment dikes around the vegetative area reduce or eliminate untreated discharge to the environment. These dikes increase contact time of the runoff water with the vegetation and reduce the effect of convergent flow paths short-circuiting through the treatment area. These are most effective on relatively flat slopes of two percent or less.

VTA management—Multiple management options should be considered in operation of a VTA. Section 8 discusses those management options.

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