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Vegetative Treatment Systems for Open Lot Runoff

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Region 7 Environmental Protection Agency

Iowa Department of Natural Resources

University of Nebraska

Kansas State University

Iowa State University

University of Minnesota

Agricultural Engineering Associates

Iowa Cattleman's Association

Preface

Vegetative Treatment Systems for Open Lot Runoff was developed under the leadership of U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) through an Intergovernmental Personnel Act (IPA) agreement, with collaboration from representatives from several land grant universities, USDA Agriculture Research Service (ARS), U.S. Environmental Protection Agency (EPA), Iowa Department of Natural Resources, Iowa Cattlemen's Association, and private sector representatives. During 2004, a work group assembled the current scientific knowledge related to vegetative treatment systems and adapted that information into the recommendations contained within this document. For additional information contact:

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Terminology

Animal Feeding Operation (AFO)	Typically used in reference to those livestock and poultry operations that do not require a permit under the EPA NPDES permit program.
Concentrated Animal Feeding Operation (CAFO)	Typically EPA or state environmental agency rules define those farms required to have a permit under the EPA NPDES permit program.
Effluent Limitation Guidelines (ELG)	These are the design and operating standards that a CAFO must meet to maintain compliance with the 1972 Federal Clean Water Act
Large CAFO	Typically national EPA or state environmental agency rules define those farms considered to be a Large CAFO based upon size. More than 1,000 beef cattle, 1,000 dairy heifers, or 700 mature dairy cows would by defined as a large CAFO by EPA regulations.
Medium or small CAFO	A permitting authority (EPA or state environmental agency) can define or designate an AFO as a CAFO based upon combination of size and environmental risk. See section 2 or *http://www.lpes.org/cafo/02FS_Permit.pdf* for more information.
National Pollution Discharge Elimination System (NPDES)	Commonly used to identify a EPA permit program created for point sources of pollution (including CAFOs) under the 1972 Federal Clean Water Act.
Permitting authority	A state regulatory agency or regional EPA office with the authority to write an NPDES permit for an individual CAFO.
Standard Operating Procedure (SOP)	A written procedure used to define the specific steps to be followed in the operation and maintenance of an agricultural system.
U.S. Environmental Protection Agency (EPA)	This agency has responsibility for administering water quality regulations related to animal feeding operations.
Vegetative Infiltration Basin (VIB)	A shallow basin containing perennial grass or forages through which all collected runoff water must infiltrate. Typically these systems include a tile drain system for collecting the infiltrate and bringing the treated runoff to the surface for additional treatment or application to grass or cropland.
Vegetative Treatment Area (VTA)	A vegetative area composed of perennial grass or forages used for the treatment of runoff from an open lot production system or other process waters.
Vegetative Treatment System (VTS)	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.

Section 1 Introduction to Vegetative Treatment Systems

Section 1 Introduction to Vegetative Treatment Systems

Contents

Topics	**1–1**
Purpose	**1–1**
Application to AFOs and CAFOs	**1–2**
Caution for large CAFOs	**1–2**
Why consider a vegetative treatment system	**1–3**
Summary of guidance document contents	**1–4**
Supporting NRCS practice standards	**1–7**

Tables

Table 1–1	Technical service providers	1–5
Table 1–2	Other audiences	1–5

Section 1 Introduction to Vegetative Treatment Systems

Topics

- Application of information to animal feeding operations (AFO) and concentrated animal feeding operations (CAFO)
- Why consider a vegetative treatment system (VTS)
- Summary of guidance document contents
- Supporting U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Practice Standards

Purpose

Runoff from open lot livestock production systems poises a risk to the environment. Contaminants in this runoff can produce fish kills due to ammonia and organic solids, eutrophication (algae blooms) due to nutrients, drinking water quality risks due to pathogens and nitrogen, and risk to recreational uses of water due to pathogens and other contaminants. Controlling and managing manure-contaminated runoff is a responsibility of every livestock producer.

Traditionally, runoff containment or holding ponds have been used to collect and store runoff until it is practical to land apply. This conventional approach is currently the only acceptable approach for large CAFOs based upon current federal regulations. A holding pond designed to meet current regulations performs well in the drier areas of the High Plains, but is difficult to manage to avoid unplanned releases in higher precipitation climates. To avoid discharges, collected runoff must often be land applied under less than desirable soil conditions. Thus, alternatives to this traditional approach are being examined.

This document introduces the use of VTSs for managing open lot runoff. A VTS approach utilizes forage or grass-based production areas to filter contaminants and infiltrate runoff in the soil. Significant research over the past 30 years has demonstrated the performance of these systems, typically on smaller livestock operations. This document focuses on application of a VTS to achieve the water quality goals of the United States relative to managing runoff on CAFOs. It summarizes the research and makes recommendations relative to siting, design, and management for achieving those water quality goals with VTS. In many circumstances, a VTS may also benefit the producer in terms of reduced capital cost, less management complexity, and reduced odor nuisances.

This document targets the performance standards required of a large CAFO and the design and management considerations of a vegetative system for meeting those standards specific to open lot runoff. This information should be useful to all AFOs. However, other siting, design, and management options may be acceptable locally for operations not required to maintain a regulatory permit.

Application to AFOs and CAFOs

Those livestock operations defined as a large CAFO must recognize that VTSs can only be utilized under the Voluntary Alternative Performance Standards of the CAFO permit program. This standard places the burden of proof on the individual large CAFO to demonstrate that this technology will perform equal or better than the conventional technology (runoff holding pond) allowed under these rules. The focus of this document is to help the large CAFO recognize the key siting, design, and management issues that must be considered to attain this level of performance. The recommendations made in this document target issues critical to the large CAFO.

Most other AFOs are not required to meet this same standard. Discussion on identifying systems options, siting systems, design of plant based systems, and management of systems will be helpful to all AFOs regardless of the need for an environmental permit. However, other approaches not discussed in this document may be equally appropriate. AFOs should consult with a local NRCS office, State environmental agency, or private sector technical service provider to identify if other options are available that meet the AFOs' environmental and economic goals.

Caution for large CAFOs

Existing large CAFOs have been required to control open lot runoff and maintain a National Pollution Discharge System (NPDES) permit since the mid-1970s. Open lot beef cattle and dairy operations with more than 1,000 and 700 head capacity, respectively, without an NPDES permit (or letter of exemption) are currently out of compliance. Additional implementation delays for a runoff control system produce significant legal liability and environmental risk until the date of achieving compliance. If implementation of a VTS will add to this delay, a more conventional system should be strongly considered.

Current and past research and field performance studies on VTS have been done exclusively on smaller open lot systems. At the time of this document, no performance evaluations of VTS on large CAFOs have been conducted. The design, siting, and management recommendations in this document are the combined best professional judgment of a team of researchers from land grant university and USDA Agricultural Research Service (ARS), field engineers from NRCS and private sector, and regulatory representatives. Those recommendations target VTS application to large CAFOs based upon the currently available knowledge.

However, if the recommendations contained in this document are carefully followed, producers and design consultants must recognize that permitting of a VTS on large CAFOs will include a burden of proof not required of a baseline technology. In addition, there are risks associated with alternative technologies if that burden of proof is not met during the design phase or in field performance is less than predicted during the operation of the VTS.

Why consider a vegetative treatment system

VTS can offer several environmental and economic benefits over a conventional holding pond and irrigation system. Some of the more common benefits include:

- Reduced capital and operating costs for some systems involving vegetative treatment options (sec. 3).
- Reduced odor and other air emissions from most systems involving vegetative treatment options as opposed to a holding pond and sprinkler irrigation system. Visually, a VTS is also more aesthetically acceptable than a holding pond.
- Little or no long-term storage of runoff in earthen ponds, resulting in less ground water risk for most systems involving vegetative treatment options.
- Lower risk of system catastrophic failures due to poor design, management, or unplanned weather events.
- Reliance on cropping systems based upon forages or grasses, as opposed to row crops (corn and soybeans). These crops provide a longer season for nutrient removal and water evapotranspiration, reducing the risk of land application of runoff early in spring and late in fall. If managed properly, these crops provide thick, dormant vegetation that also reduces environmental risk of land application of runoff during the winter. Because of the use of perennial vegetation, surface water risks should be a minor issue for well-managed systems.

From the above list, why would any producer not select a VTS for managing runoff? The design and management of a VTS include some challenges that must be recognized when this option is selected. Some of the more critical considerations include:

- Many VTS will only be accepted under the Voluntary Alternative Performance Standards set by the CAFO regulations. The burden of proof is currently placed on the producer to document that a VTS will perform equally or better than baseline technology (pond and irrigation system). Additional costs will be incurred in obtaining an NPDES permit at the time this publication was prepared.
- Improper design or management of a VTS has a risk of surface water discharge. Planner or producer mistakes could place a producer at a greater risk of violation of environmental regulations. Until VTS becomes an accepted technology by the regulatory community, a producer must accept that the permitting authority for the NPDES program could require livestock operations to replace poor performing VTS with conventional systems to maintain the NPDES permit.
- A well-managed VTS will not distribute nutrients as uniformly as a pivot irrigation system. The potential for nitrate contamination of ground water due to excess nutrients in the headlands of a vegetative treatment area (VTA) must constantly be monitored. Monitoring of VTA soil nutrient status and maintenance of uniform distribution of runoff will require a greater investment of time and financial resources than a conventional system.

Summary of guidance document contents

This publication has nine sections addressing the following issues:

- Section 2—*Understanding Environmental Regulations and Procedures for Evaluating Alternative Technologies* summarizes the regulatory standard set by the U.S. Environmental Protection Agency (EPA) for open lot runoff and the process by which alternative technologies, such as vegetative treatment systems, may be considered acceptable for an NPDES permit.
- Section 3—*Systems Options Based upon Vegetative Treatment Areas* summarizes the primary plant-based treatment technologies options for managing runoff and describes several combinations of treatment technologies (including vegetative systems) that produce a low risk of discharge and potential for application on CAFOs.
- Section 4—*Siting Criteria for Vegetative Treatment Systems* provides procedures for reviewing a potential site for risk factors associated for the location of a VTS.
- Section 5—*Liquid-Solid Separation* describes design considerations for solids removal and the role it plays in a VTS.
- Section 6—*Vegetative Treatment Area Design* describes in detail critical design considerations including sizing, distributed runoff flow, plant materials selection, and options for reducing discharge.
- Section 7—*Vegetative Infiltration Basin Design* presents in detail critical design considerations including sizing, tile drain design, and plant materials selection.
- Section 8—*Management Guidelines for Vegetative Treatment Systems* presents critical management issues including soil sampling, sheet flow maintenance, and control of runoff release. Suggested standard operating procedures and records for documenting good management for a VTS are also described.
- Section 9—*Literature Review* summarizes the current research and field experience with VTAs and vegetative infiltration basins (VIB), as well as conventional runoff control technologies.

The primary audience for this document is the technical service provider assisting with the permitting, planning, and design of a VTS. Table 1 lists common questions and the sections in which the answers are found.

Other audiences including the permit writer, livestock producer, or policy maker may find specific components of this document useful. Table 1–2 lists questions common to other audiences and may help identify parts of the document that are of greatest benefit to these audiences.

Table 1–1 Technical service providers

I am a technical service provider with the following questions:	Section
How well do vegetative systems perform?	9
What are the regulations relevant to application of a VTS to a *large*, *medium*, or *small* CAFO or to an AFO?	2
How will the performance of a VTS be compared to that of a baseline technology currently under the CAFO regulations?	2
What system options involving vegetative technologies provide the best opportunity for success?	3
What factors should be considered in reviewing a potential VTS site?	4
What design principles should be used for the:	
Settling basin or other solids removal options?	5
VTA?	6
VIB?	7
What standard operating procedures and records should be recommended for a VTS?	8
Will a VTS meet NRCS Conservation Practice Standards?	1

Table 1–2 Other audiences

I am a large CAFO and have the following questions	Section
How well do vegetative systems perform?	9
What are the regulations relevant to application of a VTS?	2
Is the site I have selected for controls appropriate for a VTS?	4
What proof must I provide EPA that a VTS works on my farm?	2
What is a VTS other than spreading runoff over a grassed area?	3, 5, 6, 7
What is the difference between a VTA and a VIB?	6, 7
What must be done to manage a VTS?	8
What records must I keep on my VTS?	8

I am with a regulatory agency and have the following questions:	Section
What research has been done with VTS?	9
How well do baseline technologies perform?	9
What tools are available for comparing a VTS and a baseline technology?	2
What design considerations minimize the potential for discharge?	3, 5, 6
What factors should be considered in reviewing a potential VTS site?	4
What design principles should be used for the:	
Settling basin or other solids removal options?	5
VTA?	6
VIB?	7
Will a VTS meet NRCS conservation practice standards?	1
What records and management procedures might be addressed by an NPDES to demonstrate a well-managed VTS?	8

Table 1–2 Other audiences—Continued

I am an AFO and have the following questions:	Section
Are there simple systems that will minimize my financial risk?	3 (options 1, 2)
What is the difference between a VTA and VIB?	3
Is the site I have selected for controls appropriate for a VTS?	4
Is a VTS more than spreading runoff over a grassed area?	3, 6, 7
How should a VTS be managed to maintain its performance?	8

Supporting NRCS practice standards

NRCS conservation practice standards provide guidance for applying conservation technology on the land and set the minimum level for acceptable application of the technology. Individual conservation practices can be collected and arranged as components of a VTS. Some conservation practice standards that are central to the design of a VTS include:

Topic	NRCS Conservation Practice Standard
Solids settling facilities	Sediment Basin (350)
Storage of feedlot runoff	Waste Storage Facility (313)
VIB	Subsurface Drain (606)
VTA	Class III Dike in Dike (356)
	Wastewater Treatment Strip (635)
Large VTA	Waste Utilization (633) Nutrient Management (590)

Some components may be considered ancillary to the major components, but, if their use is critical or extensive, they should be identified as individual components on their own. These may include:

Topic	NRCS Conservation Practice Standard
Diversion of uncontaminated runoff	Roof Runoff Structure (558) Diversion (362)
Collection and conveyance of contaminated runoff	Diversion (362) Manure Transfer (634)
Pipe drops, weirs, or other structured used to control flow	Structure for Water Control (587)
Distribution of the runoff over a VTA or VIB	Precision Land Forming (462) Irrigation Land Leveling (464)
Establishing permanent vegetation	Pasture and Hay Planting (512)
Seedbed preparation, fertilizing, seeding, and mulching for areas disturbed during the construction	Critical Area Planting (342) and Mulching (484)
Fencing out livestock or unauthorized people	Exclusion (472) and Fence (382)

Each state determines which conservation practice standards are applicable in their state. States add the specific technical detail to national standards as needed to effectively use the standards at the field office level, and issue them as state conservation practice standards. State conservation practice standards may be found in section IV of the eFOTG (Electronic Field Office Technical Guide at *http://www.nrcs.usda.gov/technical/efotg/*.

Using these practices in a VTS may be a new application of this technology. If the practice standard does not allow the desired use of the practice or if the technical criteria in the standard will not allow the practice to function as intended in this application, it may be necessary to request a variance for some of these practices. As experience in using these practices in VTS is gained, these standards can be modified at either the state or national level or, if necessary, new standards can be developed.

Section 2 Understanding Environmental Regulations and Procedures for Evaluating Alternative Technologies

Section 2 Understanding Environmental Regulations and Procedures for Evaluating Alternative Technologies

Contents

Topics 2–1

Purpose 2–1

Caution for large CAFOs 2–2

Understanding the CAFO regulations 2–2

- Large CAFOs 2–2
- Small and medium CAFOs 2–3
- AFOs 2–3
- State-specific requirements 2–3

Performance requirements for alternative technologies 2–4

- Establishing baseline ELG performance 2–4
- Comparing VTS systems against baseline ELG performance 2–5

Tools for predicting VTS and baseline performance 2–5

- Predicting baseline system performance 2–5
- Predicting VTS performance 2–5
- Comparing the baseline and VTS performance 2–7

Figures

Figure 2–1 KS and IA studies suggest that the degree of runoff control (shown as a percent of total runoff volume) varies with region (typically related to annual precipitation) for the baseline holding pond and irrigation runoff control technologies 2–6

Tables

Table 2–1 Sample comparison of baseline technology with alternative technology required from the individual livestock operation by the permitting authority to determine the appropriateness of granting an NPDES permit based upon an alternative technology 2–8

Section 2 Understanding Environmental Regulations and Procedures for Evaluating Alternative Technologies

Topics

- Understanding EPA CAFO regulations
- Performance requirements for alternative technologies
- Tools for predicting VTS and baseline performance

Purpose

For small and medium AFOs, VTSs may provide an option for avoiding classification as a CAFO and the associated permitting process. For large CAFOs, VTS may provide an option for meeting the Effluent Limitation Guidelines (ELG) of the CAFO regulations and obtaining the required environmental permit. A copy of the CAFO regulations can be found at *http://cfpub.epa.gov/npdes/afo/cafofinalrule.cfm*. The information in this section reviews the federal ELG for CAFOs, the performance requirements that a VTS must meet as an alternative technology, and tools currently available for comparing performance of a VTS with the currently accepted baseline technology. State-specific environmental regulations should also be considered in the implementation of alternative technologies.

Caution for large CAFOs

Existing large CAFOs have been required to control open lot runoff and maintain a NPDES permit since the mid-1970s. Open lot beef cattle and dairy operations with more than 1,000 and 700 head capacity, respectively, without an NPDES permit (or letter of exemption) are out of compliance. Additional implementation delays for a runoff control system produce significant legal liability and environmental risk until the date of achieving compliance. If implementation of a VTS will add to this delay, a more conventional system should be strongly considered.

Research and field performance studies on VTS have been done exclusively on smaller open lot systems. At the time of this document, no performance evaluations of VTS on large CAFOs have been conducted. The design, siting, and management recommendations are the combined best professional judgment of a team of researchers from land grant university and ARS, field engineers from NRCS and private sector, and regulatory representatives. Those recommendations target VTS application to large CAFOs based upon the currently available knowledge.

However, if the recommendations contained in this document are carefully followed, producers and design consultants must recognize that permitting of a VTS on large CAFOs will include a burden of proof not required of a baseline technology. In addition, there are risks associated with alternative technologies if that burden of proof is not met during the design phase or in field performance is less than predicted during the operation of the VTS.

Understanding the CAFO regulations

Large CAFOs

The EPA CAFO ELG, published on February 12, 2003, are applicable to operations that meet the definition of a large CAFO. The CAFO ELG establishes the technology-based standards that must be included in NPDES permits for large CAFOs (more than 1,000 beef feeders or dairy heifers or 700 mature dairy cattle). For beef or dairy CAFOs that are below these sizes, the CAFO ELG does not apply, and the permit writer will develop effluent limitations for the permit on a case-by-case basis. If these technology-based effluent limitations are not stringent enough to assure that in-stream Water Quality Standards are maintained, water-quality-based limits or conditions must be included in the permit.

The ELG includes specific requirements for both the production areas and land application areas under the control of the CAFO owner or operator. A large CAFO must not discharge manure or process wastewater pollutants from the production area except in accordance with a narrowly defined exception. Discharges due to precipitation-caused overflow are allowed if specific design, construction, and management criteria are met. A limited amount of overflow (due to extreme rainfall events) can be authorized in a permit

Baseline ELG and exceptions

ELGs for the production area for dairy cows and cattle states that there must be no discharge of manure, liter, or process wastewater pollutants into water in the United States from the production *except* when precipitation causes an overflow, and the

- Production area is designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 25-year, 24-hour rainfall event
- Production area is operated in accordance with the additional measures required for visual inspections, depth markers, corrective actions for deficiencies identified from inspections, proper disposal of mortalities, record keeping (inspections, depth of impoundment, correction of deficiencies, mortality, storage structure design)

from a system that meets the exception. No discharges are allowed in the absence of a properly designed, constructed, operated, and maintained storage structure.

The CAFO can request that voluntary alternative performance standards be used as the basis for its NPDES permit requirements instead of the ELG requirements as described above. VTS applications on large CAFOs must meet the criteria established under these provisions. Those criteria will be described later.

Small and medium CAFOs

AFOs can be defined as a medium CAFO (300–999 beef feeders or dairy heifers or 200–699 mature dairy cows) if confined animals are in contact with water bodies of the United States or if a constructed ditch or pipe carries manure, wastewater, or runoff from the animal housing or feeding area to the water. An AFO can be designated as a small CAFO (< 300 beef feeders or dairy heifers or < 200 mature dairy cows) if either of the previously mentioned situations exist and the regulatory authority determines that the operation is contributing significant pollutants to surface water.

For small or medium CAFOs, the ELG described for the large CAFO does not apply. The permit writer will develop effluent limitations for these permitted facilities based upon best professional judgment. A system based upon a VTS can be used in place of the standard holding pond system if the permitting authority agrees to the site-specific application of the VTS. At a minimum, an onsite inspection by the permitting authority would be needed to verify the acceptability of a VTS.

AFOs can avoid being defined or designated as a CAFO if any direct connection for runoff from an open lot to surface water can be eliminated. VTS provides one alternative for eliminating a direct connection if properly designed and managed.

AFOs

Smaller animal feeding operations that are not defined as CAFOs are not required to meet the CAFO ELG. However, steps should be taken by any size of open lot facility to minimize the risk to water quality from precipitation related runoff. Depending upon the site conditions at a specific AFO, a VTS may be a low-cost alternative for minimizing runoff related water quality risks.

State-specific requirements

State livestock regulatory programs can be more stringent or have additional requirements than those mandated by the EPA CAFO NPDES permit program and regulations. Producers should always identify both the NPDES permit requirements and any additional state-specific requirements before deciding what type of runoff control system to build and operate. They should also be aware of any state construction permits required before system construction. Additionally, if more than 1 acre is to be disturbed during construction of the system, an NPDES storm water permit is also necessary.

EPA regulations address surface water quality issues only. Many state regulations also address ground water issues. Those regulations may include requirements for maximum seepage rates from manure storage facilities, ground water monitoring requirements, and minimum separation distances to wells (including abandoned wells) and ground water or geology that creates a direct connection to ground water (bedrock or karst topography). Planning of a VTS should include an evaluation of ground water risks and state environmental regulations specific to ground water.

Performance requirements for alternative technologies

A large CAFO can request that *voluntary alternative performance standards* be used as the basis for its NPDES permit requirements instead of the ELG requirements. Any alternative technology proposed for a CAFO must meet at least the performance of the baseline ELG. Since the production area baseline ELG provides for no discharge except in specified circumstances, the target for the alternative standard performance should take into account those circumstances where authorized discharges do occur under the baseline ELG.

The EPA CAFO regulations accomplish this primarily by requiring calculation of the median annual overflow volume based on 25 years of actual rainfall data. Using this volume and data on pollutants in the overflow, a predicted average annual discharge of pollutants is calculated. This is the target that the alternative technology must be designed to meet. The quantity of pollutants discharged from the production area using the alternative technology must be equal to or less than the quantity of pollutants that would be discharged under the baseline ELG. Both the analysis of the baseline performance and the alternative technology performance must be done on a site-specific basis.

A VTS represents one alternative technology for managing runoff from open lot livestock systems. Iowa State University faculty developed computer models with appropriate weather data sets for several High Plains and Corn Belt locations to assist producers in comparing a VTS with a baseline system (runoff storage pond). If the appropriate documentation can demonstrate equal or better performance for the VTS, an NPDES permit for the alternative technology can be issued.

Voluntary alternative performance standards

A large CAFO seeking permit conditions based on the voluntary alternative performance standards must establish the predicted discharge of the:

- Baseline ELG (the narrowly defined exception)
- Proposed alternative technologies and management practices result

The documentation must demonstrate that the proposed alternative will achieve a discharge from the production area equal to or less than quantity of pollutants that would be discharged under the baseline ELG. This would be done by the large CAFO submitting technical analyses and other relevant information and data as specified in the regulations.

Establishing baseline ELG performance

The CAFO ELG is specific about the comparison that must be done in determining what performance a voluntary alternative performance standard must meet. The supporting technical analysis must include calculation of the quantity of pollutants discharged from the baseline or conventional technology on a mass basis, where appropriate. The technical analysis of the discharge of pollutants must include (Section 412.21 for Voluntary Alternative Performance Standards, Concentrated Animal Feeding Operations Point Source Category, Federal Register, Vol. 68 No 29, February 12, 2003):

- All daily inputs to the storage system including manure, litter, all process wastewaters, direct precipitation, and runoff. For most open lots, only direct precipitation, runoff, and milking parlor process water (for dairies) are directed to the holding pond.
- All daily outputs from the storage system, including losses due to evaporation, sludge removal, and the removal of wastewater for use on cropland at the CAFO or transport off site.
- A calculation determining the predicted median annual overflow volume based on a 25-year period of actual rainfall data applicable to the site. If (and only if) the median is zero, the facility may use the 25-year mean (average over 25-yr period of analysis) to determine baseline best available technology (BAT).
- Site-specific pollutant data, including nitrogen (N), phosphorus (P), 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), for the CAFO from representative sampling and analysis of all sources of input to the storage system, or other appropriate pollutant data.
- Predicted annual average discharge of pollutants, expressed where appropriate, as a mass discharge on a daily basis (lb/d), and calculated considering above data.

Thus, the *target* for the alternative system is the performance of the baseline or conventional technology.

This target must be quantified, by regulation, in terms of a mass discharge on a daily basis (lb/d) where appropriate). It must include at least the pollutants of N, P, BOD_5, and TSS.

The performance model of the baseline technology must be based upon a conventional holding pond sized to meet the minimum ELGs of the CAFO regulations. The ELG states that the containment facility must be "designed, constructed, operated, and maintained to contain all manure, litter, and process wastewater including the runoff and the direct precipitation from a 25-year, 24-hour rainfall event." Additional ELG requirements identify the specific visual inspection and record keeping requirements associated with this baseline technology. The modeled performance must be for a baseline system that meets these size and management requirements.

For sizing of a runoff holding pond, accepted engineering design procedures should be followed such as those detailed in section 10 of the USDA Agricultural Waste Management Field Handbook (Soil Conservation Service 1992), ASAE's Manure Storages standard (ASAE 2004), or software design tools such as Animal Waste Management software (NRCS 2005).

Comparing VTS systems against baseline ELG performance

A similar analysis of performance for the alternative technology to that described for the baseline technology must be performed. As one can surmise from this information, the regulations are written so that it is not straight forward to make a comparison when the discharge from a proposed alternative system, such as a VTS, is weather and site condition dependant, rather than being a consistent discharge that occurs everyday. To make the comparison, modeling of the performance of a VTS will be necessary. Since the acceptance of any alternative system is a site-specific decision to be made by the permitting authority, agreement should be reached with the permitting authority about what documentation is needed as early in the process as possible.

This demonstration of equal or better performance of a VTS to the baseline technology must be provided to the permitting authority as of the date of the permit coverage. For existing facilities, the VTS shall attain a performance level that meets the ELGs for the baseline technology by the date of the permit coverage (see paragraph 412.31 (a) of the CAFO regulations, *http://cfpub.epa.gov/npdes/afo/cafofinalrule.cfm*).

Tools for predicting VTS and baseline performance

Predicting baseline system performance

A computer model was originally developed by Kansas State University (Koelliker et al. 1975) to predict the portion of runoff controlled by the baseline technology defined in the ELG (runoff holding pond and irrigation system). The same model was more recently adapted to current computer technology by Iowa State University (Wulf et al. 2003) and is being used to model performance for EPA baseline technology. The Iowa State University model is one option for predicting the performance of a baseline technology for an individual farm. An example from the Iowa State University model is illustrated in table 2–1(a) for the baseline technology.

Based upon this model, researchers have predicted that the baseline technology has a greater risk of an unplanned release of runoff in climates with higher precipitation (fig. 2–1). A well-managed baseline technology using current design requirements specified in the CAFO ELG performs well under the lower rainfall conditions of the High Plains where field conditions commonly exist for irrigation of runoff from the holding pond. However, the model also suggests that in climates with higher precipitation and lower evaporation rates (Corn Belt states), fewer opportunities exist for land application of runoff. Under this scenario, a higher frequency of unplanned releases will most likely occur in higher rainfall regions. For additional information on the performance of baseline systems, refer to the literature review in section 9.

Predicting VTS performance

An Iowa State University VTS software-modeling tool predicts the performance of a site-specific VTS following the Alternative Voluntary Performance Standards described by the ELG of the new EPA CAFO rules (table 2–1(b)). The VTS model performs site-specific modeling using daily weather inputs to estimate the performance of VTS coupled to specific feedlots and VTS designs. The model is run for 25 weather years so that the performance of the alternative VTS (median VTS outflow for 25-year period multiplied by pollutant concentration) can be compared to the performance (median overflow for 25-year period multiplied by pollutant concentrations) of a baseline containment system at the same site. VTS model outputs include runoff and four pollutants into and out of the VTS along with the percentage of runoff controlled. User inputs into the VTS model include feedlot area, feedlot slope, feedlot length/width ratio, settling basin (if selected) depth, settling basin capacity, and settling basin outlet pipe diameter. If a settling basin is not selected, a settling bench is assumed by the model. The VTS also has the following user inputs for the vegetative component:

- VTA length
- VTA width
- VTA slope
- VTA vegetation (from a database internal to the model, expandable)
- VTA soil macroporosity
- VTA soil type (from a database internal to the model, expandable)

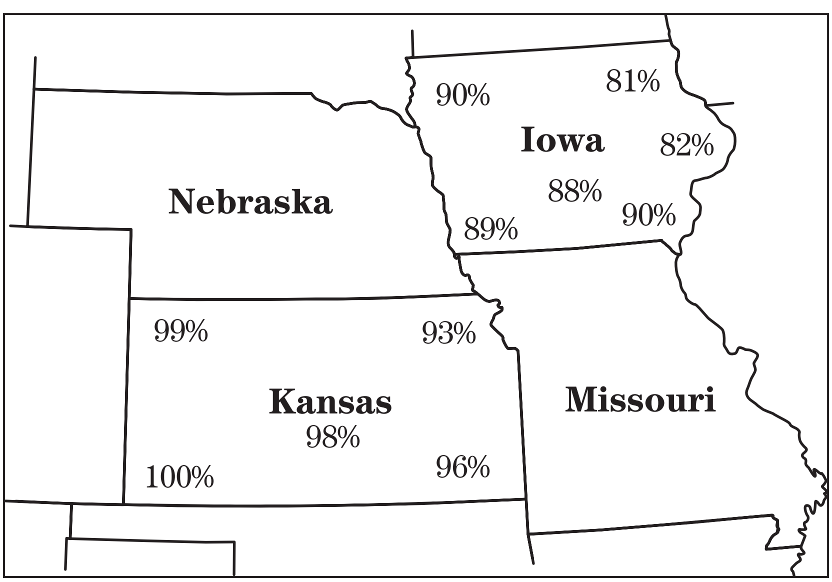
The soils database currently contains soil parameters for about 80 specific soils and 14 soil classes (loam, silty clay loam, sandy clay) with the potential to add additional soils.

The VTS model is primarily used as a model to estimate the performance of a VTS. It can be used as a tool to evaluate the importance of infiltration area of the VTA and release rate from the settling basin for a specific feedlot through one or more runs of the model. From such an evaluation, a preferred VTA size and release rate for an individual site can be identified.

After final VTS design has been completed, the VTS model is then run for each of the 25 years and the predicted average annual discharge of pollutants in the VTS outflow over this time period calculated. An acceptable system has been identified if this design results in equal or less discharge than the median (or mean) overflow from the baseline containment system at the same site.

This software has been approved by EPA as one option for the documentation necessary for an NPDES application for an alternative technology. This software is available from the Agricultural and Biosystems Engineering Department at Iowa State University, Ames, Iowa.

Figure 2–1 KS and IA studies suggest that the degree of runoff control (shown as a percent of total runoff volume) varies with region (typically related to annual precipitation) for the baseline holding pond and irrigation runoff control technologies as defined by the ELG for large CAFOs (Koelliker et al. 1975; Wulf et al. 2003). The runoff control values are conceptual examples and do not represent the site-specific performance of holding pond-based systems.



Comparing the baseline and VTS performance

To complete this process, the results of the baseline and VTS performance must be compared (table 2–1(c)). At a minimum, the comparison must include four potential pollutants including total nitrogen, ammonium, total phosphorus, and biochemical oxygen demand. The regulations suggest that a comparison be made of the median annual value over the 25-year period for the mass of each pollutant in the unplanned runoff. If (and only if) the median is zero, the facility may use the 25-year mean (average over 25-yr period of analysis) to determine baseline best available technology.

At the time of this report, final development and validation of these models were being completed by Iowa State University. For the immediate future, requests for application of these models to individual farms should be made directly to the Agricultural and Biosystems Engineering Department at (515) 294-1434.

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Table 2–1(a) Sample comparison of baseline technology with alternative technology required from the individual livestock operation by the permitting authority to determine the appropriateness of granting an NPDES permit based upon an alternative technology (Lorimor and Wulf 2004)

Baseline System: Containment System Runoff Control Performance for Prime Rib Ranch (5.5-a feedlot) located in Anytown, USA.

	Precipitation (in)	Runoff (in)	Overflow (in)	Overflow (days)	Runoff control (%)	Land applied (in)	Pump (days)	Ending pond volume (ft³)	Nutrients in feedlot runoff (lb/yr)				Nutrients in unplanned release (lb/yr)				Nutrient Control (%)
									TKN	NH_3^+	PO_4	BOD_5	TKN	NH_3^+	PO_4	BOD_5	
1970	31.64	10.59	0.00	0	100.0	10.40	21	10099	6801	5282	6602	80550	0	0	0	0	100.0
1971	28.82	10.83	0.00	0	100.0	9.90	20	31690	6951	5399	6749	82333	0	0	0	0	100.0
1972	31.07	9.82	0.00	0	108.0	8.91	18	45298	6304	4896	6120	74670	0	0	0	0	100.0
1973	60.88	32.05	9.30	16	71.0	24.75	50	58374	20574	15980	19975	243692	5333	4142	5178	63172	74.1
1974	31.30	11.20	0.00	0	100.0	13.86	28						0	0	0	0	100.0
1975	29.08	10.21	[illegible]	[illegible]	[illegible]	[illegible]	16	54123	6556	5092	6365	77652	0	0	0	0	100.0
1976	20.90	6.26	[illegible]	[illegible]	[illegible]	[illegible]	15	4097	4016	3119	3899	47565	0	0	0	0	100.0
1977	48.48	21.63	[illegible]	[illegible]	[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1697	1318	1648	20104	87.8
1978	31.00	13.48	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	100.0
1979	35.01	13.14	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	100.0
1980	32.04	15.09	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	100.0
1981	40.57	15.88	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1332	1034	1293	15774	86.9
1982	38.26	12.72	1.74	2	[illegible]	[illegible]	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	990	769	961	11726	87.9
1983	36.54	13.30	0.00	0	100.0	13.37	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	100.0
1984	37.45	12.82	0.32	1	97.5	12.87	26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	184	143	178	2176	97.8
1985	45.11	16.92	2.57	3	84.8	15.84	32	16926	10860	8435	10544	128637	1451	1127	1409	17184	86.6
1986	37.39	13.88	0.00	0	100.0	15.35	31	797	8909	6920	8650	105529	0	0	0	0	100.0
1987	36.96	12.30	0.00	0	100.0	11.88	24	13599	7893	6131	7664	93495	0	0	0	0	100.0
1988	19.42	6.38	0.00	0	100.0	5.94	12	5438	4096	3181	3977	48516	0	0	0	0	100.0
1989	38.72	18.56	4.39	4	76.4	14.85	30	6126	11915	9254	11568	141127	2517	1955	2443	29810	78.9
1990	33.90	10.63	0.00	0	100.0	10.89	22	305	6822	5299	6623	80804	0	0	0	0	100.0
1991	29.46	9.17	0.00	0	100.0	7.92	16	20262	5885	4571	5713	69703	0	0	0	0	100.0
1992	36.18	12.40	0.00	0	100.0	10.40	21	72076	7961	6183	7729	94296	0	0	0	0	100.0
1993	35.33	13.84	1.80	4	87.0	15.35	31	2939	8885	6901	8626	105234	1105	858	1073	13087	87.6
1994	27.75	9.05	0.00	0	100.0	8.42	17	2029	5811	4514	5642	68834	0	0	0	0	100.0
1995	36.04	13.33	3.09	7	76.8	9.90	20	4044	8558	6647	8309	101372	1744	1354	1693	20653	79.6

Performance of baseline technology must be predicted for the farm upon which an alternative technology is being reviewed for an NPDES permit.

Performance of baseline technology and VTS must be predicted for total nitrogen, ammonium, phosphorus, and biochemical oxygen demand.

Containment summary

Mean	**34.97**	**13.29**	**1.09**	**1.81**	**94.3**	**12.5**	**25.2**	**17473**	**8530**	**6625**	**8281**	**101032**	**629**	**488**	**611**	**7449**	**94.9**
Median	**35.17**	**12.77**	**0.00**	**0.00**	**100.0**	**12.4**	**25.0**	**10315**	**8198**	**6368**	**7959**	**97106**	**0**	**0**	**0**	**0**	**100.0**

Table 2–1(b) Sample comparison of baseline technology with alternative technology—Continued

Alternative Technology: VTS Performance for Prime Rib Ranch (5.5 acre feedlot) located in Anytown, USA.
260-foot-long x 800-foot-wide VTS in Elmont soil located below a 5.5-acre feedlot with a 20-foot-wide settling bench.

	Precipitation (in)	Feedlot runoff		VTA runoff (in)	Runoff control (%)	Nutrients in runoff (lb/yr)				Nutrients in unplanned release (lb/yr)			
		Total (in)	Snow melt (in)			TKN	NH_3	PO_4	BOD_5	TKN	NH_3^+	PO_4	BOD_5
1970	31.64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	28.82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	31.07	[illegible]	[illegible]	[illegible]	[illegible]	5660	[illegible]	[illegible]	[illegible]	0	0	0	0
1973	60.88	[illegible]	[illegible]	2.41	91.8	18776	14583	18229	222396	340	192	240	3664
1974	31.30	9.98	0.28	0	100.0	6867	5533	6917	84384	0	0	0	0
1975	29.08	7.15	1.77	0	100.0	4591	3566	4457	54376	0	0	0	0
1976	20.90	[illegible]	[illegible]	[illegible]	[illegible]	3531	2743	3429	41828	0	0	0	0
1977	48.48	[illegible]	[illegible]	[illegible]	96.3	13924	10815	13519	164927	113	64	80	1216
1978	31.00	[illegible]	[illegible]	[illegible]	97.6	7575	5884	7355	89725	41	23	29	441
1979	35.01	[illegible]	[illegible]	[illegible]	[illegible]	7757	6025	7531	91884	0	0	0	0
1980	32.04	[illegible]	[illegible]	[illegible]	98.2	10470	8132	10165	124019	37	22	27	397
1981	40.57	15.68	0.00	0	100.0	10066	7818	9773	119228	0	0	0	0
1982	38.26	11.29	0.51	0	100.0	7244	5626	7033	85801	0	0	0	0
1983	36.54	11.63	0.33	0	100.0	7466	5799	7249	88433	0	0	0	0
1984	37.45	11.71	1.65	1.00	91.5	7466	5799	7249	88434	141	80	100	1520
1985	45.11	15.61	0.17	0.08	99.5	10021	7783	9729	118696	0	0	0	0
1986	37.39	12.28	0.08	0	100.0	7883	6123	7654	93375	0	0	0	0
1987	36.96	12.25	0.61	0.81	93.4	7864	6108	7635	93147	114	89	111	1355
1988	19.42	5.58	0.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0
1989	38.72	18.34	0.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75	94	1429
1990	33.90	10.70	0.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0
1991	29.46	7.48	1.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0
1992	36.18	9.97	0.78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	15
1993	35.33	13.82	0.00	0	100.0	8872	6891	8614	105085	0	0	0	0
1994	27.75	8.60	0.05	0.14	98.4	5527	4293	5366	65469	20	15	19	234
1995	36.04	15.53	0.31	0	100.0	9957	77.33	9667	117936	0	0	0	0
Mean	34.97	12.34	0.53	0.26	98.5	7947	6180	7725	94242	36	22	27	395
Median	35.15	11.67	0.36	0	100.0	7466	5799	7249	88433	0	0	0	0

Performance of alternative technology must be predicted for the same farm.

Performance modeling must be site-specific for an individual farm.

Performance for baseline and alternative technology must be predicted for a 25-yr period based upon records from nearby weather station.

The documentation must demonstrate that the proposed alternative will achieve a discharge from the production area of equal or less quantity of pollutants to that of the baseline ELG (table 2–1, part A).

Table 2–1(c) Sample comparison of baseline technology with alternative technology—Continued

Comparison of unplanned runoff from containment system vs. VTS for Prime Rib Ranch (5.5-a feedlot) located in Anytown, USA.

Year	Containment runoff control (%)	VTS runoff control (%)	TKN containment	VTS	NH_4+ containment	VTS	PO_4 containment	VTS	BOD_5 containment	VTS
1970	100.0	100.0	0	0	0	0	0	0	0	0
1971	100.0	100.0	0	0	0	0	0	0	0	0
1972	100.0	100.0	0	0	0	0	0	0	0	0
1973	71.0	91.8	5333	340	4142	192	5178	240	63172	3664
1974	100.0	100.0	0	0	0	0	0	0	0	0
1975	100.0	100.0	0	0	0	0	0	0	0	0
1976	100.0	100.0	0	0	0	0	0	0	0	0
1977	86.4	96.3	1697	113	1318	64	1648	80	20104	1216
1978	100.0	97.6	0	41	0	23	0	29	0	441
1979	100.0	100.0	0	0	0	0	0	0	0	0
1980	100.0	98.2	0	37	0	22	0	27	0	397
1981	85.7	100.0	1332	0	134	0	1293	0	15774	0
1982	86.3	100.0	990	0	769	0	961	0	11726	0
1983	100.0	100.0	0	0	0	0	0	0	0	0
1984	97.5	91.5	[illegible]	[illegible]	[illegible]	80	178	100	276	1520
1985	84.8	99.5	[illegible]	[illegible]	[illegible]	0	109	0	17184	0
1986	100.0	100.0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
1987	100.0	93.4	[illegible]	[illegible]	[illegible]	89	0	111	0	1355
1988	100.0	100.0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
1989	76.4	94.9	[illegible]	[illegible]	[illegible]	75	2443	94	29810	1429
1990	100.0	100.0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
1991	100.0	100.0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
1992	100.0	99.9	[illegible]	[illegible]	[illegible]	1	0	1	0	15
1993	87.0	100.0	[illegible]	[illegible]	[illegible]	0	1073	0	13087	0
1994	100.0	98.4	[illegible]	[illegible]	[illegible]	15	0	19	0	234
1995	76.8	100.0	1,744	0	[illegible]	0	1693	0	20653	0
Mean	94.3	98.5	629	36	488	22	611	27	7449	395
Median	100.0	100.0	0	0	0	0	0	0	0	0

A calculation determining the predicted median annual overflow volume based on a 25-yr period of actual rainfall data applicable to the site is made. If (and only if) the median is zero, the facility may use the 25-yr mean (average over 25-yr period of analysis) to determine baseline BAT.

For this example, the means would be compared. The predictive model suggests that VTS will perform better than the conventional technology.

Section 3 System Options Based upon Vegetated Treatment Areas

Section 3 System Options Based upon Vegetated Treatment Areas

Contents

Topics 3–1

Purpose 3–1

Common plant-based treatment options 3–2

Common VTS options 3–3

Option 1: VTA and solids settling....3–4
Option 2: VTA replaced by VIB....3–5
Option 3: Option 1 plus VIB....3–6
Option 4: Option 1 with storage included in settling basin....3–7
Option 5: Option 1 with storage included in VTA....3–8
Option 6: Option 1 followed by storage basin....3–9

Minimizing the potential to discharge 3–10

References 3–12

Tables

Table 3–1	Comparison of winter precipitation versus 25-year, 24-hour storm assuming settling basin was designed to contain such an event	3–11

Figures

Figure 3–1	Option 1: VTA and solids settling	3–4
Figure 3–2	Option 2: VTA replaced by VIB	3–5
Figure 3–3	Option 3: Option 1 plus VIB	3–6
Figure 3–4	Option 4: Option 1 with storage included in settling basin	3–7
Figure 3–5	Option 5: Option 1 with storage included in VTA	3–8
Figure 3–6	Option 6: Option 1 followed by storage basin	3–9
Figure 3–7	Role of pre-treatment components of a vegetative treatment system (see options 3 and 4) for delaying and restricting flow in the VTA component	3–10

Section 3 System Options Based upon Vegetated Treatment Areas

Topics

- Common plant based treatment options
- Common systems involving VTAs

Purpose

VTSs will be considered by permitting authorities under the Voluntary Alternative Performance Standards of the ELG CAFO regulations. VTS application will be based upon the ability of a large CAFO to document that this alternative technology will meet or exceed the performance of baseline technologies (containment and land application). Chapter 3 reviews several systems utilizing a VTA or VIB as part of a system for managing runoff for their potential to be permitted under the CAFO regulations.

The work group that prepared this report determined that successful applications of a VTA to CAFOs requires:

- Systems providing multiple levels of treatment
- Passive or active management of release of liquids into a VTA
- Some level of short-term storage

These features are illustrated in six systems described in this report, four of which are believed to provide the greatest opportunity for success in large CAFO applications.

Common plant-based treatment options

Ikenberry and Mankin (2000) defined a vegetated filter as a band of planted or indigenous vegetation situated downslope of cropland or animal production facilities that provide localized erosion protection and contaminant reduction. Pasture, grassed waterways, or cropland (preferably with perennial vegetation) with planted or indigenous vegetation may be used to treat runoff through filtration, adsorption, settling, and infiltration.

The terminology VTS is used to refer to plant-based treatment systems (typically perennial grass or forage crops) intended to reduce environmental risk associated with runoff and other process waters from an open lot livestock system. These systems perform treatment functions including solids settling, soil infiltration, and filtering (soil biological and chemical treatment), thus, the term *treatment* is used as opposed to *filter*.

Several alternative types of plant based treatment components may be used in a VTS:

- *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. Total treatment area should be designed to match: (1) crop nitrogen uptake with estimated N in runoff or (2) volume of water runoff with soil infiltration capacity. Typically, the nutrient balance approach is the limiting design sizing method. Uniform flow across the vegetated slope is necessary, possibly requiring laser-guided land leveling equipment and other design considerations for distributing flow, as well as field maintenance to limit erosion and channeling.
- *Terraced VTAs* have been used to contain runoff on sloped areas. Both overflow and serpentine 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 sub-category 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 sub-surface drainage and complete enclosure by a berm designed to prevent surface discharges (sec. 7). Runoff from an open lot is allowed to infiltrate through a soil system within 72 hours or less. Soil systems allow plant uptake of nutrients and water and soil chemical and biological properties for treatment of many pollutants. Systems generally use tile drainage to recover partially treated runoff, thereby, reducing ground water contamination. The collected drainage can be discharged to a VTA or other treatment system. Typically VIBs have used soil as the infiltration media. However, sand and organic matter beds, possibly without vegetation, can also be utilized to filter many contaminants in runoff.
- *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 discussed in detail in this publication. (For additional information on constructed wetland application to animal effluents, see Payne, 1992 and Gulf of Mexico Program, 1997.)

Most VTA systems rely on sedimentation for reducing pollutant concentration and infiltration to reduce runoff and pollutant mass. However, these systems typically are not designed to prevent discharge for all storm events. Extensive research has been conducted on solids and nutrient removal by VTA systems. Typically, VTAs remove 50 to 90 percent of most contaminants associated with runoff. With careful sizing of a VTA and controlled release of runoff, a VTA can eliminate most releases of contaminants.

Less research and field experience with VIBs is currently available. A 5-year study of a VIB on an Iowa State University feedlot has suggested removal of 70 to 90 percent of most contaminants from feedlot runoff prior to its collection of infiltrate by tile drain system.

The one exception to these reductions is with nitrate. In runoff, nitrate concentration is typically negligible. The aerobic environment in a VTA and VIB allows some conversion of ammonium to low concentrations of nitrate (commonly less than 10 ppm) during the treatment processes. Management of nitrate in the liquids released from a VTA and VIB will need to be considered. More detailed information on performance of VTAs and VIBs is presented in section 9, Literature Review.

Common VTS options

A VTS is a combination of treatment components, including plant-based treatment options and a management strategy. Assembling of an acceptable *system* is critical to minimizing environmental risk and obtaining a permit under the CAFO regulations. Permit requirements are more restrictive for VTS applications on large CAFOs than for small and medium CAFOs or unpermitted AFOs. Selecting an appropriate system for large CAFOs is the focus of this section.

The following discussion reviews six systems for their ability to minimize the potential for an unplanned release and to meet the CAFO requirements. Other options are possible including options that involve constructed wetlands. Ultimately, the opportunity for each option to be applied to a large CAFO will be based upon the site-specific performance comparison provided by the producer as part of the permit application. Thus, one limit on system options is the ability of the system to be modeled using weather data over a 25-year period.

All options will include pre-treatment by solids settling. Solids settling prior to a VTA or VIB is essential to sustaining performance within the vegetative area. Without solids settling, excess solids accumulation in the upper end of the VTA or VIB will lead to greater short circuiting of liquids, uneven distribution of nutrients, and loss of healthy vegetation.

Selecting the appropriate management strategy for controlling release of runoff is an important consideration for a successful system. The risk of a discharge from a VTA is significantly greater if feedlot runoff enters the VTA simultaneously with rainfall directly falling on the VTA. The infiltration rate of the soil can be overwhelmed with the two simultaneous sources of water. Delaying or limiting the release of runoff liquids until after the storm event reduces the potential of a discharge from a VTA. Three primary management strategies will be considered as part of the system:

- *Unrestricted runoff release.* The outlet of the settling basin is not restricted because of limited or no storage capacity in the settling basin. Runoff release is designed to match the peak flow rate of liquids into the settling basin when the basin is nearly full.
- *Passive runoff release control.* The outlet of the settling basin is restricted to delivering runoff slowly over a 36- to 72-hour period. The settling basin must be sized to handle a 25-year, 24-hour storm.

- *Active runoff release control.* The outlet of the settling basin can be physically controlled so that the manager determines the best timing for the release of basin liquids, presumably when the VTA soil conditions are most appropriate. This approach requires that the settling basin have sufficient capacity for normal runoff, as well as that necessary to handle a 25-year, 24-hour storm.

Cost share assistance may be available for systems involving a VTA or VIB. The NRCS Environmental Quality Incentives Program (EQIP) and Conservation Innovation Grant programs provide competitive cost share assistance. Many State environmental agencies provide low interest rate loan programs to industry. Program guidance and technical assistance may also be available from the local NRCS office.

Option 1: VTA and solids settling

Our base system is a settling basin followed by a grass treatment area with modest storage in the system (fig. 3–1). Settling of solids is essential to the successful management of any VTS. The basin typically would be sized to hold runoff from a high intensity storm for a 1-hour period or less (sec. 5). The liquid level in the settling basin would be passively managed. Flow rate from the basin to the grass system is controlled by design of the outlet pipe(s). The manager would not have control over timing and release rate of runoff.

Following settling of most suspended manure solids and soil, runoff water would be distributed uniformly over a grass treatment area. Sizing of this system would be based upon either nutrient balance or water balance within the VTA. Potential alternative VTAs would include a constructed wetland or a terraced VTA.

Large CAFO application: Potential to discharge is high. Sizing of VTA is critical to minimizing treated releases from VTA. Model comparison of option 1 with baseline technology will provide final determination of potential for this option to be applied to large CAFOs.

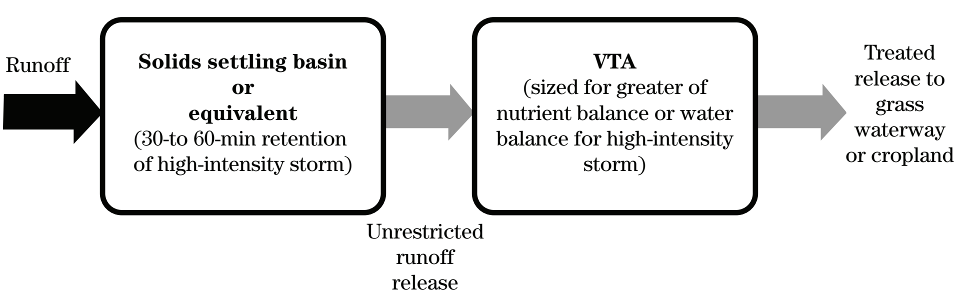
Small or medium CAFO application: Option 1 systems may reduce risk sufficiently to potentially prevent an AFO from being designated as a CAFO. The permitting authority should be consulted in any application of this system to AFOs that may have a direct connection to surface waters. This system alone may not be acceptable in all states or situations for cost share assistance from state or USDA conservation programs.

AFO application: For AFOs with sufficient distance or a lack of a direct connection to surface waters, the base system should be acceptable for most situations.

Advantages of option 1 system

- This system will eliminate some costs for land application of runoff from the open lot including management inputs for scheduling irrigation and equipment requirements for more expensive sprinkler irrigation system. However, a well-functioning VTA or VIB will require other critical management inputs (sec. 8), as well as similar levels of inputs associated with utilization of solids collected in the solids settling component.
- The cost of a settling basin component should be substantially less than the cost of a traditional storage basin.
- Because settling basins typically drain completely or with minimal retained volume, less potential for pollutant leaching (especially nitrate) to ground water and air emissions would be expected. In addition, abandonment of such facilities would likely present fewer costs and environmental challenges.

Figure 3–1 Option 1: VTA and solids settling



Disadvantages of option 1 system

- Treated discharges from this system are common, especially if size is not adequate. During major storms the grass treatment area will be receiving wastewater from the settling basin while saturated VTA conditions exist due to rainfall on the VTA. Open lot runoff events associated with frozen soil conditions would also produce potential conditions for runoff from the VTA. In many regions of the country, high-intensity rainfall events or extended wet periods during spring and summer produce the greatest potential for discharge.
- The footprint of a VTA will be greater than that of a runoff holding pond.
- Research has shown that small storms may not create sufficient flow to distribute the contaminated runoff over the VTA and will result in overloading of the VTA near the outlet from the settling basin.
- Grass systems tend to filter most solids and nutrients within the first 50 feet from the liquid inlet due to settling and contact with vegetation especially if solids settling is not included or undersized. This may contribute to high nutrient loads in the upper end of a VTA. Management considerations for monitoring and addressing nutrient loading issues are addressed in section 8.

Option 2: VTA replaced by VIB

Option 2 replaces the VTA with a VIB (fig. 3–2). No direct surface water discharge would result from this system for storm events up to a 25-year, 24-hour storm. Some discharge would be expected from the tile drain system of the VIB. The settling basin and VIB would provide better assurance of a consistent level of treatment (typically 90% or more of contaminant mass removal from feedlot runoff) even for major storm events or chronic wet periods. All runoff will infiltrate through 4 to 6 feet of soil prior to discharge.

The VIB also delays the start of the discharge to the grassed waterway or cropland for several hours and spreads the discharge out over a significantly longer time, thus reducing the chance that feedlot runoff will be discharged during the storm event.

Large CAFO application: Potential to discharge treated shallow ground water to surface water is high. The treatment efficiency of the VIB alone may not equal the performance of the baseline technology. Model comparison of Option 2 with baseline technology will provide final determination of potential for this option to be applied to large CAFOs.

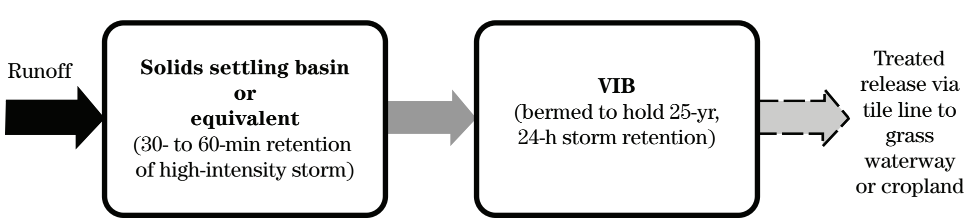
Small or medium CAFO application: This option should provide more consistent treatment than Option 1 and be applicable to many AFOs, preventing their definition or designation as a CAFO. The permitting authority should be consulted in any application of this system to AFOs that may have a direct connection to surface waters. The VIB may not be acceptable in all states or situations for cost share assistance from state or USDA conservation programs.

AFO application: For AFOs, option 2 should be acceptable for most situations.

Advantages of option 2 system

- This system should provide a more consistent level of pollutant reduction in all pollutants for a wide range of storm events, chronic wet periods, and frozen soil conditions.
- This system retains most of the advantages of Option 1 including low capital cost, low operation and maintenance cost for land application of runoff, minimal air quality concerns, and, if appropriate sites are selected for VIB, limited risk to ground water (see sec. 7 on VIBs).

Figure 3–2 Option 2: VTA replaced by VIB



Disadvantages of option 2 system

- Discharges from this system would be expected, but only after runoff has passed through settling basin and 4 to 6 feet of soil filtration.
- Ground water discharge from VIB will contain some pollutants, likely only 10 percent or less of the mass of pollutants in the original feedlot runoff. However, discharge from the VIB will still exceed concentrations acceptable for surface waters.
- Site-specific conditions will not allow VIBs to function in all soil conditions. Generally, a more restrictive soil layer is needed below the tile line within the VIB.

Option 3: Option 1 plus VIB

Option 1 has been enhanced with the addition of a VIB to the system (fig. 3–3). This approach is to ensure that no feedlot runoff is discharged from the system without first having three levels of treatment. In addition, no direct surface water discharge of runoff would be anticipated for storm events less than a 25-year, 24-hour storm due to the storage capacity in the VIB.

The VIB also delays the start of the discharge from the VIB to the VTA for several hours and spreads the discharge out over a significantly longer time (passive runoff release), thus reducing the opportunity for feedlot runoff to enter the VTA during the storm event.

Large CAFO application: Option 3 meets the ELG design size requirements of the CAFO ELG for baseline systems. It is attractive option for some large CAFOs because of its ability to minimize the risk of a discharge from the VTA plus provide substantial treatment for any releases that might occur. The permitting authority should be consulted early in the process to see if this system meets the requirements of the baseline ELG or will need to qualify under the voluntary alternative performance standards.

Small or medium CAFO application: Option 3 should be an acceptable option for many potential small or medium CAFOs. The permitting authority should be consulted in any application of option 3.

AFO application: Option 3 should be acceptable for all AFOs.

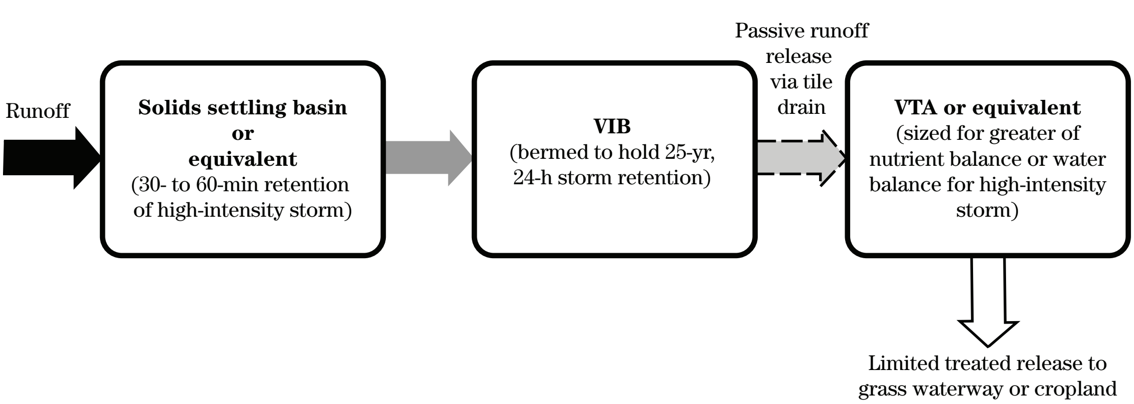
Advantages of option 3

- This system retains most of the advantages of option 1 including low operation and maintenance cost for land application of runoff, minimal air quality concerns, and limited risk to ground water if only appropriate sites are selected for VIB (see sec. 7 on VIBs).
- Potential for surface water discharges of feedlot runoff should be far less than with options 1 and 2 and equal to or less that potential for discharge from a baseline basin and irrigation system for many open lots.

Disadvantages of option 3

- The increased complexity of this system has likely eliminated some of the capital cost benefits of plant based treatment systems.
- Site-specific conditions will not allow VIBs to function in all soil conditions. Generally, a more restrictive soil layer is needed below the tile line within the VIB.

Figure 3–3 Option 3: Option 1 plus VIB



Option 4: Option 1 with storage included in settling basin

This system is similar to option 1, but design of the solid settling basin has two distinctive differences (fig. 3–4):

- Storage is included in the solids settling basin. Storage volume sized to meet the needs for a 25-year, 24-hour storm event and/or winter and early spring runoff could be included depending upon safety factor desired. The settling basin now has a volume of similar size to that of a standard runoff retention pond. However, this storage and settling basin may be a long, relatively shallow channel located down elevation from the bottom edge of the open lots for some systems as opposed to a rectangular pond.
- The outlet system for the settling basin allows the manager to control timing of runoff release to the VTA (active release control) or be carefully restricted to allow a release over a 36- to 72-hour period (passive release control).

Large CAFO application: Option 4 meets the ELG design size requirements of the CAFO ELG for baseline systems. It is attractive option for many large CAFOs because of its ability to minimize the risk of a discharge from the VTA. The permitting authority should be consulted early in the process to see if this system meets the requirements of the baseline ELG or will need to qualify under the voluntary alternative performance standards.

Small or medium CAFO application: Option 4 should be an acceptable option for many potential small or medium CAFOs. The permitting authority should be consulted in any application of option 4.

AFO application: Option 4 should be acceptable for most situations fitting this category.

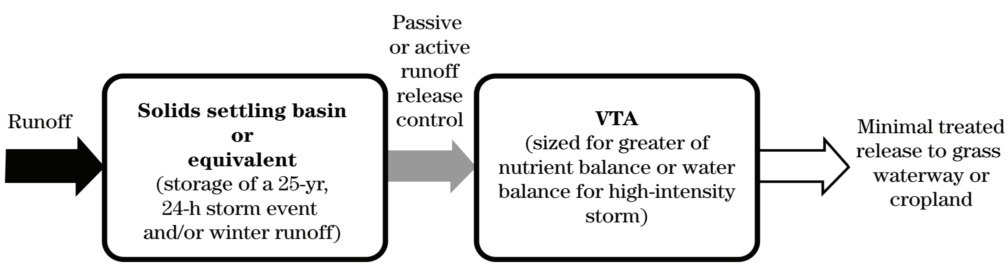
Advantages of option 4

- This system retains some of the advantages of option 1 including low operation and maintenance cost for land application of runoff (especially for a passive runoff release control) and minimal air quality concerns (passive runoff release control only).
- Storage in the settling basin will delay most (passive release control) or all (active release control) runoff addition to the VTA until the storm event has passed, minimizing discharges from the VTA during major or chronic storms or during frozen soil conditions.
- If sized correctly, the solids separation and storage basin could serve as a traditional storage basin if the VTA failed to perform as planned.

Disadvantages of option 4 (active release control)

- The size of the settling and storage basin will approach the size of the traditional storage basin and may have the same liner requirements and similar construction cost.
- The settling and storage basin will require a commitment to managing runoff release and maintenance of level gauges and records as required for traditional runoff control systems.
- The combination of settling and storage in the same structure has many management problems (difficulty with timely solids removal, damage to liner during solids removal, increased odors) and is typically not recommended for traditional systems.

Figure 3–4 Option 4: Option 1 with storage included in settling basin



Disadvantages of option 4 (passive release control)

- The size of the settling and storage basin will approach the size of the traditional storage basin.
- The settling and storage basin would require similar level gauges and records as required for traditional runoff control systems.
- The combination of settling and storage in the same structure has many management problems (difficulty with timely solids removal, damage to liner during solids removal, increased odors) and is typically not recommended for traditional systems.

Option 5: Option 1 with storage included in VTA

A partial or total berm around the VTA (similar to a VIB with no tile drainage) would be designed to minimize discharges from the system. The berm would need to create sufficient storage capacity for the open lot runoff, as well as the runoff from the settling basin and grass treatment area. Vegetation capable of withstanding occasional flooding would need to be selected.

Large CAFO application: Option 5 should minimize risk of discharge and improve the opportunity for this option to be approved under the ELG voluntary alternative performance standards. Ponding of effluent can create greater ground water risks causing concerns for state agencies that regulated ground water. The permitting authority should be consulted in any application of this system to a CAFO.

Small or medium CAFO application: Option 5 should be an acceptable option for most small or medium CAFOs. The permitting authority should be consulted in any application of option 5, especially where ground water issues are regulated.

AFO application: Option 5 should be acceptable for most situations fitting this category.

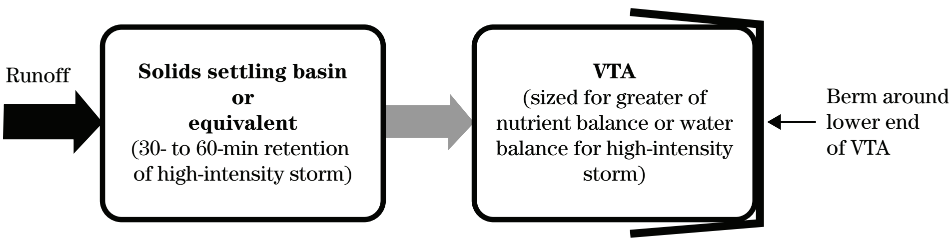
Advantages of option 5

- If the berm is sized properly for the 25-year, 24-hour storm, option 5 may meet the design size requirements of the ELG.
- This system retains most of the advantages of option 1 including low capital costs, low operation and maintenance cost for land application of runoff, and minimal air quality concerns.
- If the VTA has minimal slope, the storage within the VTA will provide improved distribution of the storm flows during major and chronic rainfall events.

Disadvantages of option 5

- Crop damage is possible if water due to ponding during major and chronic storms. Accumulated runoff during frozen soil conditions may also expose crop to submerged conditions for extended periods of time. During these periods, grass-based systems may become stressed, fail completely, or become displaced with undesirable species.
- The VTA may infiltrate runoff at times and rates that could lead to contamination of ground water (especially systems designed on a water balance as opposed to a nutrient balance).

Figure 3–5 Option 5: Option 1 with storage included in VTA



Option 6: Option 1 followed by storage basin

This system places the storage component after the VTA. It will also require a mechanical pumping and distribution system for transferring runoff back to the VTA. The active management of the irrigation of the VTA and the placement of the storage after the VTA should result in a truly *no-discharge* system.

Large CAFO application: Option 6 presents an additional alternative for most CAFOs that could meet all ELG requirements of the baseline technology. Nearly all risk of surface water discharge should be eliminated by this approach. The permitting authority should be consulted in any application of this system to a CAFO.

Small or medium CAFO application: Option 6 should be an acceptable option for most small or medium CAFOs. The permitting authority should be consulted in any application of option 6 to higher risk small and medium CAFOs.

AFO Application: Option 6 should be acceptable for most situations fitting this category.

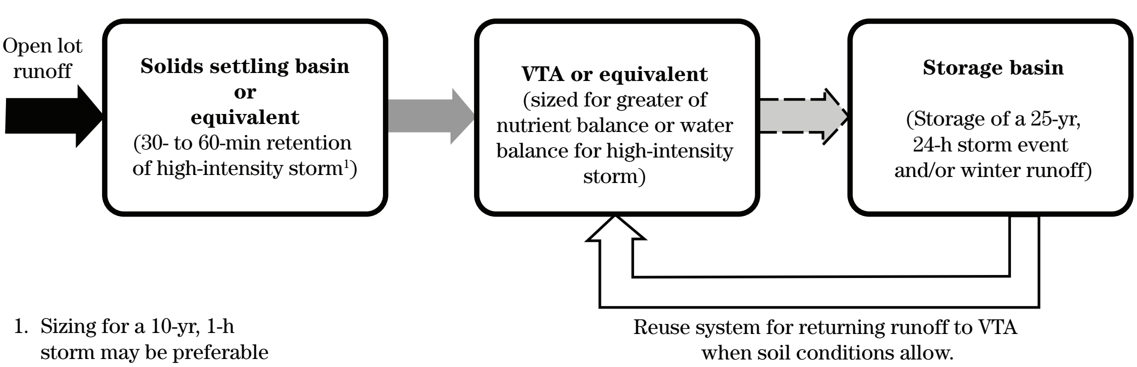
Advantages of option 6

- The system may be a true no-discharge system with advantages for surface water over the base system, as well as the traditional containment system. Option 6 meets the ELG design requirements of the CAFO regulations for beef and dairy systems and may not need to be permitted under the voluntary alternative performance standard.
- The treated wastewater stored in the storage basin will have little potential for odors or less potential for ground water contamination due to two stages of treatment before runoff is held in storage.

Disadvantages of option 6

- This system will have some significant cost and management time requirement associated with land application, possibly similar or greater than traditional systems.
- Remote power will be needed to recycle storage pond contents to VTA.
- The storage basin will have to be sized to store the effluent from the open lot, settling basin and the runoff from the VTA. This will require a larger storage basin than a traditional system.

Figure 3–6 Option 6: Option 1 followed by storage basin



1. Sizing for a 10-yr, 1-h storm may be preferable

Minimizing the potential to discharge

Two situations are commonly raised as having potential for producing a discharge from a VTS. First, during a storm event that last over an extended period, the runoff released from the solids settling into the VTA would coincide with precipitation falling on the VTA. The combination of feedlot runoff and direct precipitation could overwhelm the infiltration rate of the soil causing a potential discharge of diluted and partially treated feedlot runoff. Second, winter runoff events are a common concern, especially when soils are frozen.

To address the first situation when feedlot runoff and direct precipitation enter the VTA simultaneously, preferred system options will include significant storage in advance of the VTA (settling basin sized for a minimum 10-yr, 1-h storm or, preferably, a 25-yr, 24-h storm event) and either passive or active control of the settling basin release of liquid to the VTA (fig. 3–7). A VIB also slows the release of liquid into the VTA (similar to a passive runoff release) and extends the release over a much longer period of time, much of it after the storm event. A settling basin with an active runoff release can delay most runoff entry into the VTA until after the end of the storm events. Options 3 and 4 offer the preferred systems for controlling and delaying the runoff release into the VTA. Options 5 and 6 also minimize the risk of discharge by simply adding additional storage.

Winter runoff is typically associated with snowmelt or low-intensity rainfall events when the feedlot surface and VTA soils are frozen. The literature suggests that runoff associated with frozen soil conditions can be characterized as typically high in solids and low in volume. VTS options that include some storage should minimize a winter related runoff release into a VTA. System options 3, 4, 5, and 6 all include significant storage and may meet these criteria. A review of local weather records should provide additional insight as to a system's ability to store winter runoff. Comparing the precipitation related runoff for winter conditions with a settling basin capacity based upon a 10-year, 1-hour or 25-year, 24-hour storm event should provide some insight as to the need to release liquid into a VTA under frozen soil conditions.

A comparison for three sites in Nebraska (table 3–1) would suggest that the settling basin sized for a 25-year, 24-hour storm would be almost sufficient to handle all winter precipitation assuming 100 percent runoff and no release until spring. In reality, the average runoff of precipitation during December through March is less than 10 percent in Nebraska. A reasonable storage capacity of the settling basin or VIB in advance of a VTA should be able to minimize releases of liquid into a VTA under frozen soil conditions in Nebraska. A similar check for other sites should provide insight as the risk associated with frozen soil conditions.

If runoff must be release into the VTA under winter conditions, the sedimentation treatment role of a VTA is generally not restricted by dormant vegetation assuming that the VTA enters winter with thick vegetation. Some researchers have suggested thick matted vegetation in winter will equal or out-perform growing summer vegetation performance for encouraging settling. Fall VTA management is critical to achieving a desirable thick matted vegetation for winter treatment.

The infiltration treatment function of a VTA is lost if soils are frozen. Thus, all runoff would experience the normal reductions of solids and nutrients in the settling basin (about 50%) and VTA due to sedimentation (60 to 80%) for the few situations when runoff is released into a VTA when soil is frozen. However, frozen VTA soils create a significant potential for a discharge of the treated liquid runoff.

Thus, a VTS that includes some storage capacity and the ability to control release of runoff from the VIB or settling basin to the VTA should minimize the risk associated with these two more common higher risk situations.

Figure 3–7 Role of pre-treatment components of a vegetative treatment system (see options 3 and 4) for delaying and restricting flow in the VTA component

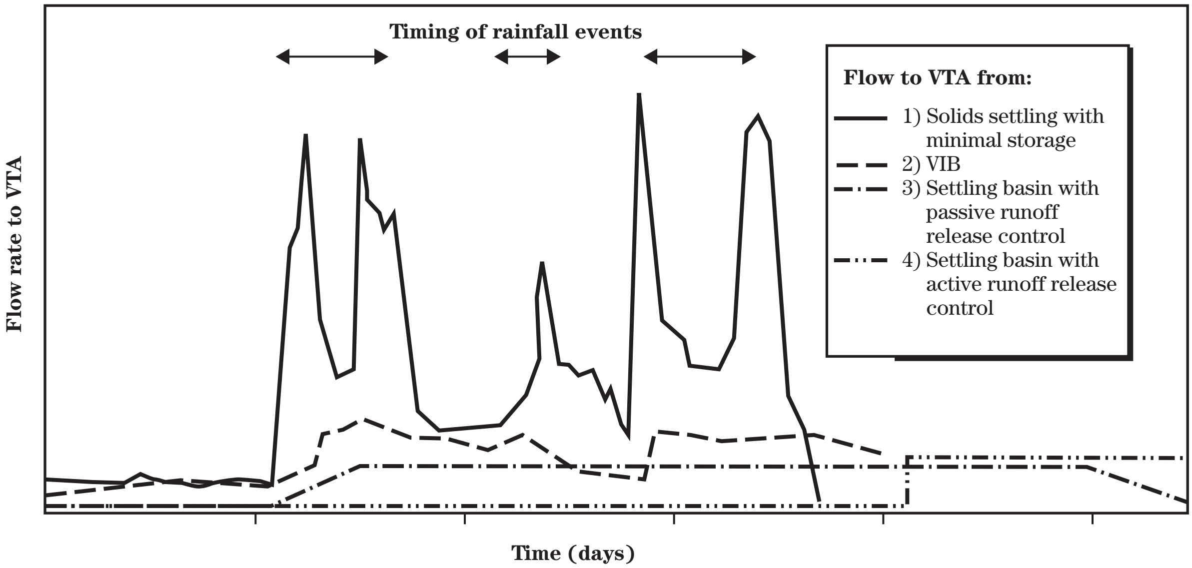


Table 3–1 Comparison of winter precipitation versus 25-yr, 24-h storm assuming settling basin was designed to contain such an event (references Soil Conservation Service 1992). Note settling basin capacity compares favorable to anticipated winter runoff.

	Eastern NE	Central NE	Western NE
Average winter runoff characteristics			
Precipitation (Dec – Mar)	4.4 in	3.6 in	2.6 in
Average runoff (Dec – Mar)	10%	<10%	<10%
Minimum settling basin capacity designed for:			
25-yr, 24-h storm	3.9 in	3.4 in	2.4 in
10-yr, 1-h storm	1.5 in	1.4 in	1.0 in

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U.S. Department of Agriculture, Soil Conservation Service. 1992. Agricultural waste management field handbook. National Engineering Handbook. USDA Soil Conservation Service. *http://www.wcc.nrcs.usda.gov/awm/ awmfh.html*.

Section 4 Siting Criteria for Vegetative Treatment Systems

Section 4 Siting Criteria for Vegetative Treatment Systems

Contents

Topics	**4–1**
Introduction	**4–1**
Purpose	**4–2**
Mapping a potential VTS site	**4–2**
Assessing ground water risks	**4–9**
Reducing odor nuisances	**4–11**
Connections to surface water	**4–12**
Is a proposed site unacceptable?	**4–13**
Conceptual design	**4–14**

Tables

Table 4–1	Risk assessment tool for evaluating connections to ground water associated with a VTS	4–5
Table 4–2	Risk assessment tool for evaluating connections to surface water associated with a VTS	4–6
Table 4–3	Risk assessment tool for evaluating odor nuisance risks associated with a VTS	4–10

Figures

Figure 4–1	Base map for identifying potential VTS sites	4–3
Figure 4–2	Base map after identification of site issues than may influence location of a VTS	4–4
Figure 4–3	Base map after identifying preferred VTS site	4–8
Figure 4–4	Generalized map of areas of karst and analogous terrains	4–10

Section 4 Siting Criteria for Vegetative Treatment Systems

Topics

- Mapping of a potential VTA site
- Assessing ground water risks
- Assessing surface water risks
- Reducing odor nuisances
- Determining whether proposed site is acceptable

Introduction

Siting Criteria for Vegetative Treatment Systems identifies specific risk factors for reviewing a potential VTS site. Limits are not identified for any of these factors. Check with your state environmental agency or other appropriate conservation agencies for information on state-specific siting regulations or other limitations applicable to construction of a VTS.

Information from NRCS Agricultural Waste Management Field Handbook, Chapter 7, Geological and Ground Water Considerations and Chapter 8, Siting Agricultural Waste Management Systems is used in this section.

Purpose

VTSs typically offer significant value to siting runoff management systems within rural watersheds for open lot animal feeding facilities. These systems replace large holding ponds with natural grasslands or forage production areas which provide advantages for wildlife, reduce odors and other gaseous emissions, and enhance visual appearance of the livestock system.

However, VTS land requirements, as well as environmental risks associated with potential connection to surface and ground water, must be considered in the evaluation of a potential VTS site. Risk factors are introduced that should be closely evaluated during review of appropriate VTS site strengths and weaknesses. Some risk factors may be significant enough to eliminate a site from consideration for a VTS.

This section reviews key principles to be considered in siting of a VTA and related system components. Three steps should be considered in this process:

Step 1: Preparation of an overhead map of the area around the open lot livestock system including potential VTA sites and potential offsite impact areas

Step 2: Review of potential sites for environmental and neighbor risks

Step 3: Identification of a preferred site

Mapping a potential VTS site

Placement of a VTS to avoid unnecessary environmental and neighbor risks should begin by developing a map for use in evaluating potential sites. The following steps provide tools for use in potential site evaluation.

Step 1: Develop a base map of the area around the open lot system where a VTS is being considered (fig. 4–1).

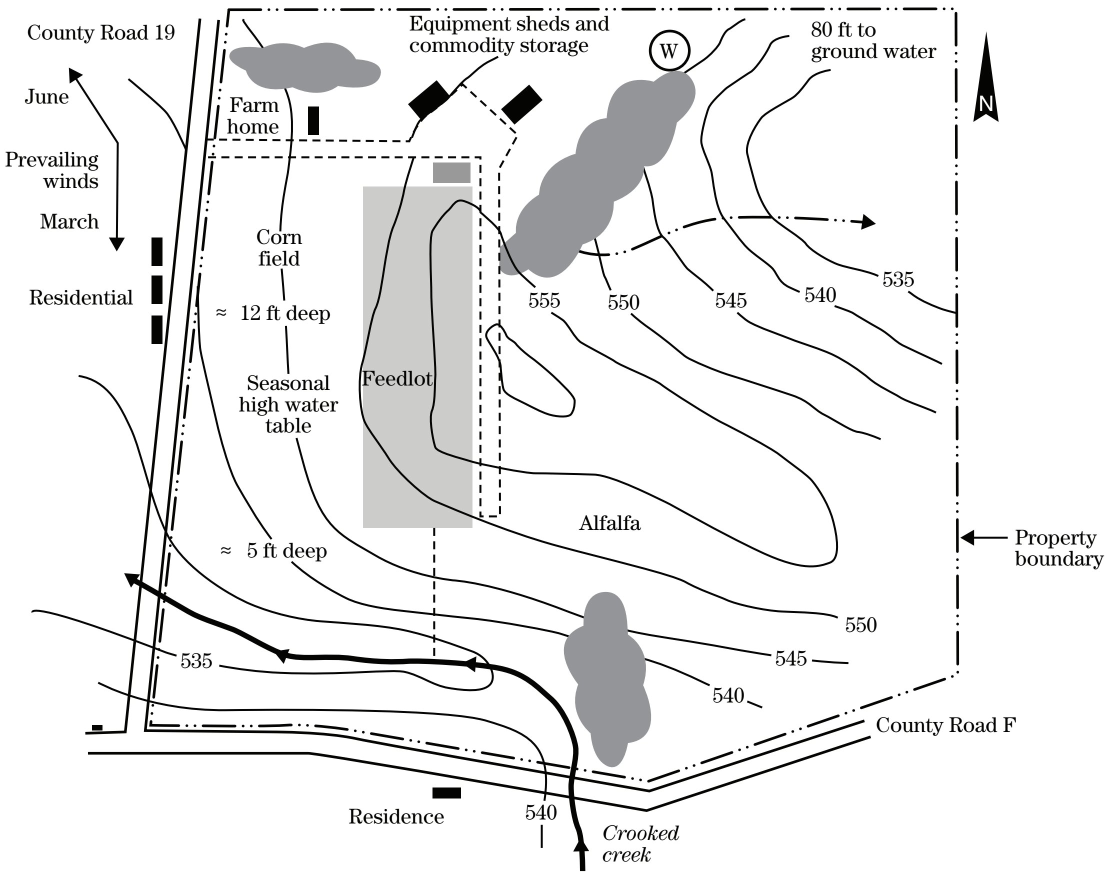
The planning process should begin with a base map. A topographic survey or aerial photograph is a preferred starting point. Potential sources of topographic maps are summarized in appendix A. Although the decision-maker's objectives will influence the scope and detail of the survey, the following data should be obtained and included on the map:

- Property lines, local roads
- Locations of adjacent residences, public facilities (schools, churches, parks), and business locations
- Positions of farm homes, buildings, other permanent structures, roads, and paved areas
- Edges of wooded areas
- Contour lines showing elevation—A USGS topographic map (or equivalent) should provide appropriate elevation information.
- Land uses
- North arrow
- Map scale

Key features that influence environmental risks that should be noted include:

- Soil types
- Location of wet areas, streams, and surface waters
- Prevailing summer and winter wind directions
- Depth to ground water—Regional water table maps, well logs for local wells, and knowledge of seasonal high water tables can be used to identify ground water location.
- Rock outcrops and other geological features
- Wells and septic systems
- Karst topography and sinkholes
- Flood plains

Figure 4–1 Base map for identifying potential VTS sites



USDA NRCS Agricultural Waste Management Field Handbook, Chapter 5, Role of Soils in Waste Management, discusses soil physical and chemical characteristics which could impact a particular soils suitability for VTA installation. [*ftp://ftp.wcc.nrcs.usda.gov/downloads/wastemgmt/AWMFH/awmfh-chap5.pdf*]. Chapter 7, Geologic and Ground Water Considerations, discusses potential ground water issues on VTA suitability. [*ftp://ftp.wcc.nrcs.usda.gov/downloads/wastemgmt/AWMFH/awmfh-chap7.pdf*]

Step 2: Conduct a site analysis to identify potential issues or problems (fig. 4–2).

The purpose of a site analysis diagram is to identify potential environmental risks and opportunities associated with installation of the VTA. A review of potential surface water, ground water, and odor risks is provided later in this section including three assessment tools for reviewing a site (tables 4–1, 4–2, and 4–3). Individual state regulatory agencies may have state-specific tools for evaluating site-related risks that emphasize issues of regional concern. Any potentially permitted facility should identify if state-specific rules or evaluation procedures apply. If not, tables 4–1, 4–2, and 4–3 will assist with a review off-site strengths and weaknesses. Higher risk issues identified should be identified on the base map or within a summary of site considerations.

Figure 4–2 Base map after identification of site issues than may influence location of a VTS

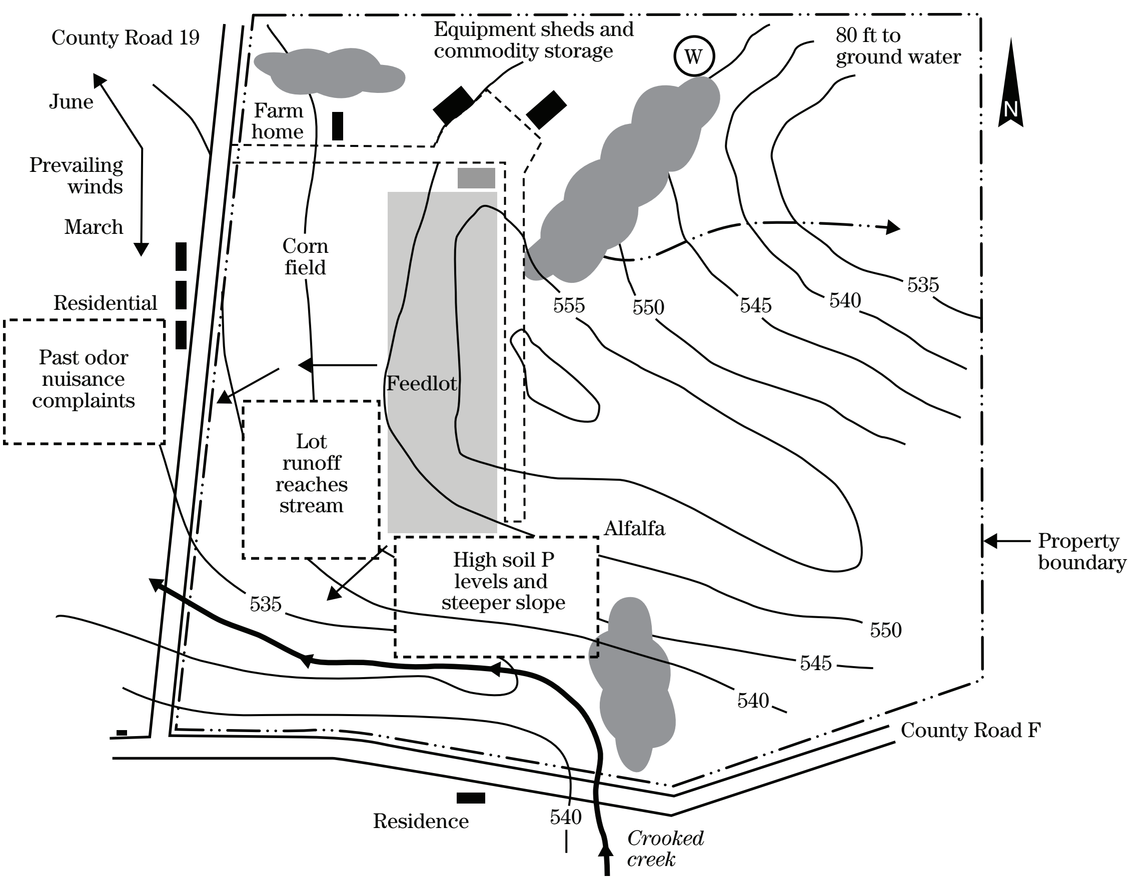


Table 4–1 Risk assessment tool for evaluating connections to ground water associated with a VTS. Use this tool to identify high risk situations that should be identified on a base map for potential VTS location.

Issue	High risk	High-moderate risk	Moderate-low risk	Low risk
Characteristics of soil (below storage site and solids settling basin; see surface water discussion for soil properties for VTAs)	Coarse-textured soils: Clean gravel (GP), or clean sands (GW, SW, SP)	Fine sand, silty, sand and gravel mixes (SM, GM, GW-GM, GP-GM, SW-SM, SP-SM)	Medium-textured soils: silt, clay, and sand-silt-clay mixes, organic mixes, organic silts, and organic clays (GC, , SC, MH,ML, ML-CL, GW-GC, GC-GM, SW-SC, SP-SC, SC-SM)	Fine-textured soils: clay (CL or CH)
Travel distance and time: Soil depth below VTA to fractured rock, coarse-textured soils or Karst	Very shallow soils (<20 in)	Shallow (20–30 in)	30–48 in deep	>48 in deep
Soil depth below storage or settling basin to fractured rock, coarse-textured soils or Karst	<4 ft below storage bottom or depth is unknown		High risk geology is more than 4 ft below storage bottom	Impermeable layer of clay or unfractured bedrock exists between storage and high-risk geology
Flow distance from feedlot and VTS to: Private well	<100 ft down slope of barnyard/feed lot/ VTA site		100–200 ft down slope of barnyard/ feed lot	>200 ft downslope or well is located upslope from barnyard/feed lot/VTA
Public water well	<1,000 ft down slope of barnyard/feed lot/ VTA or Less than separation distance required by state or local regulations		>1,000 ft down slope of barnyard/feed lot/ VTA	>2,000 ft downslope or Well is located upslope from yard/ feed lot/VTA or More than separation distance required by state or local regulations
Ground water flow direction: Location of water well in relation to pollution sources	Well is in or near depression near and down gradient of pollution source or Surface water runoff from livestock yard, settling basin, or VTA can reach well head	Down slope from most pollution sources	Upslope from or at grade with pollution sources. No surface water runoff reaches drinking water source	Upslope from all pollution sources; all surface water is diverted away from drinking water source
Depth to ground water	<10 ft	10–20 ft	20–50 ft	>50 ft
Higher risk site features or other connections to ground water within area of proposed VTA	___Karst material ___Sink-holes ___Drainage wells, ___Shallow fractured bedrock ___Exposed bedrock	___Depressions		

Table 4–2 Risk assessment tool for evaluating connections to surface water associated with a VTS. Use this tool to identify high risk situations that should be identified on a base map for potential VTS location.

Issue	High risk	High-moderate risk	Moderate-low risk	Low risk
Flood plain	VTS system in located in 10-yr flood plain	VTS system in located in 25-yr flood plain		VTS system is located outside of 25-yr flood plain
Soil: Infiltration rates:	<0.6 in/h or > 2 in/h for VIB <0.2 in/h or > 2 in/h for VTA			0.6–2.0 in/h for VIB 0.2–2.0 in/h for VTA
Are there areas of excessive soil compaction, which inhibit plant growth and infiltration?	Soil compaction is a common problem, limiting plant growth			There is little or no soil compaction. It is not limiting to plant growth
What is the slope of the area to be used for: VTAs VIBs	 >10% Dependent upon earth moving costs to create a flat basin	 5–10% or <1% >3%	 1–3%	 1–5% 0–1%
Is there damage from gully, sheet or rill erosion	Erosion sites are not controlled and perpetually get worse	Erosion control measures installed, some are failing, and no signs of improvement are apparent	Control measures have been installed, but few signs of potential failure are showing	There is no damage occurring or control measures are very successful
Area for VTS	<0.5 acres of VTS to 1 a of feedlot	>.5 and <1 a of VTS per 1 a of feedlot	1–2 a of VTS to 1 a of feedlot	>2 a of VTS to 1 a of feedlot
Discharges from VTA: Where would discharge drain	 Excess water is released directly to surface water	 Excess water is released into ditch, waterway, or ravine	 Excess water is released into crop or pasture land	 Topography does not allow water to runoff from proposed VTA site
Down gradient distance to surface water from edge of proposed VTA?	<100 ft	100–199 ft	200–500 ft	>500 ft
Soil phosphorus levels	P Index review suggest a very high risk or >150 ppm Bray 1 or comparable soils analysis	P Index review suggest a high risk or >100 ppm Bray 1 or comparable soils analysis		P Index review suggest a low to moderate risk or <50 ppm Bray 1 or comparable soils analysis

Table 4–3 Risk assessment tool for evaluating odor nuisance risks associated with a VTS. VTAs alone will produce little or no odor. A runoff collection basin, settling basin, and the feedlot are more likely odor sources. Answer the following questions relative to these three odor sources. Use this tool to identify high risk situations that should be identified on a base map for potential location of storage or settling basins.

Issue	High risk	High-moderate risk	Moderate-low risk	Low risk
Direction: Neighbors are…	Located downwind for prevailing winds during wet seasons of the year (typically spring)		Located downwind for prevailing winter winds only	Located upwind for prevailing winds during wet seasons of the year (typically spring)
Homes, public use areas, or businesses				
Distance:				
300 a.u. and less	<¼ mile	¼–½ mi	½–1 mi	>1 mi
>300 a.u.	<½ mi	½–1 mi	1–2 mi	>2 mi
Elevation: Neighbors are located at…	Lower elevation than odor source **and** in valley	Lower elevation than odor source **and** in open area	Similar elevation than odor source **and** in open area	Higher elevation than odor source or sizeable hill, shelterbelt, or other change in topography lies between neighbor and odor source
Typography	Open flat terrain is located between odor source and neighbor			Significant variation in terrain exists between the odor source and neighbor resulting from forests, shelterbelts, buildings, or hills
Visibility (feedlot and runoff storage component of VTS)	Odor source is highly visible due to location close to road	Odor source is recessed from neighbors and road but visible	Partial screening by topography or vegetation of odor sources from neighbors and roads	Full screening by topography or vegetation of odor sources from neighbors and roads
Wind speed	Odor source is located in protected area (due to trees or topography) with low wind speeds			Odor source is located in open area with no trees or topography slowing wind speed

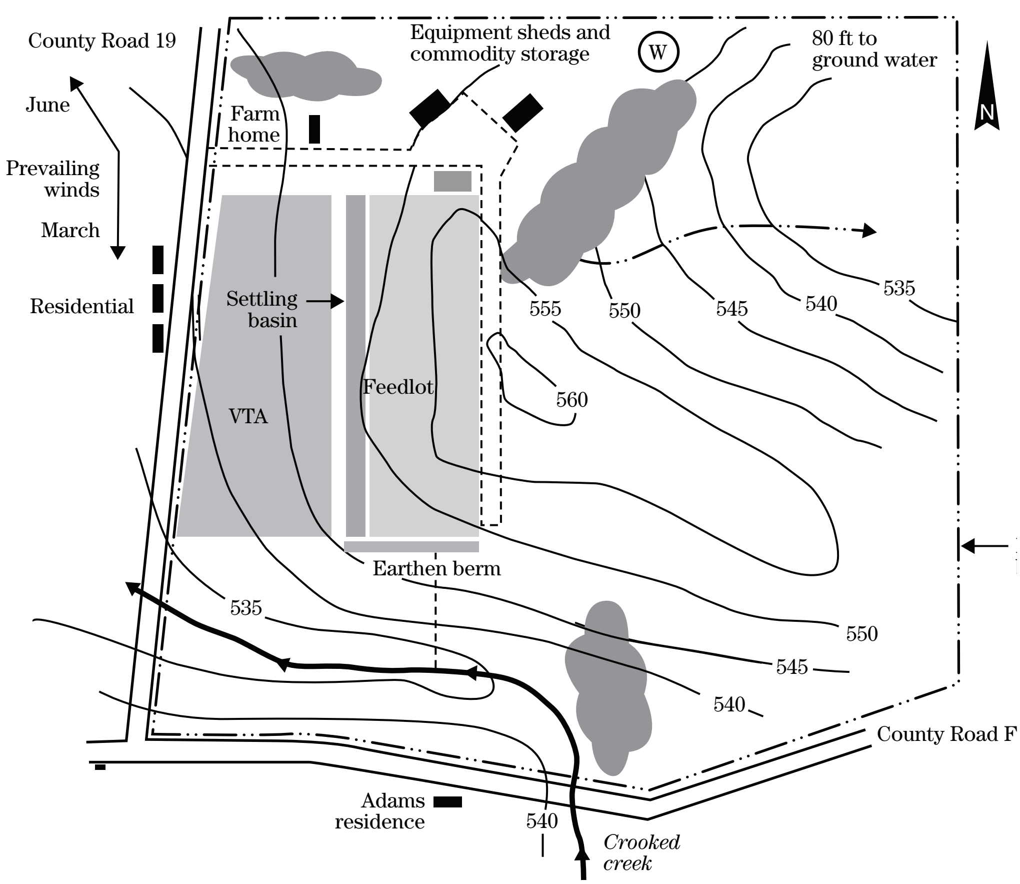
After completing these risk assessments, some of the following issues may also be important:

- Are there conflicts or incompatibilities in land use within the neighborhood (VTA bordering a neighbor's home)?
- Will potential VTA sites fit with normal traffic pattern (animals, equipment, and people)?
- Is there a history of neighbor odor concerns? Are storage and settling basin components being added that may cause odor concern?
- Are there potential neighbor or general public visual concerns?
- Will potential VTS sites require expensive relocation of buildings and utilities?
- Is a potential VTA site already high in soil P levels?
- Does a potential VTA site include areas of potential erosion?

Step 3: Develop an initial concept plan showing potential site(s) of a proposed VTS (fig. 4–3).

Next, a concept plan or plans are developed to evaluate alternative VTA component locations (fig. 4–3). The areas required for collection, storage, solids removal, and VTA are determined and displayed at this step of the process. At the concept plan stage, assume that a VTA area at least equal to the area of the feedlot and related drainage area will be needed. A site should then be evaluated for the ability to provide sufficient space for adequate VTA area. If the space appears to be marginal, a more exact estimate of VTA or VIB should be reviewed. If sufficient space still is not available, a conventional runoff holding pond and land application site should be considered.

Figure 4–3 Base map after identifying preferred VTS site



Additional related VTA siting issues, such as associated use areas, access ways, water management measures, vegetated buffer areas, and ancillary structures should be drawn freehand to approximate scale and configuration directly on the site analysis plan or an overlay. In instances where several sites may satisfy the decisionmaker's objectives, propose the site that best considers cost differences, neighbor concerns, environmental impacts, legal ramifications, and operational capabilities.

The final step in this process is a finalized site plan for the proposed VTS. However, before proceeding to a final site map, a number of environmental issues associated with site selection should be reviewed in greater depth. As those risks are reviewed, consider if high risks can be identified on your base map. With each environmental risk, an associated assessment tool is included (tables 4–1, 4–2, and 4–3).

Assessing ground water risks

A proposed VTA site should be evaluated for potential risks to ground water. More critical factors specific to a VTA installation that impact ground water are reviewed and can be assessed for an individual site using table 4–1. A more complete description of these factors critical to any manure management system can be found in NRCS Agricultural Waste Management Field Handbook, chapter 7, (*http://www.info.usda.gov/CED/ftp/CED/neh651-ch7.pdf*).

Soil characteristics—Many biological, physical, and chemical processes break down, lessen the potency, or otherwise reduce the volume of contaminants moving through the root zone of surface soils. These processes, collectively called attenuation, retard the movement of contaminants into deeper subsurface zones. The soil's attenuation potential increases as clay content increases, the soil deepens, and distance increases between the contaminant source and the well or spring. The cation exchange capacity of clay soils limits movement of positively charged contaminants such as ammonium (NH_4^+). Clay also has a very low permeability, thus slowing contaminant movement and increasing the contact time that allows more opportunity for attenuation. Deeper soil increases the contact time a contaminant will have with mineral and organic matter of the soil. Longer contact time provides greater opportunity for attenuation.

Travel distance and time—The greater the travel time of a contaminant, the greater the opportunity for attenuating the contaminant. The depth to ground water and the horizontal distance between the source of the contamination and a well, spring, or other ground water supply influences the time of travel.

Ground water flow direction—A desirable site for a VTS is in an area where ground water flows from the facility in a direction away from a well, spring, or potable aquifer source. The direction of flow in a water table aquifer generally can be ascertained from the topography. In most cases, the slope of the land indicates the ground water flow direction. However, radial flow paths and unusual subsurface geology can too often invalidate this assumption. Local information on ground water flow direction may be available through a Soil and Water Conservation District or NRCS office or through private well drillers. In addition, a VTS site should be checked for its potential location within a recharge area for a public water source. The local rural water district or municipal water supplier should be able to identify these recharge areas.

Proximity to designated use aquifers, recharge areas, and well-head protection areas—A potential VTA site should be reviewed for its proximity to sensitive ground water areas including:

- Sole source or other types of aquifers whose uses have been designated by the state
- Important recharge areas
- Well-head protection areas

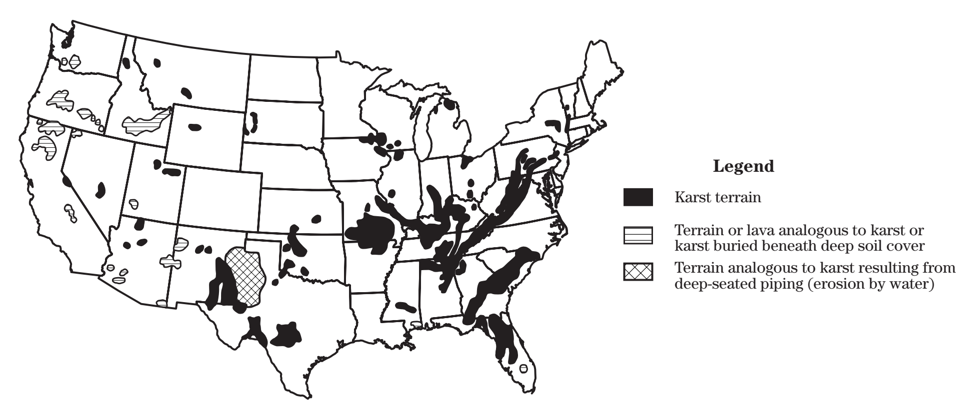
Depth to ground water—The elevation and shape of the water table may vary throughout the year. Obtain preliminary estimates of the depth to seasonal high water table from well logs, published soil surveys, and the NRCS National Soil Characterization database. Site-specific ground water depths may vary from values given in these sources. Stabilized water levels observed in soil borings or test pits provide the most accurate determination in the field. Seasonal variations in the water table also may be inferred from the logs of borings or pits. Perennially saturated soil is typically gray. Perennially aerated soil is typically various shades of red, brown, or yellow.

Depth to bedrock—Storage systems may be restricted by shallow depth to bedrock because of physical limitations or state and local regulations. Vegetative practices, such as filter strips, may be difficult to establish on shallow soil or exposed bedrock. Waste stored or land applied in areas of shallow or outcropping rock may contaminate ground water because fractures and joints in the rock provide avenues for contaminants.

For runoff holding ponds and solids settling basins, shallow bedrock generally is a serious condition requiring special design considerations. Bedrock of all types is nearly always jointed or fractured when considered as a unit greater than 0.5 to 10 acres in area. Fractures in any type of rock can convey contaminants from an unlined storage to an underlying aquifer. Fractures have relatively little surface area for attenuation of contaminants. In fact, many fractures are wide enough to allow rapid flow. Pathogens may survive the passage from the site to the well, and thereby cause a health problem. Consider any rock type within 2 feet of the design to be a potential problem.

High risk geological features—Sinkholes, karst topography, or underground mines may disqualify a site. The physical hazard of ground collapse and the potential for ground water contamination are severe limitations. Common regions of the United States with karst topography are illustrated in figure 4–4.

Figure 4–4 Generalized map of areas of karst and analogous terrains. State and local soils and geological surveys should provide a more accurate local characterization of high risk geological features such as karst topography.



Reducing odor nuisances

The movement or dispersion of airborne emissions from an animal production facility is affected by many factors including topography, prevailing winds, and facility orientation. Odor plumes decrease exponentially with distance, but long distances are needed if no odors, gases, or dust are to be detected downwind from a source.

VTSs are unlikely to be a source of odor nuisances. However, if storage is included in the VTS, the storage can produce some odors. A settling basin with significant accumulation of wet solids is also likely to cause odor concerns. Solids storage and composting areas can also cause odors. However, none of these sources is likely to be as large of a source as the open lot where cattle are housed. Despite the lower odor risk of a VTS, it is still important that basic principles of siting a facility to reduce neighbor risk be considered (table 4–3).

Prevailing winds should be considered so facilities are sited to minimize odor transport to close or sensitive neighbors. Odor moves the same direction as wind direction and disperses laterally very little. By recognizing prevailing wind direction especially during wetter periods of the year, one can begin to identify those neighbors at greatest risk. If options exist for siting of any runoff storage, solids settling basin, or temporary stack of harvested solids, location of those facilities to avoid placing neighbors immediately downwind based upon prevailing winds can offer significant nuisance reduction.

For open lot systems, spring and early summer conditions can often be the period of greatest odor nuisances. Prevailing winds are often changing during the spring from being dominated by winter weather pattern to being driven by summer weather patterns. Officials associated with local airports may have statistical data on prevailing wind direction versus time of year.

Distance is a second key consideration. Although models are beginning to be developed for predicting distance of odor travel, general distance recommendations are difficult to make. However, more is always better. If sources of odor can be located to increase distance to the neighbor, there may be value in reducing odor nuisances.

Elevation is also an important consideration. Avoid location of an odor source upslope from a nearby neighbor. During times of greatest potential odor risks, calm evening hours, odors settle near the ground and tend to move downslope. Downslope neighbors, especially those located in a valley or depression, are at greatest risk from an upslope odor source.

Downwind of a facility, variable topography is preferable to flat terrain. Hills, shelterbelts, stacked bales of hay, and buildings all encourage mixing of the odors from an odor source with fresh air thus encouraging dilution and reduced impact on neighbors. If facilities, hills, or trees can be located between a neighbor and an odor source, the odor nuisance can be reduced.

Wind speed is important for mixing fresh air with odorous air and reducing the area impacted by an odor source. High wind speeds contribute to greater turbulence, greater dilution of odorous air, and less chance of neighbors being impacted by an odor source. It is preferable to avoid locations for an odor source downwind of a shelter belt or hill. Open locations where few obstructions slow the wind speed are preferred locations for odor sources.

Connections to surface water

A review of surface water risks associated with a VTS should consider several risk factors. Table 4–2 can be used to assess those risks for an individual site.

Flood plain—VTAs and associated storage and treatment components should be located outside the 25-year flood plain. State and local regulations should be checked for separation requirements from even less frequent flood events. Information on flood plains can be obtained locally from county planning and zoning agencies, Soil and Water Conservation Districts, and NRCS offices.

Soil type—Identification of the soils in the proposed location of the alternative treatment system gives prior knowledge of suitability for construction of VIBs or VTAs and nutrient treatment capabilities. Soils with moderate permeability are best for VIBs and VTAs. Soils with high permeability will reduce potential for discharge from a VTA, but increase the risk to ground water. Soils with a low permeability improve protection of ground water, but increase the potential for a discharge from the VTA. For VIBs, soils with 0.6 to 2 inches per hour to a 5-foot depth are recommended. For VTAs, soils with 0.2 to 2 inches per hour to a 5-foot depth are suggested.

Slope—Zero slope is preferred for VIBs. Slopes from 1 to 5 percent provide the maximum opportunity time for treatment of effluent within a VTA.

Erosion damage—The site should be reviewed for past damage due to erosion. Gully erosion will require greater investment in land leveling to ensure uniform runoff flow over the VTA. Past indication of gully or sheet erosion will also suggest that the soils may not be suitable for withstanding erosion from additional runoff flow volumes.

Sufficient area for VTA—A rough rule of thumb for assessing the area available for a VTA is 1 acre of potential VTA area for every acre of feedlot. Thus, a 10-acre feedlot will require approximately 10 acres of VTA. Additional area may be required for solids settling and possibly runoff storage. If the available land base is less than this rough rule of thumb, a more accurate calculation of VTA and VIB area should be made using procedures in sections 5 and 6. Greater areas than the 1 to 1 ratio of VTA to runoff area further reduce the risk of a discharge from a VTA. Some systems have been designed with as large as a 2 to 1 area ratio.

Separation requirements between VTAs and environmentally sensitive areas are intended to reduce the potential impact of discharges from VTAs on designated streams, rivers, lakes, and wetlands. For some VTSs, discharge is likely and treatment within VTA will not reduce pollutant concentration to acceptable levels for discharge to surface waters. Additional separation distance allows opportunity for infiltration of pollutants into soil or their dilution. Separation distances are arbitrary (more is better) and may be established by state or local regulations. Drainage from a VTA into pasture or crop land is preferred over drainage into ditch or waterway where channel flow occurs directly into surface waters.

VTS site soil P level—A thorough soil testing program should be conducted for sites considered for a VTS. Soil P test levels should be obtained within the potential VTA or, better yet, a P index evaluation conducted on any potential VTS site. A VTS should not be located where high soil P levels already exist. The poultry industry has learned that pasture sites with high P levels from past litter applications will produce significant off-site movement of P with runoff water. Although feedlot runoff should not contribute significant P to a VTS (assuming good solids settling in advance), a site with high P levels from past manure applications should be avoided due the potential for soluble P movement from these sites.

Is a proposed site unacceptable?

Not every site is suitable for a VTS. Because of the limited past experience with VTS on commercial farms, a relatively high standard for VTS sites will need to be followed until better field experience is available. In the end, a site-specific analysis must be prepared by the producer comparing the baseline technology performance with that of the VTS as described in section 2 to determine if a site is acceptable. However, before making this substantial investment in such an analysis, ask the following questions:

- Does your site violate any minimum requirements established by the permitting authority or state environmental agency (likely to be one in the same)? A Yes answer is most likely a VTS stopper.
- Have any high or high to moderate risk factors been identified in tables 4–1 and 4–2? There are significant differences in the degree of importance of individual risk factors in these two tables. The level of risk is often specific to local or regional conditions. Any high or high to moderate risk factors should be reviewed with independent experts before proceeding further.
- Do any of the higher risk factors identified represent a VTS stopper? This answer should be determined locally based upon state-specific regulations and local environmental priorities. However, there are some factors that will make application of a VTS a substantial challenge for almost all circumstances. Some of these include:
  - Slopes greater than 8 to 10 percent. Research and field experience with VTS options on high slopes is almost non-existent and the risk of runoff is substantial.
  - Less than 1 acre available for the VTS (VTA and settling basin) per acre of feedlot surface. To encourage significant infiltration and modest runoff release from a VTA, space limitations should not be violated.
  - High soil P levels. Dissolved P moves from sites with high P levels in spite of permanent vegetation. Sites with a direct connection to surface waters and high soil P levels should be avoided.
  - High risk geological features. If a VTS cannot be separated from high risk geological features such as Karst material, shallow fractured or exposed bedrock, or drainage wells, a VTS should not be installed.
  - Less than 100 feet to private wells or 1,000 feet to public water supplies (check local Wellhead Protection Area regulations for greater setback requirements) produce too great of liability for all runoff control systems including VTS.

Conceptual design

The risk assessment of a proposed VTS site should lead one to some preliminary design decisions including the following:

- *Siting*—Is the proposed site still acceptable after completing the risk assessment? Are there alternative sites that may have advantages? At the conclusion of this process, a preliminary decision should be made as to the preferred site for a VTS.
- *VTS system options*—Several options were discussed in section 3. Which of these options is the better fit for a proposed site? If space is limited, systems involving a VIB may be preferred. If close proximity to surface waters is of concern, options that include greater storage and passive or active management of runoff release, oversized VTAs, or additional treatment (VIB prior to VTA) might be considered.
- *Location of VTS components*—What is the relative location for the solids removal component? VTA? Other selected components?
- *Utilities*—Does this design allow for gravity flow of runoff liquids through the system, or will electrical service be required to pump runoff? Is there a need for other utilities in the area around the VTS (water supply, roads for equipment access)? Identify the utilities and services that will need to be provided to the VTS site.
- *Footprint of components*—One should do a preliminary size estimate for individual components and compute the area required for these components? Don't forget to include space for berms and access roads. The footprint of these components should be added to the developing map for the proposed site. Sections 5, 6, and 7 provide tools for sizing settling basins, VTAs, and VIBs.

With these conceptual design decisions made, the proposed VTS is now ready to endure the scrutiny of the design process for the individual components (sec. 5 through 7) and the comparison of the proposed alternative technology with the baseline system (sec. 1). Selection of a preferred site is especially critical for the comparison process of alternative versus conventional treatment systems. Several site-specific conditions are required for this comparison process including soil types, slopes, and dimensions of VTS components. Refer to section 2 for additional site specific information required of the performance comparison process.

Section 5 Liquid-Solid Separation

Section 5 Liquid-Solid Separation

Contents

Topics 5–1

Purpose 5–1

Description 5–2

Solids removal design issues 5–2

Settling basin design 5–3

Settling basin outlets 5–5
- Perforated pipe outlets ... 5–5
- Porous dams ... 5–6
- Settling basin emergency spillway ... 5–8

Settling basin sizing 5–8

Alternative solids-settling facilities 5–13
- Settling bench ... 5–13
- Design recommendations: ... 5–13
- Operation and maintenance recommendations: ... 5–13
- Geotextile fabric (silt fence) ... 5–14
- Gravel spreader/barrier ... 5–14
- Vegetative barrier ... 5–14

Active versus passive management 5–15
- Active management ... 5–14
- Passive management ... 5–15

References 5–16

Tables

Table 5–1	Average chemical characteristics of runoff from beef cattle feed yards in the Great Plains	5–2
Table 5–2	Orifice plate opening design for settling basins	5–7
Table 5–3	Riser pipe open slot design for settling basin outlets	5–12
Table 5–4	Sizing of riser pipe	5–12

Figures

Figure 5–1	Earthen sidewall settling basin	5–4
Figure 5–2	Concrete settling basin for regions with higher precipitation	5–4
Figure 5–3	Riser pipe outlets for settling basins	5–5
Figure 5–4	Porous dam outlet design for settling basins	5–6
Figure 5–5	Spillway should be included for storm intensities that exceed design capacity and flow rate of settling basin	5–8
Figure 5–6	Capacity of pipe	5–11
Figure 5–7	Typical settling bench	5–13

Section 5 Liquid-Solid Separation

Topics

- Settling basin design
- Alternative solids settling facilities
- Active versus passive management

Purpose

The liquid-solid separation component within a VTS is intended to:

- Intercept all open lot runoff
- Remove most settleable solids from feedlot runoff. Solids removal is critical to reducing nutrient and related pollutant loading on the VTA or VIB and minimizes vegetation damage due to solids accumulation.
- Release liquids to VTA or VIB in a controlled manner. Controlled release of liquids to a VTA at an appropriate time is critical to minimizing the potential for discharge.

This section describes the design features of the liquid-solid separation component critical to achieving these three goals.

Some of the information in this section is from Livestock Waste Facilities Handbook (MWPS-18), Chapter 5, Liquid Solids Separation. Printed with the permission of the Midwest Plain Service, 1985.

Liquid-solid separation is an essential pre-treatment component for both CAFO and AFO applications of a VTA or VIB.

Description

Liquid-solid separation within feedlot runoff is most commonly achieved by flow velocity reduction to allow settling of solids from the runoff. Settled solids can be collected from the liquid-solid separation component and land applied according to a nutrient management plan.

Settling basins are the most common type of liquid-solids separation used to treat runoff from an animal feeding operation feedlot or pen surface. Alternative settling facilities include settling benches, silt fences, and gravel spreaders. Settling tanks and settling channels can also be used in certain situations.

A settling basin, when preceding a VTA, may also be designed to delay or spread out the release of liquids over a significant period of time to minimize the risk of a discharge from the VTA. This may require the settling facility to include storage with active or passive control of the release of liquids over time.

The initial treatment of any open feedlot runoff control system should be solids removal, as is currently required by many state laws. Properly designed and managed solids settling basins should remove about 30 percent of the N and P from the runoff from swine lots and 50 percent or more of each from cattle lot runoff. For additional information on the performance of solids settling, see the literature review in section 9.

Solids removal design issues

Contaminated runoff from lots carries organic matter and other solids. Typical open lot runoff characteristics are summarized in table 5–1. See section 9 for addition information on characteristics.

Settling facilities are designed to intercept all lot runoff, settle out most of the solids, and release liquids to a VTA or VIB. Settling separates solids from dilute liquid slurry by reducing velocity. Fast moving liquids pick up and transport solids; when velocity slows, some of those solids settle by gravity.

Solids separation and periodic solids removal is the key to successful treatment of precipitation runoff from beef and dairy feedlot surfaces. Liquid that is to be released to a VTA or VIB should always have solids removed first minimizing solids, nutrient, and salt buildups within the vegetated area. Buildups of these materials would potentially harm vegetation in the treatment area and negatively impact soil structure and water intake characteristics.

Physical size of the settling facility is typically based upon two considerations:

- Solids settle at a rate of approximately 4 feet per hour. Based upon a selected depth for a settling basin, a minimum holding time (hydraulic retention time) can be established. For example, a 2-foot deep basin would require a 30-minute minimum holding time (2 ft deep ÷ 4 ft/h = ½ h)
- A basin size designed to hold a selected frequency precipitation event. The most critical design situation is the high-intensity, short-duration rainfall event. A large water volume picks up manure and carries it in the runoff. Experience has shown that the 10-year, 1-hour storm (app. B) is

Table 5–1 Average chemical characteristics of runoff from beef cattle feed yards in the Great Plains (see sec. 9 for additional information on characteristics)

Source	Total solids (ppm)	Volatile solids (ppm)	Electrical conductivity (mmhos/cm)	Total nitrogen (ppm)	Total phosphorus (ppm)	Potassium (ppm)
Feedlot runoff[1]						
Average	11,200		6.5	580	120	1,020
Range	3,000–17,500		3.2–8.6	80–1,080	50–300	340–1,320

1 Sweenten 1991

acceptable for designing settling facilities tied to VIBs and runoff holding ponds. A larger 25-year, 24-hour storm (app. B) may be appropriate for settling basins in advance of a VTA on a large CAFO, especially where runoff release to the VTA is actively or passively managed. When a larger storm occurs than the design volume, the percent of manure solids removed by the basin is reduced slightly. However, a system can manage larger runoff peak flows and lose little in treatment efficiency if the minimum holding time is not substantially reduced.

Control over the release of liquids from a settling basin into the VTA is a second critical design feature. Allowing feedlot runoff water to pass through the settling basin and into the VTA simultaneously with a rainfall event has the potential to exceed the infiltration capacity of the soil in the VTA and result in discharges. VTAs have gained limited acceptance within the regulatory community for CAFO applications due to this concern. Two options are available for controlled release of liquid from the settling facility to a VTA:

- Restrict the settling facility outflow to extend flow over 30 to 72 hours (passive runoff release control). This minimizes the contaminated runoff addition to the VTA during the storm event to minimize the chance of exceeding infiltration rates.
- Actively manage the outflow to avoid any release during a storm event (active runoff release control). Contaminated runoff stored in the settling facility would then be released after the storm event. If released at a slow enough rate, smaller VTAs may be possible while retaining a match between soil infiltration rate and release of liquid from the settling basin.

A combination of a settling facility with significant storage capacity (sized for a 25-yr, 24-h storm) in combination with active or passive release of liquids to the VTA will minimize the potential for a discharge from the VTA.

Settling basin design

A settling basin temporarily retains runoff and permits liquids to drain to a waste storage pond, lagoon, or VTA in a controlled manner. Solids remain in the basin for drying and later removal with a front-end loader or similar equipment.

The best basin shape is relatively large and shallow. If solids are removed from the basin with conventional solid manure handling equipment, basin depth should normally be 3 feet deep or less. Settled solids can be removed by driving unloading equipment on the basin floor. In arid areas where settling basins dry out readily, earthen basins may be satisfactory (fig. 5–1).

In humid areas, concrete bottoms or complete concrete basins may be necessary so equipment can enter the basin for clean out (fig. 5–2). Provide at least one vertical wall when constructing settling basins of concrete. This will provide a bucking wall for a front-end loader when removing separated solids from the basin.

Access ramp slope should be 10:1 (horizontal length: vertical fall) or flatter, for front-end loaders. Basin bottoms are often provided with a slight uniform grade (0–5 in/100 ft) to the discharge point to ensure proper drainage at low flows and prevent ponding and encourage drying of the solids in the basin.

Build earthen basins with 3:1 side slopes; if erosion is a problem, use a 4:1 slope or flatter slope on the inlet side. The top width of earth basin ridges must be at least 12 feet wide if planned for vehicle traffic; a minimum 3-foot ridge top width would be required to maintain the design height of earthen settling basin ridges. Plant and maintain grass cover where possible on all settling basin ridges. The bottom of the basin where solids accumulate may need to be concrete in higher precipitation areas, while earthen bottoms are typically satisfactory in more arid climates.

Maintenance and pen clean-out frequency greatly influence settling basin treatment efficiency. A properly managed open lot and settling basin can retain up to 85 percent of the non-floating solids in the lot or basin, regardless of lot slope. Research indicates that solids can accumulate at a rate 0.5 acre-inch settled solids per acre of unpaved lot per year. 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. Provide temporary storage areas for separated solids (within the area from which runoff is collected) unless they are transported directly from the basin to the final end use (land application).

Figure 5–1 Earthen sidewall settling basin. For dry regions, an earthen base for the basin is acceptable. In higher rainfall areas, the base should be concrete.

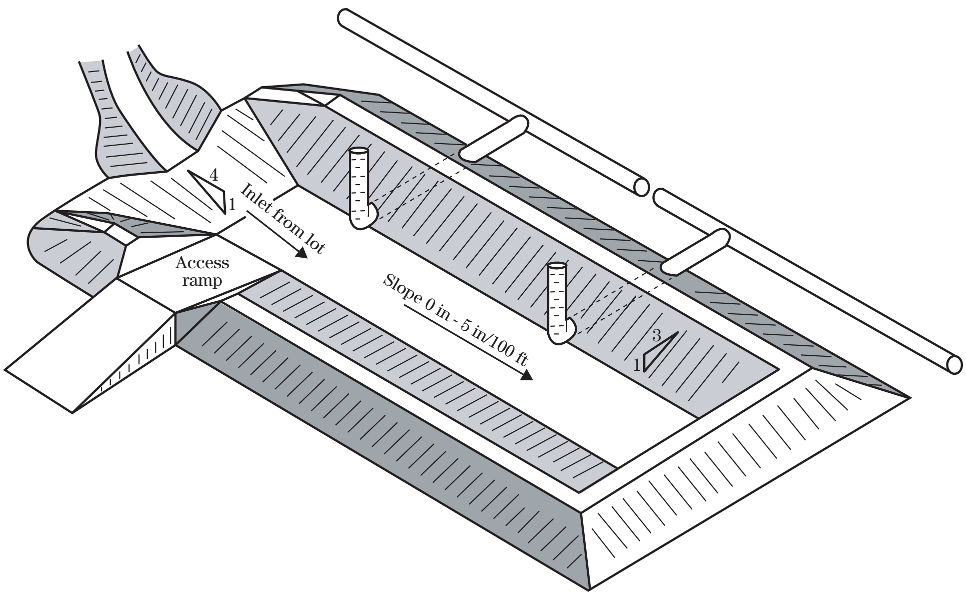
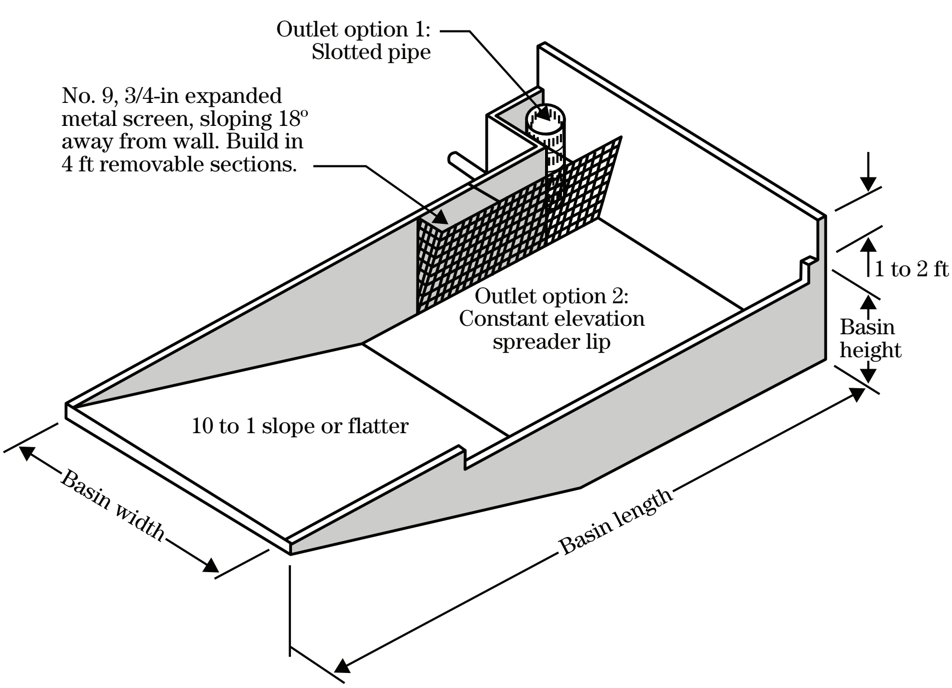


Figure 5–2 Concrete settling basin for regions with higher precipitation



Settling basin outlets

Several types of basin outlets are available to drain liquids from the full depth of the settling basin and dewater solids. Perforated or slotted pipe risers, and porous plank dam are examples.

Manure plugs, outlet openings, debris, and bedding tend to plug even large openings. As the settling basin drains, the liquid drains through fewer slots or perforated openings and solids concentration increases further adding to the plugging problems. Cleaning of outlet openings is commonly required to allow the settling basin to fully drain and solids to dry allowing their removal. The outlets should be designed for easy cleaning. A portable propane weed/brush burner will clean most debris from a metal screen but does not work on a PVC pipe.

Consider adding a slanted expanded metal screen around the settling basin outlet to increase the screening area (fig. 5–2). These screens are usually expanded steel, usually .75 inch, No. 9 or heavy quarry screen, with about 1- to 1.5-inch 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 that passes runoff liquids through a screen requires screen cleaning of solids after each runoff event. This maintenance is critical to drying solids for their eventual removal.

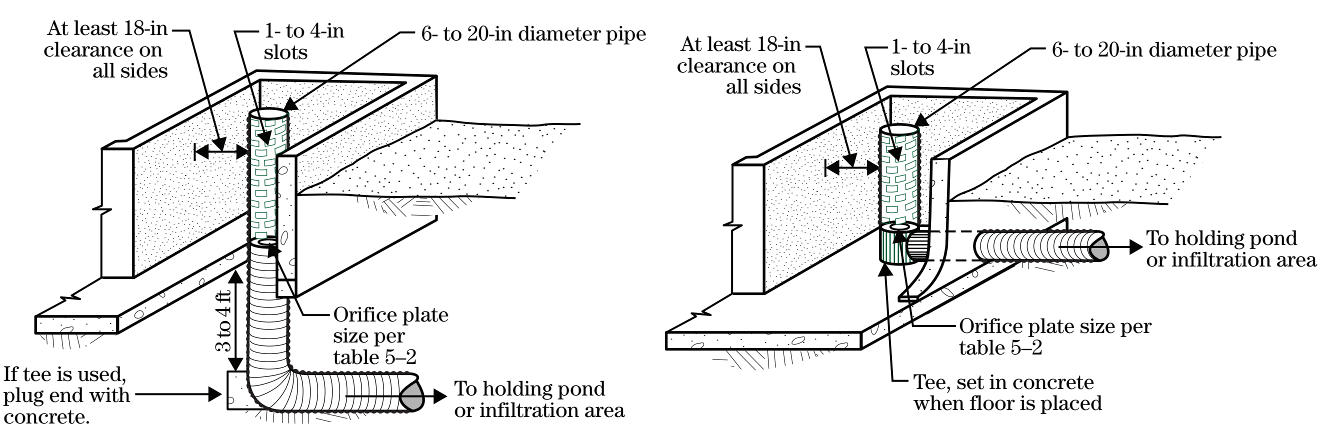
Perforated pipe outlets

Perforated pipe may be constructed with PVC plastic, galvanized steel (can have limited life), or concrete. The perforations can be 5/8- to 1-inch diameter holes or 1- by 4-inch slots. Where excessive clogging of perforated pipes is a problem, a removable trash screen ahead of the perforated pipe improves performance (fig. 5–2).

The outlet is sized to drain anticipated design discharge rates while providing adequate detention time. Basin outlet flow rate should be controlled with a properly sized orifice plate (fig. 5–3). Flow rate through the holes or slots in the perforated pipe should be checked to ensure that this estimate of flow rate exceeds that of the orifice. Because of the likelihood of clogging the holes or slots, a safety factor should be included in their design.

The outlet is sized to maintain sufficient flow to prevent overflow of the settling basin, while providing adequate detention time to allow solids to settle. When a settling basin is installed in conjunction with a VTA, the outlet flow may be controlled to slow the release of liquids over an extended period of time (30 h to 3 d). To achieve this level of control, a properly sized orifice plate is essential to achieving these objectives for settling basins tied to VTAs.

Figure 5–3 Riser pipe outlets for settling basins



Orifice plates should be sized to provide the design flow rate (table 5–2). 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. The equation for estimating flow rate from an orifice plate (MWPS 1985) is:

$$Q_o = C \times A \times (2 \times g \times h)^{0.5} \tag{1a}$$

where:
Q_o = flow rate of orifice in ft^3/s
C = orifice constant: assumed to be 0.61. The actual value varies with type of orifice. The assumed value is conservative.
A = open orifice area in ft^2
g = 32.2 ft/s^2
h = head on orifice in ft

With an orifice plate, make the flow rate of the slotted pipe (Q_S) at least 25 percent larger than the flow rate of the orifice (Q_o). Orifice plates should be vented with a .75-inch diameter PVC pipe, or PE tubing from just below the orifice plate to the elevation of the maximum anticipated settling basin depth. The equation for estimating flow rate through the slotted pipe (MWPS 1985):

$$Q_S = C \times A \times (2 \times g \times h)^{0.5} \tag{1b}$$

where:
Q_S = flow rate of slots in slotted pipe in ft^3/s
C = slot constant: assumed to be 0.61. The actual value varies with type of slot. The assumed value is conservative.
A = open slot area in ft^2
g = 32.2 ft/s^2
h = head on openings in ft

The pipe height was divided into 0.5-foot increments. The head on all slots in the first 0.5-foot increment is assumed to be 0.25 foot. The head on the subsequent 0.5-foot pipe increments increases at 0.5 foot for each increment.

Porous dams

Select a material for porous dams that can be easily cleaned by scraping the surface with a hoe. Spaced planks, welded wire fabric, or expanded metal mesh can be scraped clean. Design of the spaced plank porous dams is illustrated in figure 5–4.

Porous dam outlets are acceptable for controlling runoff to holding ponds and VIBs. However, for settling basins designed with a slow release to a VTA, the porous dam approach is not recommended for this application. Plugging and challenges with construction of a porous dam with the desired flow rate makes this outflow approach unacceptable for this application.

Figure 5–4 Porous dam outlet design for settling basins (MWPS 1985)

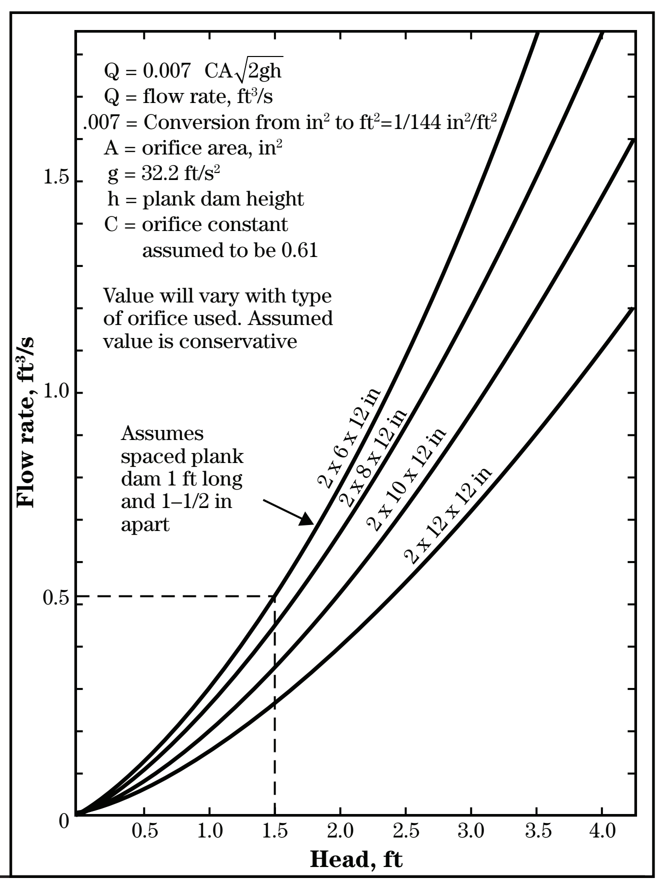


Table 5–2 Orifice plate opening design for settling basins. Boxed values refer to example in appendix C (MWPS 1985)

Diameter	area	Head, ft						
in	ft²	1.0	1.5	2.0	2.5	3.0	3.5	4.0
		Flow rate, ft³/s						
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	0.466	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	0.702	0.751
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	1.529	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

Settling basin emergency spillway

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. 5–5).

Settling basin sizing

Runoff solids settle at a rate of 4 feet per hour. Therefore, a detention time of 30 minutes in the settling basin is an acceptable design criterion for a 2-foot deep basin, where no other criterion is available. When local design criteria are not available, use the following design procedure. An example using this procedure is illustrated in appendix C.

Step 1

Determine rainfall volume for a 10-year, 1-hour storm (fig. B–1) and the 25-year, 24-hour storm (fig. B–1) if the settling basin is matched to a VTA.

Step 2

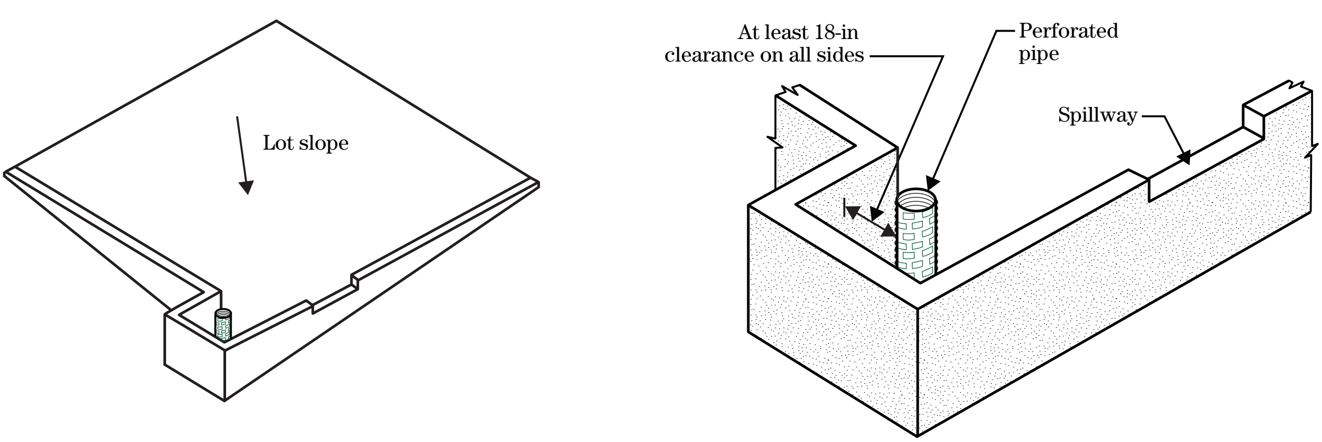
Peak flow rate off the lot:

$$\text{Peak flow rate} = \frac{(\text{lot area} \times \text{rainfall intensity})}{43{,}200} \qquad (2)$$

Units: Peak flow rate in ft^3/s
Lot area in ft^2
Rainfall intensity (in/h) for 10-yr, 1-h storm is approximated as volume/1-h duration
43,200 is derived from 3,600 s/h x 12 in/ft

Step 2 produces an estimate of peak flow rate and may be unsatisfactory for larger open lots. The runoff rate from a lot depends on three basic factors: surface con-

Figure 5–5 Spillway should be included for storm intensities that exceed design capacity and flow rate of settling basin



dition, slope(s) of the surface, and flow length. The small lots can be represented by the longest flow path from the top of the lot to the inlet to the settling basin. Larger lots have more than one flow surface, normally to an interceptor ditch that collects the flow from multiple surfaces and conveys them to the settling basin. Relatively slow velocities result in the overland section and rapid flows in the ditches. There is a wide range of conditions including flow, length, and slope(s). A more precise methodology is presented in the NRCS Engineering Field Handbook, chapter 2.

Step 3

Surface settling rate equals 4 feet per hour if the basin will be at least 2 feet deep. If site limitations (lack of fall away from lot) restrict depth to less than 2 feet, over design the basin area by using a surface-settling rate less than 4 feet per hour (2 ft/h is a reasonable compromise).

Step 4

Basin surface area:

$$\text{Area} = \frac{(\text{flow rate off lot x } 3{,}600 \text{ s/h})}{\text{surface settling rate}} \qquad (3)$$

Units: Area in ft^2
Flow rate off lot in ft^3/s
Surface settling rate in ft/h (from step 3)

Step 5

Basin liquids storage depth:

$$\begin{aligned}&\text{Liquid storage depth} =\\&\text{surface settling rate} \times \text{detention time}\end{aligned} \qquad (4)$$

Units: Surface settling rate in ft/s (from step 3)
Detention time in h. 1/2 h is considered a minimum.
Maximum depth is 4 ft because excessive depth makes access difficult and hinders dewatering.

Step 6

The larger volume from the calculation based on detention time or storm event size should be selected for the liquid storage volume. First, calculate liquid storage volume based upon selected detention time:

$$\begin{aligned}&\text{Liquid volume } =\\&\text{Liquid storage depth} \times \text{basin surface area}\end{aligned} \qquad (5)$$

Units: Liquid volume in ft^3
Liquid storage depth in ft (step 5)
Basin surface area in ft^2 (step 4)

A settling basin volume should also be checked to ensure a liquid storage capacity for a 10-year, 1-hour storm if preceding a holding pond or a VIB, or a 25-year, 24-hour storm if preceding a VTA (see app. B, fig. B–1). See appendix B for estimating runoff from a single storm event.

The larger volume of detention time estimate and storm event estimate should be selected. If the storm event estimate is larger, the liquid depth should remain constant and surface area recalculated.

Step 7

Solids storage volume:

$$\begin{aligned}&\text{Solids storage volume } =\\&\text{Sludge buildup rate} \times \text{feedlot area}\\&\times \text{fraction of year} \times \frac{43{,}560 \text{ ft}^2/\text{a}}{12 \text{ in/ft}}\end{aligned} \qquad (6)$$

Units: Solids storage volume in ft^3
Sludge buildup rate in a-in/a/yr
Feedlot area in a
Fraction of yr between basin solids removal

Use a sludge buildup rate of 0.5 acre-inch/acre of unpaved lot per year, and 0.1 acre-inch/acre of paved lot per year. Increase these values by 50 percent if lots have steep slopes (>8–10%) or are poorly maintained (pens cleaned less frequently than twice per year).

Step 8

Solids storage depth:

$$\text{Solid storage depth} = \frac{\text{solids storage volume}}{\text{basin surface area}} \quad (7)$$

Units: Solid storage depth in ft
Solids storage volume in ft^3
Basin surface area in ft^2

For vertical wall structure, use area at top of structure. For sloped wall structure, use average area of top and bottom of structure.

Step 9

Overall basin depth:

$$\text{Overall basin depth} = \text{liquids depth} + \text{solids storage depth} \quad (8)$$

Units: Liquids depth in ft (step 5 or 6)
Solids storage depth in ft (step 8)

Step 10

Size the sloping screen prior to riser pipe (if used). Screen area is sized to limit flow velocity through the screen to less than 2.5 feet per minute when basin is full. Assume an expanded metal screen has 60 percent open area.

$$\text{Screen area} = \frac{(\text{flow rate off lots} \times 60\ \text{s/min})}{(0.6 \times 2.5\ \text{ft/min})} \quad (9)$$

Units: Screen area in ft^2
Screen length in ft
Flow rate off lots in ft^3/s
Screen height in ft

Step 11

Basin length:

$$\begin{aligned}\text{Minimum basin length} &= \text{Ramp length} + \text{screen length}\\ &= (\text{Overall basin depth, ft} \\ &\quad \times \text{ramp slope}) + \text{screen length}\end{aligned} \quad (10)$$

Units: Minimum basin length, ft
Ramp length, ft Ramp slope should be 10:1 or flatter
Overall basin depth, ft
Screen length, ft

Step 12

Basin width

$$\text{Basin width} = \frac{\text{Basin surface area, ft}^2}{\text{basin length}} \quad (11)$$

Units: Basin surface area, ft^2

Basin length in feet should not be less than minimum basin length calculated in step 11. If site limitations restrict basin width, increase basin length and recalculate. The basin width must be at least 10 feet wide for equipment access to remove solids.

Step 13

Flow rate from basin to VTA

For a settling basin that precedes a VTA, flow rate should equal design storm volume spread over a 30- to 72-hour period. This would be encouraged for VTAs applied to all size livestock operations and specifically recommended for EPA permitted CAFO operations. The exception would be where the VTA's lower end is bermed or the runoff is collected in a holding basin. The outlet will need to have an orifice plate that provides control over outflow rate.

a. Estimate flow rate:

$$\text{Outlet flow rate} = \frac{\text{liquid volume}}{(\text{flow period} \times 3{,}600)} \quad (12)$$

Units: Outlet flow rate, ft^3/s
Liquid volume, ft^3 as estimated by the storm event method in step 7
Flow period, h (30–72 h recommended)
3,600 is the conversion from h to s

b. Size orifice from table 5–2

c. Determine the required open area/feet of pipe height from table 5–3 for the riser pipe.

d. Increase the open area of the riser pipe by 25 percent.

e. Size the riser pipe diameter using table 5–4. Minimum riser pipe diameter should be at least 2 inches greater than orifice diameter.

For a settling basin that precedes a holding pond or VIB, allow outflow to equal the peak flow rate off the lot (step 2) when the basin is full, using the following procedure:

a. For a riser pipe with an orifice, follow the procedure described above with the exception of selecting flow rate from step 2.

b. For a perforated pipe without an orifice plate, determine the required open area/foot of pipe height from table 5–3. Then size the riser pipe diameter using table 5–4.

c. For a porous dam, determine required dam length from figure 5–4.

Step 14

Select an underground discharge pipe from figure 5–6. Size the pipe to discharge at the peak flow rate off the lot. Determine pipe slope as shown in figure 5–6.

Figure 5–6 Capacity of pipe. Although developed for clay tile drainage lines, these charts approximate the capacity of low pressure lines (MWPS 1985, fig. 4–5).

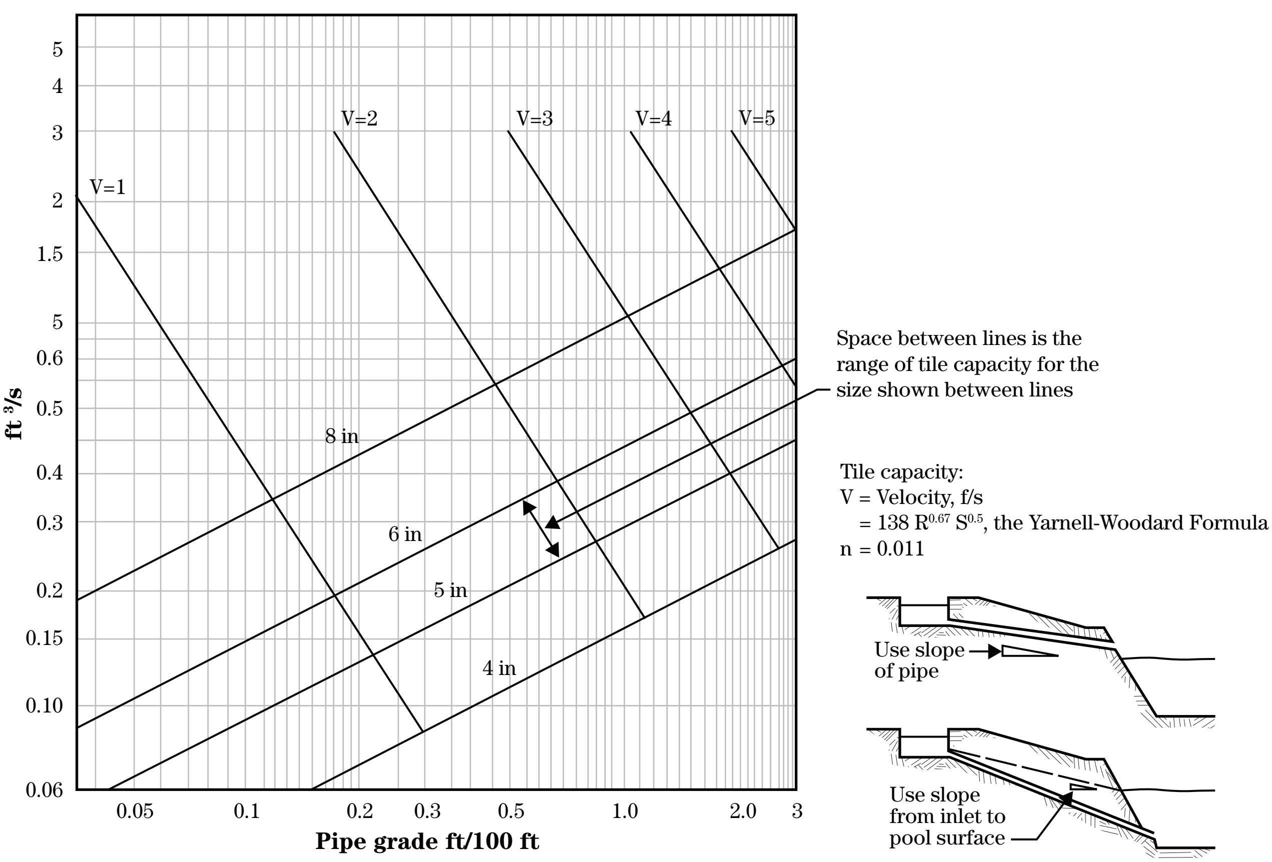


Table 5–3 Riser pipe open slot design for settling basin outlets. Determine open slot area per linear ft of pipe for design flow; then, increase that value by 25%. Boxed values refer to example in appendix C (MWPS 1985).

Open slot area/ft of pipe height, in²/ft	Head, ft							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Flow rate, ft^3/s							
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	3.980	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

Table 5–4 Sizing of riser pipe. Capacity of smooth plastic riser pipe (ft^3/s) at design water depth

Riser diameter, in	Head, depth of water over inlet							
	0.5	1	1.5	2	2.5	3	3.5	4
	ft^3/s							
3	0.18	0.26	0.31	0.36	0.41	0.44	0.48	0.51
4	0.33	0.47	0.57	0.66	0.74	0.81	0.87	0.94
6	0.76	1.08	1.32	1.52	1.70	1.87	2.01	2.15
8	1.37	1.93	2.37	2.74	3.06	3.35	3.62	3.87
10	2.15	3.04	3.72	4.30	4.81	5.27	5.69	6.08
12	3.11	4.40	5.38	6.22	6.95	7.61	8.22	8.79
14	4.24	6.00	7.35	8.48	9.48	10.39	11.22	12.00
16	5.55	7.85	9.61	11.10	12.41	13.59	14.68	15.70

Minimum riser pipe diameter selected should be the largest of the following three possibilities: (1) the diameter of the mainline, (2) 2 in larger than the planned orifice diameter , or (3) the diameter from table 5–4 with capacity of 1.5 times design flow rate.

Alternative solids-settling facilities

Several alternative, low-cost solids-settling facilities may be practical in some circumstances. All of these alternatives balance reduced cost against greater maintenance requirements. If maintenance requirements are not followed closely, higher solids will move into the VTA or VIB, increasing the potential for loss of vegetation and short-circuiting in the VTA.

These alternative solids-settling facilities do not provide control over the rate of feedlot runoff entering the next stage of treatment. Thus, high-intensity storms will cause high flow rates from these settling options into the VTA. For a CAFO permitted under current EPA regulations, precise control of the release timing or rate of flow into the VTA is important for reducing the risk of runoff exiting the VTA. Thus, application of these alternative solids-settling facilities in permitted CAFOs would not be recommended unless this concern is offset by lower risk system options (sec. 3) or more conservative VTA sizing.

Settling bench

A settling bench (fig. 5–7) is an area of relatively flat slope of a width such that the low velocities produce runoff flow rates producing significant solids settling. Maintaining vegetation on the settling bench improves settling efficiency. Solids must be removed at appropriate intervals to maintain the settling and distribution function. Reseeding of grass will likely be necessary after each solids removal.

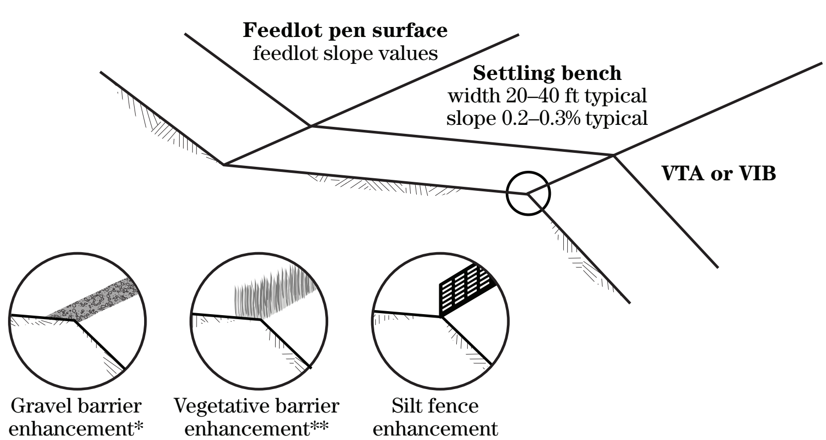
Design recommendations:

- Width: 20 to 40 feet
- Minimum length: Preferably the width of the bottom edge of the feedlot
- Slopes: 0.002 to 0.003 feet per foot towards the VTA
- Location relative to feedlot and VTA. It is preferable to locate the bench just below the feedlot pens (not within the pen itself) since flow may already be distributed over a fairly wide area. The settling bench should also be located directly between the feedlot and VTA or VIB.

Operation and maintenance recommendations:

- Monitor solids accumulation closely; remove any significant solids which will disrupt distributive flow.
- Solids removal will impair the grass stand; therefore, seeding may be required after solids removal.
- Grade control will be required on the bench to maintain the flow producing characteristics of the bench.
- A geotextile fabric placed below the bench surface may be beneficial for allowing vehicle traffic for solids removal only in higher rainfall climates.

Figure 5–7 Typical settling bench



* Reference: "Ground Level Lip Spreader for Barnyard" Pennsylvania NRCS Drawing
** Reference: "Vegetative Barrier" Texas NRCS Conservation Practice Standard Code 501

Geotextile fabric (silt fence)

A barrier or series of barriers of semi-porous material is set at right angles to the flow (*http://www.salixacc.com/siltfence.html*). This method can be used without additional settling options, or in conjunction with a settling bench to remove suspended solids.

Recommended design and construction criteria

- Silt fences should not impound water more than 18 inches in depth from a 10-year, 1-hour storm assuming no drainage through the fabric.
- Place silt fence on the contour, turning ends upslope in order to impound water.
- Soil should be sliced and fabric placed and compacted.
- Post spacing should not exceed 6 feet.
- Fabric is wired directly to the posts.
- Steel T-posts weighing at least 1.25 pounds per foot of post are required.

Recommended operation and maintenance

- Silt fence may need to be replaced at 1- to 2-year intervals. Geotextiles usually cannot be recycled. Check with the supplier of the material as to recycling opportunities. Also, visit with the local landfill as to the costs for disposal of this material.
- Inspect fence after every runoff event. Watch for undercutting of fence by water.
- Remove solids on a regular basis to prevent substantial buildup of materials.

Gravel spreader/barrier

Gravel spreader/barrier is a small ridge of graded gravel with a uniform elevation and width used as a solids removal and settling enhancement. This practice lends itself well to use with a settling bench. Placed at the downstream edge of a settling bench, it reduces sheet flow velocities, traps solids, and enhances flow distribution. Gravel benches could also be placed at the upper end of a VIB allowing the solids settling and VIB to be combined into a single structure.

Recommended design criteria

- Height of barrier 6 inches, top width 1 foot
- Ends of barriers turned upslope

Operation and maintenance

- Gravel will require periodic maintenance due to accumulated solids plugging the flow paths through the gravel. Gravel may need to be replaced or redistributed to a level grade.
- Remove solids on a regular basis to prevent substantial buildup of materials.

Vegetative barrier

Permanent strips of stiff, dense vegetation along the general contour of slopes or across concentrated flow areas are installed to reduce erosion, manage runoff flow, and trap solids (NRCS Conservation Practice Standard 601, Vegetative Barrier, *http:www.nrcs.usda.gov/technical/Standards/nhcp.html*). This method will normally be used in conjunction with other practices such as a filter strip or VTA.

Recommended design and construction criteria

- Vegetative barriers will be planted to vegetation having large enough stems to keep the barrier upright during runoff events.
- Gaps between plants will be no greater than 3 inches at the end of the first growing season.
- Species must be adapted to local soil and climate conditions, be easily established, long-lived, and manageable.
- Species will be selected that exhibit characteristics required for adequate function.
- Barriers may be established from transplanted vegetation or from seed.
- Barrier widths will be the largest of 3 feet wide or 0.75 times the design vertical interval.

Recommended operation and maintenance

- Establishment failures will be replanted or reseeded immediately; short gaps in seeded barriers may be re-established with transplanted plant material.
- Mowing herbaceous barriers may be used as a management practice to encourage the development of a dense stand and prevent shading of other vegetation. Mowing will not be closer than 15 inches or the recommended height for the species, whichever is taller. Mowing in concentrated flow areas is discouraged because it will lower the vegetative stiffness index (VSI) by reducing average stem diameter.

- Weed control will be accomplished by mowing, spraying, or wick application of labeled herbicides.
- Vegetation in the barrier will be tolerant to or protected from herbicide used in surrounding cropped fields.
- Washouts or rills that develop will be filled and replanted immediately. Short gaps in established barriers will be re-established with transplanted plant material.
- Vegetative barriers will not be used as a field road or turn row. Vegetative barriers in concentrated flow areas will not be crossed with machinery.
- Vegetative barriers will not be crossed with water furrow plows or similar implements to cut drainage ditches to allow the passage of surface and subsurface water. If necessary, water should be drained by underground outlets installed up gradient of the barrier.
- Crop tillage and planting operations will be parallel with vegetative barriers.
- Pest control in adjacent fields will be performed with techniques and pesticides that will not damage the vegetative barrier.

Active versus passive management

Two distinct strategies are suggested for management of the outflow from a settling basin to a VTA. The producer's choice as to the appropriate management strategy may depend upon whether state or federal regulations apply to the facility and regulatory agency's interpretation as to how a VTA should be managed.

Active management

Active management of release of liquid from the settling basin involves producer control over release of all collected runoff until the liquid can infiltrate readily into the soil. This approach would minimize outflow onto the VTA when soils are frozen or saturated. The producer would actively prevent release of liquids until desired soil conditions were acceptable.

Advantages of active management strategy

- The least risk of a discharge from the VTA
- Maximum solids removal from the runoff
- May allow a smaller VTA (see sizing discussion in sec. 6)

Disadvantages of active management strategy

- The settling basin must be sized, designed, and managed as a runoff holding pond.
- The advantages of reduced seepage from the holding pond to ground water and air emission offered by the VTA system are less.
- For wetter climates, very large holding pond structures need to be installed in advance of the VTA.

Passive management

Passive management of the outflow of the settling basin into a VTA allows continuous outflow during the storm event. To minimize risk of VTA discharge, the flow rate from the settling basin is carefully controlled by the sizing of the settling basin discharge. Successful functioning of this system is dependent upon the ability to control flow so that it is released over an extended period of time, 30 to 72 hours after the storm event. This produces a situation where the settling basin liquid addition to the VTA represents only a small fraction of the precipitation falling directly on the VTA, and, thus, adds little risk to increased runoff. Because the contaminated runoff liquids are applied to the upper end of the VTA, the risk of runoff is further reduced.

Advantages of passive management strategy

- Low risk of runoff from the VTA
- Environmental failures of the collection and distribution system due to poor management are eliminated.
- Although the settling basin has significant size, it is still less than required for a holding pond.
- Liquids remain in the settling basin for less than 72 hours after any one storm event, reducing the risk of seepage to ground water and aerial emissions.

Disadvantages of passive management strategy

- Discharge from the VTA may occur for runoff events resulting during frozen soil conditions or for more intense storms that occur during extended wet periods.
- Permitted CAFO may need to record discharges and sample discharge for reporting to the permitting authority.

If outflow of the settling basin is to a holding pond or VIB, the preferred management strategy should always be a passively managed system. Both the holding pond and VIB have little chance of a discharge, unless poorly managed and the storm event exceeds the design storm capacity of a 25-year, 24-hour event. Alternative settling facilities will always be operated as a passive system as determined by the nature of their design.

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Section 6 Vegetative Treatment Area Design

Section 6 Vegetative Treatment Area Design

Contents

Topics	**6–1**
Purpose	**6–1**
VTA definition	**6–2**
VTA sizing	**6–3**
VTA sizing by nutrient balance	6–3
Critical assumptions the producer should check	6–8
VTA sizing by water balance	6–9
Critical assumptions the producer should check	6–9
Sheet flow considerations	**6–12**
Initial runoff distribution	6–12
Distribution within VTA	6–13
Plant materials selection	**6–14**
Slope considerations	**6–16**
Additional options for reducing VTA runoff release	**6–16**
References	**6–17**

Tables

Table 6–1	Method 3 for estimating nitrogen in runoff	6–5
Table 6–2	Plant nitrogen uptake by forages removed with the harvested part of the crop	6–7
Table 6–3	Ratio of VTA Area/Drainage Area for three saturated soil infiltration rates and three settling basin drain times	6–10
Table 6–4	Level spreader spacing recommended by Iowa NRCS	6–13

Figures

Figure 6–1	Method 2 estimate of annual N released from paved and earthen feedlot surfaces	6–5
Figure 6–2	Water balance method for VTA	6–9
Figure 6–3	Options for creating and maintaining sheet flow within a VTA	6–12
Figure 6–4	Effect of soil salinity on growth of selected forage crops	6–14
Figure 6–5	Considerations for forage selection in different VTA locations	6–15

Section 6 Vegetative Treatment Area Design

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.

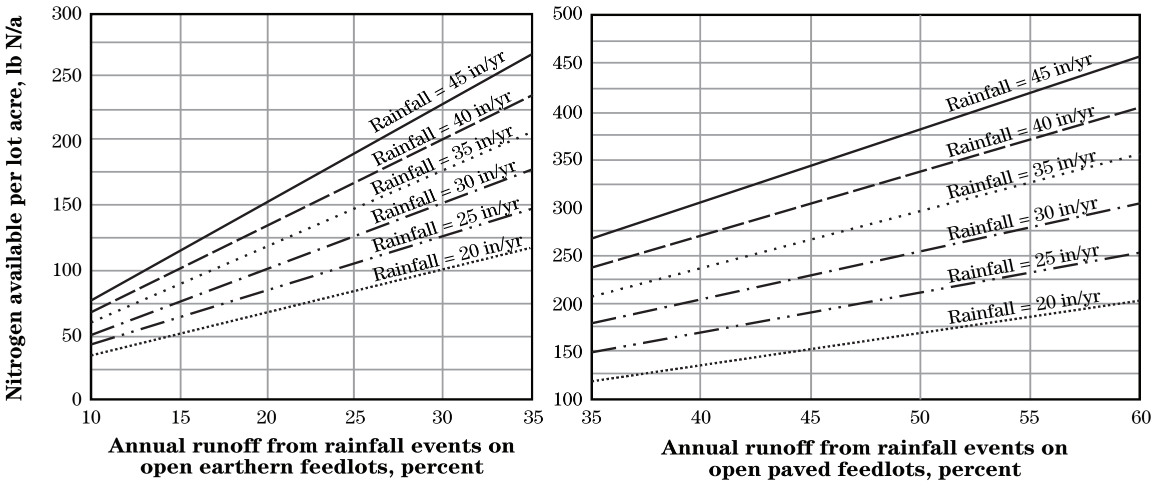


Table 6–1 Method 3 for estimating nitrogen in runoff

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 ft^2 ÷ 43,560 ft^2/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.

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.

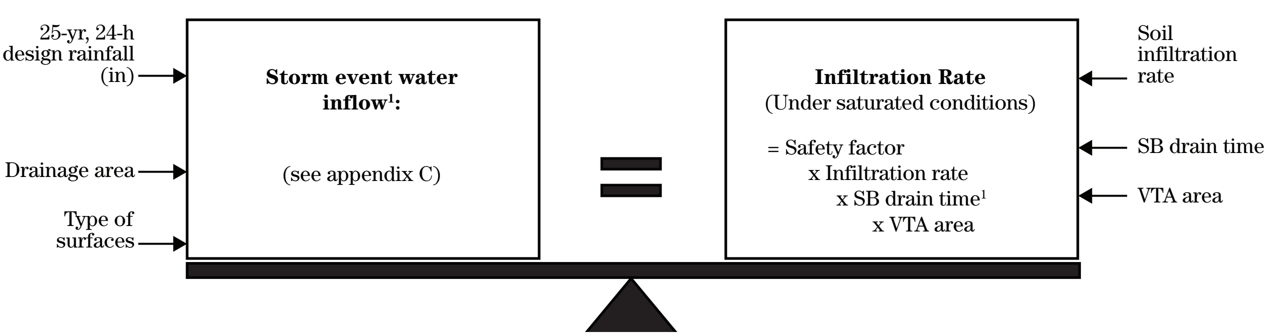
In summary, a water balance can serve as one option for estimating the minimum size requirement for a VTA. This estimate should be compared against an estimate based upon nutrient balance methods. Generally, the nitrogen-based balance will produce the larger VTA design. However, for systems involving 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 x 11.5 feedlot a) + (0.4 x 8 additional a) = 7 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:

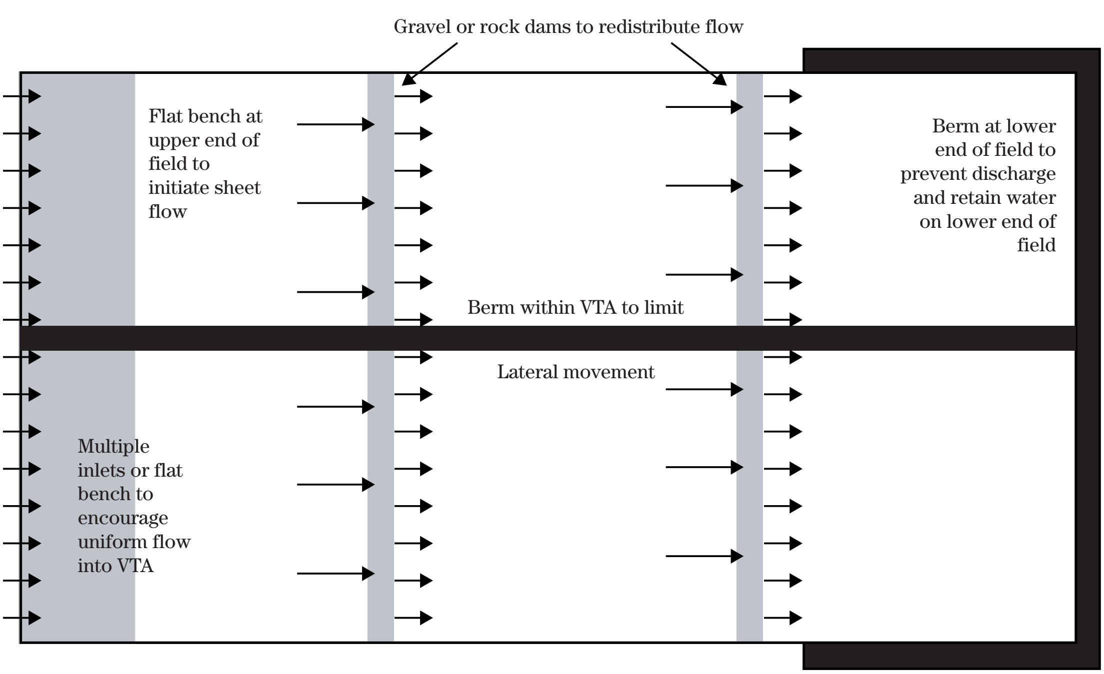
- Uniform distribution of runoff at the entrance
- Flow may converge within the VTA, and in field measures should be considered to redistribute flow within the VTA
- VTA management must monitor and maintain conditions to encourage sheet flow (sec. 8).
- A soil and/or forage nutrient monitoring program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

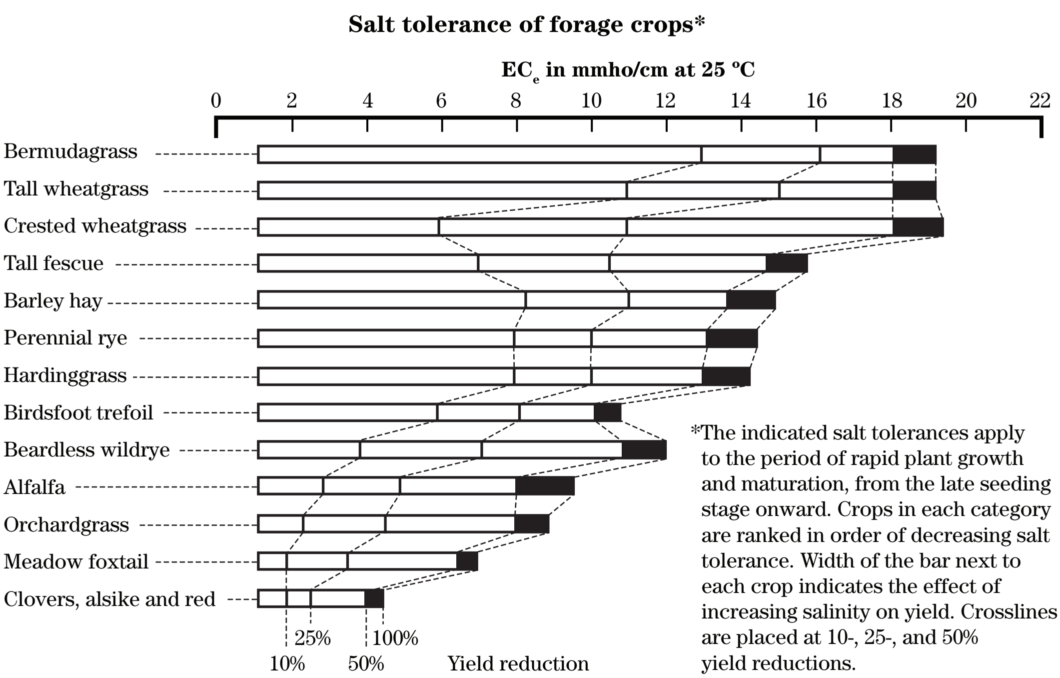
Plant materials selection

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)



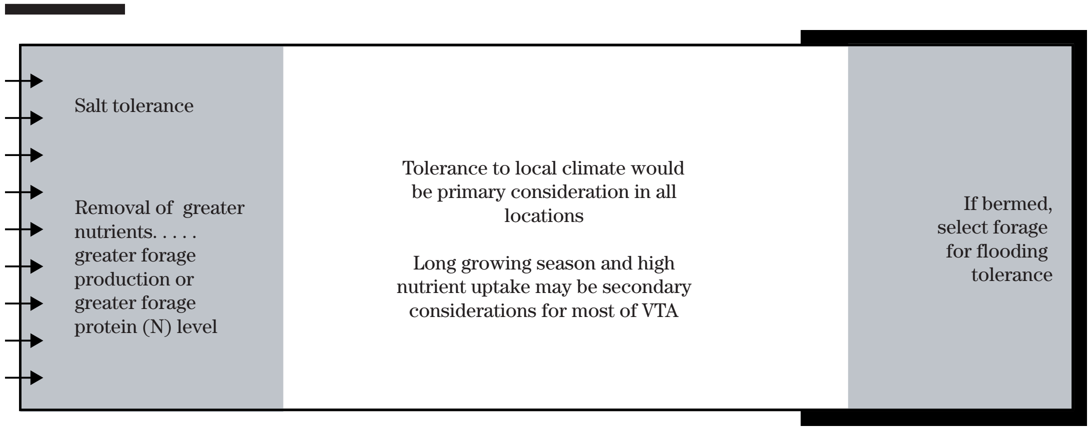
- *Tolerance to ammonia*—Many plants cannot tolerate high concentrations of ammonia. Influent concentrations should be 200 milligrams per liter or less. Typical feedlot runoff may contain higher ammonia concentrations (400–700 mg/L) than the plants can tolerate, although, actual concentrations may vary 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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Section 7 Vegetative Infiltration Basin Design

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Contents

Topics	**7–1**
Purpose	**7–1**
VIB description	**7–2**
Performance	**7–3**
Site selection issues	**7–4**
Sizing a VIB	**7–4**
Tile drain design	**7–5**
Plant materials	**7–8**
VIB effluent management	**7–10**
References	**7–10**

Tables

Table 7–1	Minimum grade, %	7–6
Table 7–2	Maximum velocity without protective measures	7–6

Figures

Figure 7–1	Infiltration basin is typically an additional treatment component between the solids settling basin and VTA designed to minimize the potential for a discharge from a VTA.	7–2
Figure 7–2	Sample runoff flow rates into VIB and out of VIB for June 18–23, 2002	7–3
Figure 7–3	Tile line should be located at least 4 feet below the ground surface and between the low and high seasonal water tables	7–6
Figure 7–4	Effect of soil salinity on growth of selected forage crops	7–8

Section 7 Vegetative Infiltration Basin Design

Topics

- Sizing
- Site selection
- Tile drain design
- Plant materials
- Managing vegetative infiltration basin outflow

Purpose

Vegetative infiltration basins (VIB) provide an optional treatment component that relies on soil properties for filtering nutrients and other contaminants from the runoff water. They have demonstrated the ability to significantly reduce concentration of nutrients and solids in runoff and substantially delay the release of runoff into a latter treatment stage. These benefits can make VIBs a useful component in a VTS. This section will summarize VIB performance and review critical VIB design issues.

VIB description

A VIB has many similarities to a VTA described in section 6. It is an area planted to perennial forages or grasses and relies upon the treatment capabilities of the plant material and the soil for removal of potential pollutants. However, the VIB also has several unique differences:

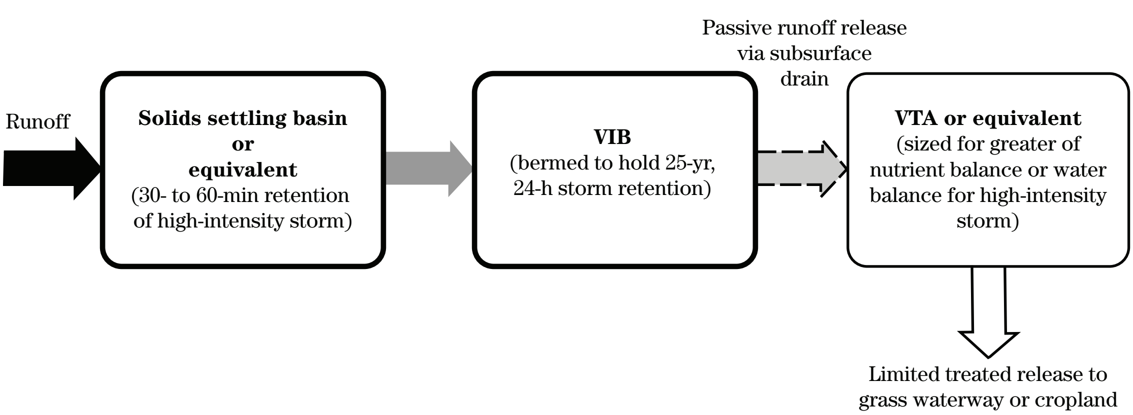
- A VIB is completely enclosed by a berm designed to handle the open lot runoff and precipitation for a design storm (25-yr, 24-h storm is recommended).
- All runoff and precipitation must infiltrate through a 4- to 6-foot soil layer. Surface water discharges are very unlikely with an VIB.
- A tile drain system collects the infiltration and delivers the treated sub-surface discharge to the next treatment component, commonly a VTA.

VIBs downstream of open feedlots are designed to be treatment areas using soil as a filter medium. Basin design is based on hydraulic loadings and soil properties that allow infiltration within a specified length of time based on plant tolerance to wet conditions. Nutrients will likely exceed agronomic nutrient loadings. Nutrient removal is significant, but not complete. The infiltrated water that passes through the system is collected in a subsurface tile drainage system and returned to the surface for further treatment. Unlike wetlands, VIBs should remain dry (aerobic) the vast majority of the time and only be saturated for short time periods immediately following runoff events.

For CAFOs, a VIB is typically considered to be one treatment component of a larger system. It is designed to compliment solids removal and VTA components and minimize the potential for a discharge from the VTA (fig. 7–1). It performs three critical functions when placed before the VTA and after the solids removal components:

- It provides significant additional reduction of potential pollutant concentration and mass prior to the runoff release into a VTA.
- It significantly delays the release of runoff and spreads the release over an extended period of time (fig. 7–2). This should substantially limit the release of treated effluent into a VTA that follows a VIB during most storm events and minimize the risk of a release from the VTA.
- For smaller non-CAFO open lots, a settling basin and VIB may satisfactorily treat runoff water without the VTA. VIB sub-surface discharge is **not** sufficiently treated for direct discharge to surface or ground water. However, the smaller volumes associated with small open lots may be released to crop or pasture land.

Figure 7–1 Infiltration basin is typically an additional treatment component between the solids settling basin and VTA designed to minimize the potential for a discharge from a VTA.



Performance

Three recent studies of VIBs have shown significant water quality improvements resulting from this technology. Lorimor et al. (2003) observed that a VIB associated with a 380 head beef feedlot produced an average of a 65 percent reduction in suspended solids, 80 percent reduction in total Kjeldal nitrogen, 81 percent reduction in ammonium nitrogen, and 77 percent reduction in total phosphorus over a 5-year period. Nitrate levels increase substantially as runoff moved through VIB. Typically, almost no nitrate exists in feedlot runoff. In an aerobic environment, nitrification of ammonia occurs. Any treatment component following a VIB will need to utilize or treat nitrate. Lorimor et al. (2003) reported that nitrate represents about 0.5 percent and 4 percent of the total nitrogen in the influent and effluent of the VIB, respectively.

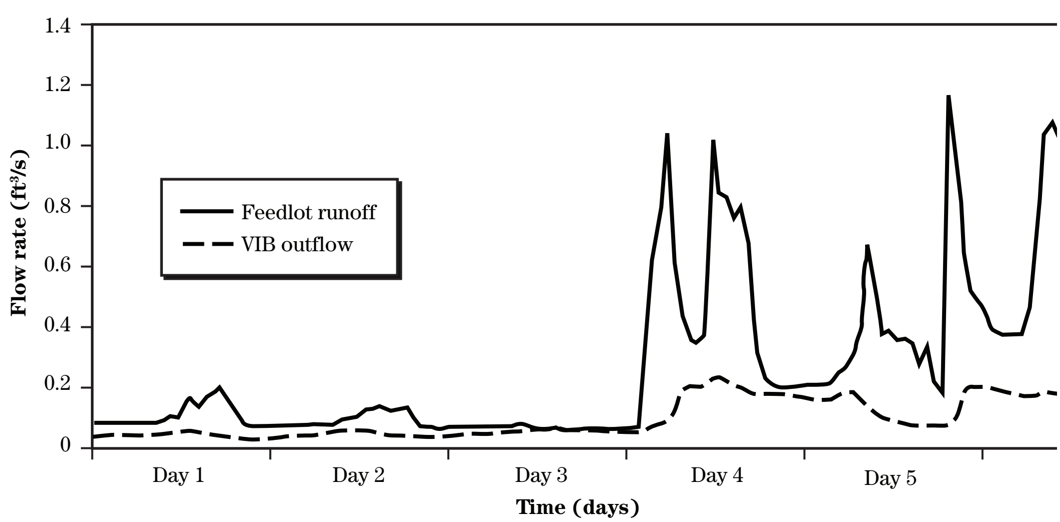
If a VIB precedes a VTA, removal of nutrients by the VIB should reduce the nitrogen based sizing requirements of the VTA by 70 to 80 percent. A water balance method for VTA sizing must also be checked. For the large storm events used to size a VTA based upon a water balance, it is appropriate to assume that the VIB **will not significantly reduce the volume of water** moving to the VTA. Thus, the water balance sizing method may become the limiting method for estimating VTA size when combined with a VIB. Additional information on VIB performance is summarized in section 9.

VIB performance under winter conditions is a common concern. Although current experience is limited, it is the professional judgment of the authors and their experience based upon 6 years of VIB operation at the Iowa State University feedlot that frozen soil conditions do not represent a problem.

Runoff volumes under winter conditions are generally small. High-intensity or large storm events are rare during the winter. The normal volume of runoff is also typically very small during this period. In most locations, the fraction of rainfall that exits a dirt lot as runoff is typically very small during the winter (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 months (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: 0.08, 0.07, and 0.30 in of runoff in Jan., Feb., and Mar., respectively).

A settling basin upstream of a VIB can provide a safety mechanism for protecting the VIB under winter conditions. The settling basin would need to include some storage capacity (runoff volume for 10-yr, 1-h storm or greater) and a valve on the settling basin outlet that can be closed for winter conditions. This would allow the settling basin to store winter runoff when VIB soils are frozen. Designing the settling basin to include such options in regions with higher snowfall should eliminate frozen VIB soil concerns, although the limited experience to date would suggest that this is not a concern.

Figure 7–2 Sample runoff flow rates into VIB and out of VIB for June 18–23, 2002 (Lorimor et al. 2003). VIB delays and reduces peak flow from feedlot into any treatment component following the VIB.



Site selection issues

Only soils with acceptable infiltration rates are usable for VIBs. Permeability, as shown in soil surveys, should be from 0.6 to 2.0 inches per hour. Soils with lower permeability generally will not drain quickly enough for vegetation maintenance unless a very large footprint and shallow impoundment depth is used. More permeable soils will not provide adequate treatment of contaminants as the liquids move through them too quickly. It is recommended that a site evaluation for a potential VIB location should include a site-specific measure of infiltration rates.

Sites with low slopes are preferable for VIB construction. VIBs should be built essentially flat to facilitate spreading of inflow across the entire bottom area. A slight slope (≤0.5% away from the inlet) may be built into the basin to encourage small events to spread out for more uniform loading. The top elevation of the berm should be approximately level, with a spillway for safely handing storm events exceeding the design storm.

Impervious subsurface soils, creating a perched water table (saturated conditions) below the VIB is important for the tile system to function properly, and to avoid water movement below the tile depth. Situations for which a VIB may not be suitable include:

- Sandy or gravelly subsoils due to increased potential for contamination of ground water.
- Fractured bedrock (including karst or incipient karst topography) is closer than 10 feet from the surface again due to potential for contamination of ground water.
- Loess soils. If the water table is deep, a VIB may be considered especially if subsurface drains will function. VIB application to loess soils should be reviewed with local NRCS or conservation district staff for risk to ground water and potential subsurface drain function.

Section 4 should be reviewed for additional site selection issues.

Sizing a VIB

VIBs for CAFOs should be designed to retain a 25-year, 24-hour storm, plus an additional 6 inches for freeboard. Designs based upon a smaller storm may be acceptable for non-CAFO facilities. A VIB should impound all collected runoff to no greater depth than will infiltrate into the soil within a predetermined time dependant on the vegetation's tolerance to flooding. Seventy-two hours is generally considered a maximum limit. Determine the VIB area by using the following steps.

Step 1 Calculate maximum depth of VIB (including freeboard) based upon steady-state soil infiltration rate (in/h) and maximum design time for drainage of VIB (h):

$$D_{MAX} = \left(I_{VIB} \times T\right) + F \tag{1}$$

where:
D_{MAX} = maximum basin depth (in)
I_{VIB} = steady-state infiltration rate (in/h)
T = infiltration time to empty VIB (h)
F = freeboard (in)

Step 2 Determine a practical VIB depth. A practical limit to a VIB liquid depth is approximately 24 inches (30 in with freeboard). This practical limit will often be less than the maximum depth calculated in step 1. If the maximum VIB depth is smaller than the practical depth, proceed to step 3. If the practical VIB depth is smaller than the maximum depth calculated in step 1, skip to step 4.

Step 3 Calculate VIB volume and area based upon a maximum allowable depth. The VIB volume can be estimated by two unique equations. Equation 2 is based upon runoff from feedlot and additional contributing area plus direct precipitation falling on the settling basin and VIB. Equation 3 is the depth of water that will infiltrate through the VIB in an allowable design time period.

$$V_{VIB} = R + \left[\left(A_{SB} + A_{VIB}\right) \times P\right] \tag{2}$$

$$V_{VIB} = A_{VIB} \times I_{VIB} \times T \tag{3}$$

Using equations 2 and 3, solve for area of the VIB and use the result of this calculation to then estimate VIB volume with either equations 2 or 3:

$$A_{VIB} = \frac{R + (A_{SB} \times P)}{(I_{VIB} \times T) - P} \tag{4}$$

where:
V_{VIB} = total volume of VIB, a-in
R = total runoff from feedlot and contributing area from appendix B, a-in
A_{SB} = area of the settling basin, a
A_{VIB} = area of VIB, a
P = design storm depth, in

Step 4 Calculate area of VIB based on practical depth. Equation 4 can be altered by substituting a practical basin depth (D_P) minus freeboard (F) in place of the estimate of depth based upon infiltration rate and design time to empty a VIB (I_{VIB} x T). The resulting equation for area of VIB is:

$$A_{VIB} = \frac{R + (A_{SB} \times P)}{(D_p - F) - P} \tag{5}$$

where:
D_p = practical VIB depth (in)

This result can be substituted into equation 2 to estimate VIB volume for a practical depth.

Warning: Do not use equation 3 to estimate VIB volume if area of VIB is based upon a practical depth.

Tile drain design

The VIB will be underlain by subsurface drain tiles (fig. 7–3). The drains shall be installed deeper than the seasonal high water table and not less than 4 feet deep (5–6 ft is recommended). In addition, drains shall be placed above the seasonal low water table to prevent year round water flow from the tile system into the next treatment stage. The time to drain the 25-year, 24-hour precipitation event including runoff from the feedlot area should be compatible with selected vegetations tolerance to flooding and generally not exceed 72 hours.

The spacing of tile drains shall be designed to efficiently remove excess water. Kirkham's method (Kirkham 1957) for flow to drains under ponded conditions is valid for the design of drain tile spacing for the VIB. The Web site, *http://msa.ars.usda.gov/ms/oxford/nsl/java/Kirkham_java.html*, provides a tool for using Kirkham's method. An example design using this procedure is illustrated in appendix E.

In addition to determining the required drain spacing, the tile size must be determined, and the grade of the installed tile lines must be specified. The capacity of the tile drains shall be computed using Manning's equation and the equation of continuity. An example calculation using the following two relationships is illustrated in appendix D.

$$Q = AV \tag{6}$$

$$V = \frac{C_v R^{\frac{2}{3}} s^{\frac{1}{2}}}{n} \tag{7}$$

where:
Q = discharge, ft³/s
C_v = 1.49 for Q, ft³/s
V = velocity, ft/s;
A = cross section of pipe flow, ft² (tile drain should not be less than 4-in diameter)
R = hydraulic radius of the pipe, ft
s = slope of the pipe, ft/ft
n = Manning's roughness coefficient

The minimum drain size required to provide adequate discharge capacity can be computed using these equations (ASAE 2003). The minimum grade to prevent siltation for installed tile lines shall be in accordance with table 7–1. The maximum velocities in tile drains to prevent erosion shall be designed to not exceed the values provided in table 7–2. An example design can be found in appendix D.

Installation of tile lines will disturb natural soil conditions. The potential exists for short-circuiting of runoff to tile lines in these disturbed areas. Consideration should be given to tile installation methods that minimize soil compaction during backfilling and restore the soil over the tiles lines to as natural a condition as possible. In addition, macro-pore flow may develop in the drained profile with time. It is critical to prevent tree and weed establishment that could create direct flow pathways due to root systems. It is also important to till an infiltration basin every few years with heavy tandem disk or chisel plow and reestablish vegetation to diminish macro-pore flow.

Figure 7–3 Tile line should be located at least 4 ft below the ground surface and between the low and high seasonal water tables.

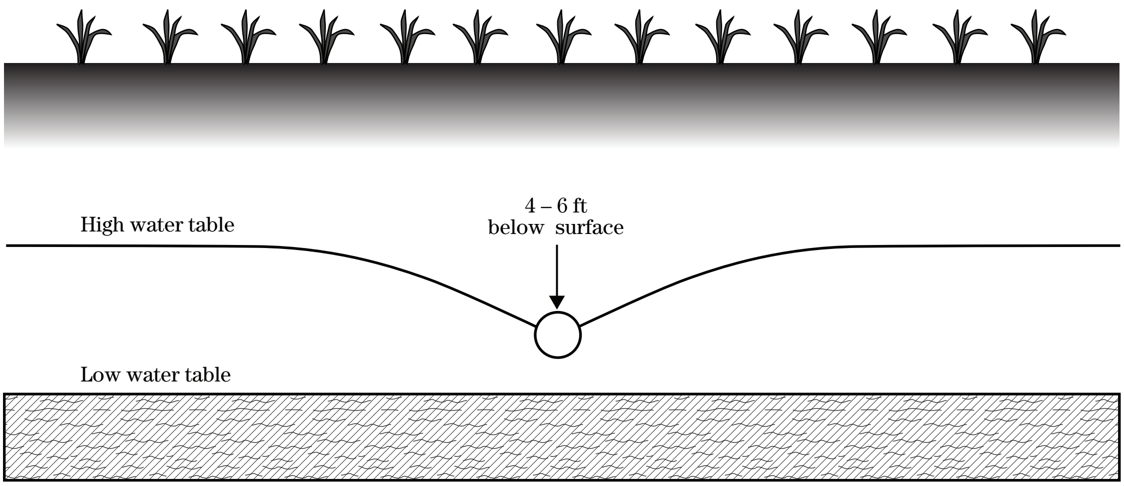


Table 7–1 Minimum grade, % (ASAE 2003)

Inside pipe diameter mm (in)	Corrugated plastic pipe *not* subjected to fine sand or silt [1]	Corrugated plastic pipe subjected to fine sand or silt [2, 3]
75 (3)	0.10	0.81
100 (4)	0.07	0.55
125 (5)	0.05	0.41
150 (6)	0.04	0.32

1 Grades provide a minimum cleaning velocity of 0.15 m/s (0.5 ft/s)
2 Grades provide a minimum cleaning velocity of 0.42 m/s (1.4 ft/s)
3 If a sock is installed, use values listed for corrugated plastic pipe not subject to fine sand or silt

Table 7–2 Maximum velocity without protective measures (ASAE 2003)

Soil texture	m/s	(ft/s)
Sand and sandy loam	1.1	(3.5)
Silt and silt loam	1.5	(5.0)
Silty clay loam	1.8	(6.0)
Clay and clay loam	2.1	(7.0)
Coarse sand and gravel	2.7	(9.0)

Design example for VIB depth and volume

Design a VIB for a 2,000 head 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 that drains into the settling basin. The VIB will be located in a soil with an infiltration rate of 0.6 to 2 inches per hour (found in county soil survey). It is desirable that the basin drain in 72 hours for a 25-year, 24-hour storm. Refer to examples in appendices B and C for additional information.

From appendices B and C, a 25-year, 24-hour storm (P) is 5.5 inches, feedlot runoff for this size storm (R) is 93 acre-inches, and area of settling basin (A_{SB}) is 123,000 ft^2 or 2.8 acres.

Step 1 Calculate maximum depth of VIB including freeboard (assume 6 in) and lower permeability value listed in county soil survey for this soil:

$$D_{MAX} = \left(I_{VIB} \times T\right) + F$$

$$D_{MAX} = \left(0.6 \text{ in/h} \times 72 \text{ h}\right) + 6 \text{ in} = 49 \text{ in}$$

Step 2 Estimate a practical VIB depth to be 30 inches including 24 inches for runoff storage and 6 inches for freeboard. Since the practical VIB depth is less than the Maximum VIB depth, use equation 5 in step 4 to calculate VIB area.

Step 3 Skip[1]

Step 4 Select a practical VIB depth of 30 inches (including 6 in of freeboard) and estimate VIB area:

$$A_{VIB} = \frac{R + \left(A_{SB} \times P\right)}{\left(D_p - F\right) - P}$$

$$A_{VIB} = \frac{93 \text{ a-in} + \left(2.8 \text{ a} \times 5.5 \text{ in}\right)}{\left(30 \text{ in} - 6 \text{ in}\right) - 5.5 \text{ in}} = 5.9 \text{ a}$$

Substitute the results of equation 5 into equation 2 to calculate VIB volume:

$$V_{VIB} = R + \left[\left(A_{SB} + A_{VIB}\right) \times P\right]$$

$$V_{VIB} = 93 \text{ a-in} + \left(2.8 \text{ a} + 5.9 \text{ a}\right) \times 5.5 \text{ in} = 141 \text{ a-in}$$

1 Do not use equation 3 to estimate VIB volume if area of VIB is based upon a practical depth.

Plant materials

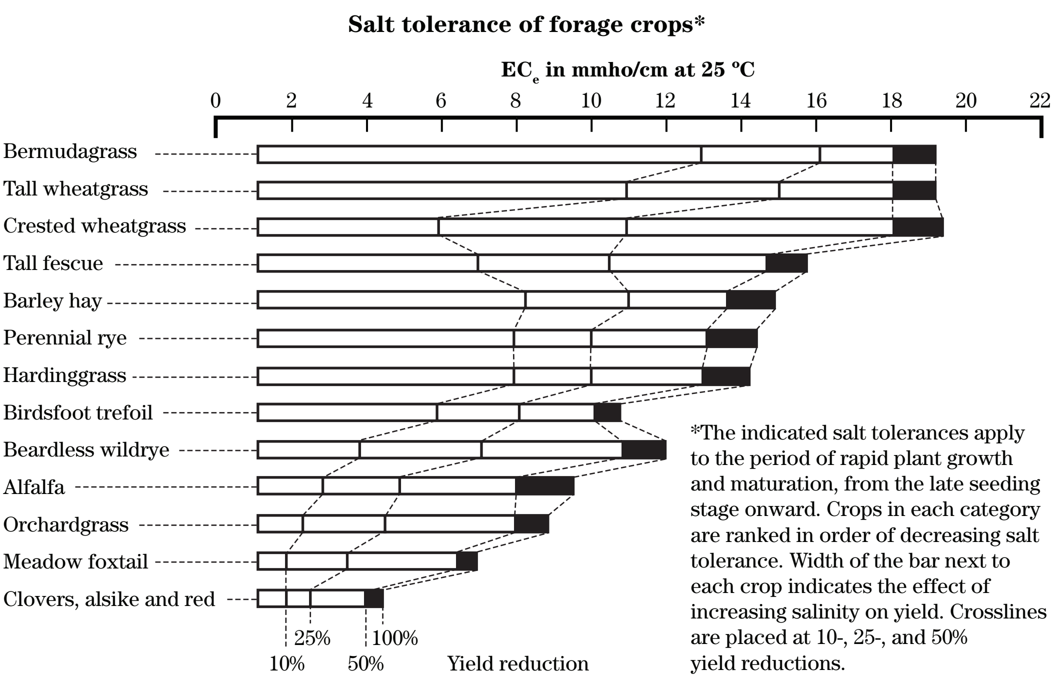
Forages or other crops selected for VIBs should be selected based on their ability to tolerate a variety of conditions. Appendix E provides summaries of plant characteristics that will assist in selecting appropriate species for VIBs. Additional information on plant materials selection can be found in:

- Comparative characteristics of forage species in Montana:
  http://www.animalrangeextension.montana.edu/Articles/Forage/Comparative/Comparative-char.htm
- USDA Conservation Plants Pocket Guide
  http://plant-materials.nrcs.usda.gov/pubs/mopmcpuidguide.pdf
- USDA VegSpec Web site
  http://ironwood.itc.nrcs.usda.gov/Netdynamics/Vegspec/pages/HomeVegspec.htm
- USDA Crop Nutrient Tool
  http://npk.nrcs.usda.gov/

Some of the more critical plant characteristics to consider include:

- *Tolerance of local climate*—Tolerance to temperature extremes, rainfall, and drought conditions specific to location should be a first consideration.
- *Tolerance to flooding and saturated soil conditions* for extended periods—VIBs will be designed to collect the runoff from the open lot and possibly contributing drainage from cropland and associated feedlot facilities plus the precipitation falling directly on the VIB. Typical infiltration design will require up to 72 hours for this volume of water to infiltrate through the basin during peak storm events. Forages or other crops maintained in the VIB will need to withstand flooding and saturated conditions over this time period, but also tolerate drier conditions that may predominate in the basin most of the time, especially in high plains states.
- *Tolerance to salts*—Because of the volumes of water that will move through the soil profile, soluble salt accumulation in the root zone may not be a large concern. However, a period of multiple small storms with little infiltration through to the tile lines may produce periods of salt accumulation in the VIB. Salt tolerance of the crop should be considered in selecting appropriate forage or grass species. Figure 7–4 provides an indication of some crops more tolerant to higher EC levels. Salt tolerance of locally specific crops should be available by contacting your local county coop-

Figure 7–4 Effect of soil salinity on growth of selected forage crops (USDA 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.

erative extension program or the local NRCS service center.

Runoff associated with rainfall events is the primary source of water that will be collected by a VIB. Average reported electrical conductivity (EC) levels ranges from 3.2 millimhos per centimeter for eastern Nebraska to 8.6 millimhos per centimeter for central Colorado. Drier climates typically produce the higher average EC levels. Smaller, less intense precipitation events typically produce higher salt concentration in runoff. 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. These EC levels will be diluted by rainfall directly on the settling and VIBs.

- *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 VIB than the plants can tolerate, vegetation will be lost. If high concentrations are anticipated, pretreat by blending the settling basin effluent with outside clean water to lower the influent concentration. Blending increases the total drainage area and will result in a larger VIB.

In addition to the crop's tolerance to the previously discussed limiting conditions, a preferred crop for a VIB should have some of the following characteristics:

- *High nutrient uptake*—Forages that harvest high levels of nitrogen coupled with regular harvesting of forages is important for minimizing excess nitrogen movement through VIBs. However, with effluent existing from VIBs only through dedicated drainage tiles (no surface runoff discharge), soil phosphorus accumulation will be of limited concern in most situations. VIBs that directly discharge via tile lines to a VTA should provide sufficient opportunity for managing dissolved phosphorus.
- *Value as animal feed*—VIB basin forage growth will need to be harvested regularly. It is preferable to select forages that will be of value as an animal feed to gain some value for the land committed to a VIB. 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*—VIBs can reduce the total water volume supplied to secondary treatment (VTA) if a forage or grass is selected for its high evapotranspiration rates.
- *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 VIB, 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 with large taproots are undesirable, increasing the potential for preferential flow.

To date, only limited field experiences with VIBs can be drawn on for the selection of plant materials. A VIB used with a small beef cattle feedlot observed that Reed Canary grass performed well. A VIB operating on a central Iowa feedlot has also observed that Reed Canary grass has survived well over a 5-year period. Grass and forage species selected for VIB should be tolerant of local growing conditions.

VIB effluent management

Effluent from the VIB is removed via the underground tile drainage system. Based on data from Iowa's research system, even though significant contaminant reductions will have occurred, the water quality in the tile flow should not be discharged directly to surface waters. The tile flow should be brought to the soil surface for further treatment via a VTA, wetland, or grass waterway.

Management considerations specific to VIBs include:

- Harvesting of forage regularly to remove as many nutrients as possible and maintain lush plant growth. Utilize the forage for animal feeding (if quality is reasonable) or alternative uses such as animal bedding. Avoid stock piling of unusable forage.
- Monitor crop nitrate levels if crop is fed to livestock.
- Soil test every 3 to 5 years to monitor potential phosphorus or salt buildup in the soil profile.
- Maintain records on precipitation events, peak VIB water levels, repairs and maintenance, inspections of site, and soil and plant tissue testing.
- Annually sample tile drain flow for nutrient and solids concentration.
- Prevent growth of trees and weeds with large taproots to minimize macro-pore flow. Every few years, the VIB should be tilled with a heavy tandem disk or chisel plow to disturb surface macropore flow and reestablish VIB vegetation.

Additional discussion on management of plant based treatment systems is contained in section 8.

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Section 8 Management Guidelines for Vegetative Treatment Systems

Section 8 Management Guidelines for Vegetative Treatment Systems

Contents

Topics **8–1**

Purpose **8–1**

Vegetation management **8–2**

Soil fertility for optimum growth 8–2
Harvesting a VTA 8–4
Management of soil moisture in VTA 8–4
Weed and brush control 8–5

Environmental management **8–5**

Soil sampling for environmental protection 8–5
Sheet flow maintenance 8–6
Passive versus active management of liquid release 8–7
Solids harvesting 8–7
Vegetation inspection 8–8

Standard operating procedures **8–8**

Records for monitoring performance **8–9**

CAFO regulation compliance 8–9
Ground water protection 8–12
Vegetation management 8–12

Tables

Table 8–1	Possible actions to be taken in response to soil sample test results	8–3
Table 8–2	Record expectations for a CAFO using a conventional or VTA system	8–13

Figures

Figure 8–1	Suggested soil sampling locations within a VTA	8–2

Section 8 Management Guidelines for Vegetative Treatment Systems

Topics

- Vegetation management for a VTS
- Environmental management for a VTS
- Standard operating procedures
- Records for monitoring performance

Purpose

Just as with any conventional manure or runoff management system, proper management of alternative treatment systems is critical to their proper functioning and longevity. After the appropriate plant species are established in the VTA or VIB, there are a number of operation and maintenance activities essential to their proper function. The following critical management issues should be addressed:

- Management of vegetation (soil fertility and harvesting)
- Management of environmental risks (tracking nutrient concentration, maintaining sheet flow, and controlling release of runoff into the VTA)
- Establishment of standard operating procedures for critical management tasks
- Implementation of a record keeping system for documenting performance of overall VTS

The purpose of this section is to discuss implementation of the critical management practices. The overall management requirements of VTSs will vary with individual components and their specific design selected for the overall system. For example, a solids settling area designed with sufficient volume to hold a year's accumulation of solids may only require infrequent inspections and yearly cleaning. Other choices may require more active manager participation—an actively managed outlet from the solids setting basin to the VTA may require the manager to check VTA soil moisture levels and basin liquid levels after each storm event when timing liquid release.

Both the producer and the regulatory agency (CAFO application) should be actively engaged in planning the management program as design alternatives are being evaluated. Once the level of essential management inputs are identified, VTS designs can be finalized, standard operating procedures assembled, and appropriate record keeping identified for the producer to meet these management expectations.

Vegetation management

Vegetation is the critical component in the success of a VTA. Selection of appropriate vegetation for application to a VTA and VIB is discussed in sections 6 and 7, respectively. Vegetation is established in VIB to produce and maintain a soil condition that promotes infiltration and removes and transforms nutrients. In the VTA, the vegetation slows movement of water to improve settling out of sediments, nutrients, and other contaminants; promotes infiltration; encourages chemical transformations; maintains soil permeability; and provides forage for animal use. The roots also provide a substrate for a highly active microbial zone that breaks down organic material, utilizes nutrients, and destroys pathogens. Proper vegetation management is essential for a high-performing VIB or VTA.

Soil fertility for optimum growth

Two distinct issues should be considered in selecting a soil-sampling program: maintaining optimum crop growth and environmental protection. A general discussion of soil-sampling issues for management of a VTA or VIB follows. A later section describes the soil sampling needed to monitor environmental performance. State-specific soil-sampling recommendations are typically available from your land grant university or other accepted resources.

A key to healthy vegetation is the proper fertility status. Usually, because of the nutrient enriched nature of the runoff entering the vegetated areas, lack of nutrients is not a problem. What can become a problem is an imbalance of nutrients, resulting in poor crop growth that could compromise the effectiveness of the vegetation. To monitor the fertility status of the VIB and VTA, a regular soil-testing program should be a part of the operation and maintenance plan.

For the purposes of soil nutrient monitoring, sample the top 8 to 10 inches of the soil. A deep soil sample (preferably to a depth of 36 in) is necessary if residual soil nitrogen, measured as nitrate-nitrogen, is to be monitored. Collect sufficient samples to give a good representation of the area. Cooperative extension programs at land grant universities may provide recommended sampling procedures. Because greater nutrient settling and runoff infiltration is expected near the inlet end of both a VIB and VTA, collect separate soil samples from the first 50 feet from the inlet area and separate samples from the rest of the VTA. Figure 8–1 illustrates one way of subdividing a VTA. A separate set of samples is taken in each sub-area (A, B, and possibly C), because the soil nutrient status may be different as you move farther from the point where runoff enters the VTA.

Analyze shallow soil samples for plant available phosphorus and potassium, important micronutrients, pH, soil electrical conductivity, and salts (sodium, calcium, and magnesium). Deep soil samples should be analyzed for nitrate-nitrogen. Based upon the results of the soils report, some management changes may be necessary (table 8–1). Only a fraction of the nitrogen and phosphorus (5% or less) excreted by the animals travels with runoff. About half of that in the runoff will be removed by a well-designed solids separation component. For the nitrogen that is transported to the VTA or VIB (primarily as ammonium-nitrogen), there also will be additional losses from denitrification and volatilization.

A greater percentage of the total potassium in the system will reach the VTA or VIB than either nitrogen or phosphorus. Potassium is soluble, so it will stay in solution as runoff leaves the pens and lots. Only a small percentage stays with the solids that settle out in the settling basin. The salt level in VTA and VIB soils should be monitored. Salts may accumulate in the root zone during periods of small rain and runoff events that do not saturate the soil and leach salts. Check soil electrical conductivity as part of a soil-sampling program, and discuss the results with your crop consultant. See the vegetation discussion in sections 6 or 7 for additional information on the salinity tolerance of different species.

The frequency of soil sampling will vary depending on the purpose. To track general fertility status, follow the land grant university, NRCS, or local conservation district's guidelines for forage or grass species fertility

Figure 8–1 Suggested soil sampling locations

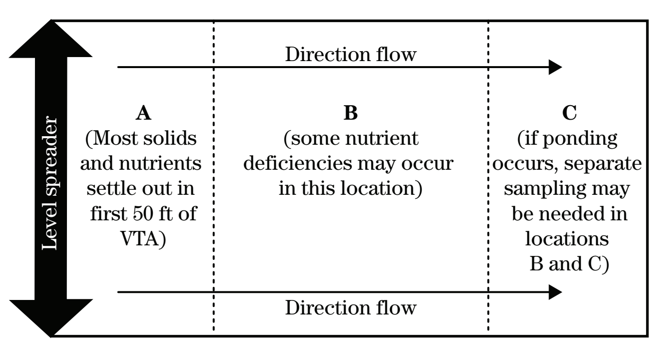

Table 8–1 Possible actions to be taken in response to soil sample test results

Soil sampling test result	Possible action to be taken
Soil P levels	
Low or medium soil test P	Follow land grant university recommendation for fertilizing VTA
High or very high soil test P levels	Is runoff from VTA occurring frequently? If no, continue to monitor frequency of runoff events If yes: • Increase the frequency of soil sampling to once every 2 years • Reduce the nutrient loading rate to the VTA, either by reducing outflow from the solids removal area or by increasing the efficiency of pretreatment solids removal • Over-seed or introduce legumes into the VTA to increase harvest of P from the VTA forage • Treat VTA with P-adsorbing material (iron or aluminum) • Stop use of the VTA until harvesting lowers the soil test
Increasing soil test P levels	Increasing soil test P levels indicate an emerging concern. Follow recommendations for high or very high soil test P levels
Soil nitrate levels	
Low or medium soil nitrate levels	Follow land grant university recommendation for fertilizing VTA
High soil nitrate levels	Increase forage removal by possibly changing harvesting frequency. Check nitrate concentrations of forage Consider alternative grasses or forages that remove greater amounts of nitrogen Consider controlled drainage to modify soil moisture in root zone
Soil potassium levels	
Low or medium soil test K levels	Follow land grant university recommendation for fertilizing VTA
High or very high soil test K levels	If harvested forage is used for livestock feed, monitoring forage K levels, and visit with nutritionist about need for modifying use of forage in diet
Soil micro-nutrient levels	
Low or medium soil test levels.	Follow land grant university recommendation for fertilizing VTA
High or toxic soil test levels	Stop use of VTA if soil analyses show unacceptable levels of heavy metals Other micro-nutrients should be monitored
Soil electrical conductivity	
High soil EC	Irrigate VTA with fresh water Provide drainage to leach away excess salts Divide the VTA into two sections so that one section can be rested except during high intensity or large storms. Resting a VTA section will allow rainfall to move salts out of the root zone

needs. If no guidelines exist, soil sample at least once every 3 years. Deep soil sampling for nitrate nitrogen may be beneficial near the VTA inlets on an annual basis. When samples are taken on subsequent occasions, try to take samples close to the same location each time. This ensures that any differences that show up are a result in the actual nutrient status of the site and not due to a soil difference.

Harvesting a VTA

Another requirement for maintaining a healthy stand of vegetation is periodic mowing and removal of the crop. VTAs and VIBs should be harvested at least once a year so that the nutrients contained in the plant material are removed from the treatment area. Depending on the plant species used in the VTA or VIB, more frequent harvesting may promote a more vigorous stand of vegetation, greater utilization and removal of nutrients, and higher quality feed. Frequent mowing promotes thicker sod and controls weeds.

When harvesting, leave a minimum stubble height of 3 inches to ensure the required stem density and stiffness to maintain sheet flow through the VTA. Some species, particularly warm-season prairie grasses, require a taller stubble height to be left to maintain plant vigor and stand density. For all species, the last harvest in the fall should be early enough to allow sufficient regrowth prior to dormancy for proper functioning during the winter.

Sometimes there are toxic levels of some salts and ions, (NH_4^+) in the runoff from concentrated livestock areas. These can have a major deleterious effect on the vegetation. If this occurs, pre-treat (usually by dilution) the outflow from the solids removal area to reduce toxic levels. The key here is to maintain vigorous crop growth and density to maximize nutrient uptake and disperse overland flow.

In the ideal world, harvest a VTA or VIB when soil moisture conditions will not produce tire tracks or ruts. Tire tracks that are parallel to the direction of runoff flow create channel flow and substantially reduce the effectiveness of a vegetative system. If harvesting equipment or other field traffic presents a risk for creating tire tracks, the equipment should travel perpendicular to the flow of water.

Management of soil moisture in VTA

Soil moisture plays an important role in the functioning of a VTA. Soil water is essential for plant growth and high level of activities by microorganisms. If soil moisture is deficient, the plants and microbes are not functioning to their potential and the benefits of a VTA are not realized. In dry climates, supplemental irrigation may be required to maintain an actively growing VTA. Historic weather data, soil moisture indicators, and visual observations can assist in supplying adequate soil moisture.

Soil moisture content is critical for the transformation of many contaminants that will be passed through the VTA. The nitrification of ammonia occurs when aerobic bacteria have ample soil oxygen to convert the ammonia to nitrate nitrogen. Without oxygen, the saturated soil conditions are conducive to anaerobic bacteria that convert nitrate nitrogen to atmospheric nitrogen gases. In this case, nitrogen is lost from the system and potential greenhouse gases are formed. Saturated soils also can change the availability and solubility of phosphorus. Soil minerals, like iron, tend to release the stable, fixed phosphorous making it more susceptible to translocation by water moving through the soil profile. Saturated soils also promote downward movement of draining water that can cause excess leaching.

Saturated soils compact easily. If machinery or livestock are used to harvest the forage in a VTA, dry, firm soil conditions are required to prevent compaction or rutting. Wheel tracks and hoof traffic can cause disruption in the surface flow down the VTA, concentrating flow and reducing infiltration.

Two management measures should be considered to alleviate saturated soil conditions. First, the surface topography should be smooth and uniform to promote sheet-like flow. This will slow the flow through the VTA, encourage uniform infiltration, and prevent depressions and wet spots. Second, soil profile moisture can be managed with subsurface drainage. Tile drains beneath VTAs must be controlled. Tile drain outlets can become sources of contaminants. Drains must be managed to allow excess soil moisture to be removed from the soil profile, but not allow for a conduit of leached nutrients, salts, and pathogens. Installing tiles at the appropriate depth and location will off set some of these risks. Being able to regulate flow (drain during rainy season, closed during dry season) will promote plant root growth and crop uptake, plus provide favorable conditions for soil biology. Effluent can be discharged into a vegetated area or routed back into the VTA. Drainage water should be monitored for elevated levels of contaminants. Local NRCS resources should be used in determining appropriate local use of subsurface drainage.

Weed and brush control

Weeds, brush, and other pests should be controlled in the VTA to ensure proper functioning. Periodic mowing, at least frequent enough to prevent seed formation, is an effective weed control measure. Harvesting the VTA forage on a prescribed schedule will usually control weeds. Herbicides are another alternative for controlling weeds. Precautions are needed in selecting the proper registered products, applying proper rates, and being knowledgeable of grazing and forage harvest restrictions. A healthy stand of vegetation, absent of any bare spots, will prevent weed encroachment. All bare spots should be reseeded.

Grazing is not commonly recommended for harvesting of VTA vegetation. Grazing removes very few nutrients from a VTA and is not a good alternative to mechanical harvesting of forage. However, occasional grazing can assist with weed control. Grazing needs to be controlled, both in timing and extent. Livestock should not be allowed when soils in the VTA are moisture saturated. Footprints can compact the soil surface and reduce infiltration. Foot traffic can also damage crowns and roots of vegetation. Care should be taken to remove cattle when proper grazing height of vegetation is reached.

Environmental management

The nutrients nitrogen and phosphorus represent a primary environmental risk associated with open lot runoff. Nitrogen in a nitrate form represents a risk to ground water and possibly drinking water supply. Nitrogen in an ammonium form can be toxic to aquatic life, contributing to fish kills. Both phosphorus and nitrogen can contribute to eutrophication (algae blooms and large swings in dissolved oxygen levels) of surface waters. Pathogens in animal manures can produce a human health risk for recreational and drinking water uses of our water resources. Management strategies designed to limit these risks and monitoring programs to document proper management implementation are essential for a VTS.

Soil sampling for environmental protection

The second soil sampling purpose is to monitor environmental performance of the VTA. There are two separate concerns: nitrogen leaching below the root zone and phosphorus accumulation. *Monitoring for increasing soil phosphorus will provide a forewarning of water quality problems originating from the VTA, enabling proactive instead of reactive management changes.*

If the nitrogen entering the VTS exceeds vegetation removal, the excess nitrogen that is converted to nitrate can move beyond the root zone under saturated soil conditions. Rainfall on the VTA and runoff from the open lot creates the opportunity for leaching nitrate past the root zone. Since plants can no longer use nitrate leached beyond the root zone, it will eventually reach tile lines or ground water.

For environmental protection, a deep sampling regime can provide a snapshot of root zone nitrate levels and the potential for future movement. Samples should be taken within the root zone and analyzed for nitrate-nitrogen content. Most of the plants that are suitable for the VTA have the majority of their roots in the top 36 inches, so the soil samples should be taken below the surface in 1-foot intervals.

For additional information on nitrogen management within a VTA, forage nitrate monitoring may provide some insights about potential excess nitrate levels in the VTA. Check with your land grant university as to the availability of recommendations for forage nitrate levels that may suggest excess soil nitrate levels. *Forage nitrate should be measured for any harvested* *material that will be fed to livestock, especially ruminants, because high nitrates can be toxic.*

Soil sampling for assessing environmental risk associated with phosphorus can be measured with surface soil samples described previously for managing a vegetative system for optimum growth. As phosphorus enters the soil, it readily precipitates out of solution and it is readily adsorbed as calcium, iron, and aluminum phosphates. It typically accumulates near the surface of the soil. If the amount removed by harvesting vegetation is less than the amount entering the VTA or VIB, the soil exchange matrix can eventually become saturated.

Excess soil phosphorus levels can have two effects. High phosphorus levels will commonly remain near the soil surface of fine textured soils such as silt loam or silty clay loam soils (higher adsorption capacity). Excess phosphorus in course textured soils, like sands and loamy sands lack adsorption capacity and allow phosphorus to migrate further into the soil profile. Excess phosphorus accumulation in the top 2 inches of soil will desorb as dissolved phosphorus when runoff water passes over these soils and transport phosphorus off site with soil erosion. Movement of phosphorus with soil erosion should not be a significant concern for well-maintained VTAs. A standard soil sample used for optimum growth (0–8-in sample) can provide an indication of potential environmental risk due to excess phosphorus. An occasional separate soil sample of the top 2 inches of soil layer analyzed for available phosphorus will detect stratification of phosphorus in the soil surface.

Course textured sandy loam or loamy sand soils (lower adsorption capacity) tend to become saturated with phosphorus more quickly allowing phosphorus movement deeper into the soil profile. This is unlikely to become an environmental concern unless the VTA is located over a shallow water table or subsurface drainage. Previously described 0- to 8-inch and 0- to 36-inch soil samples should be valuable for reviewing this risk.

If soil phosphorus test levels become excessive, the need for changes in management depends on the amount of runoff water (and associated dissolved phosphorus) exiting a VTA. A properly designed and managed VTA may rarely experience runoff with the exception of the most intense storms. Thus higher soil phosphorus levels will have little impact on surface water quality. Poor design or management may produce greater runoff and require greater attention to a need for modifying management with increasing soil phosphorus levels.

If VTA runoff is common and soil test levels reach a high or very high range for crop production, some management techniques need to be implemented (table 8–1). These can include harvest and removal of vegetation biomass, better management of solids in sediment basin, or removal and mixing of topsoil layers in the VTA. If soil test analysis shows soil test levels are extremely elevated (three times the high soil test level) the soils become a source of runoff and remedial management is necessary including end of the VTA use.

Sheet flow maintenance

For VTAs to provide maximum water quality protection, the overland flow should be as uniformly distributed as possible across the treatment area. Uniform flow minimizes localized areas of higher flow velocity and encourages greater particulate removal. In addition, since a portion of the runoff entering the VTA will infiltrate, maximizing uniform flow will allow for a greater portion of the VTA to contribute to the infiltration of runoff. Concentrated flow within the VTA reduces infiltration. A thorough discussion of options for encouraging sheet flow is reviewed in section 6 on VTA design. The literature review in section 9 summarizes the research experiences detailing the critical importance for maintaining sheet flow.

Sheet flow is not an issue with a VIB. VIBs are designed to pond water resulting from runoff from most storms. A flat or very low slope is important to creating a uniform depth of liquid within a VIB. However, other issues discussed below are relevant only to a VTA.

Inlets from the solids removal component to the VTA may require annual re-leveling to ensure initial even distribution of feedlot runoff to the VTA. Irrigation pipe distribution systems may need to be repositioned on the contour and pipe gates adjusted. Flow rates from irrigation pipe gates should be adjusted to encourage full pipe flow during most runoff events. Achievement of this goal should be checked seasonally. For concrete structures with weir plates for controlling flow, the elevation of all weir plates should be checked and matched on a periodic basis. The gravel and rock structures used to redistribute flow at the upper end of a VTA should be re-leveled and structural integrity checked. Piped outlets from the settling basin should be adjustable and periodically matched for a consistent elevation. Most distribution systems will require screening of debris to prevent plugging of outlets. Debris screens and other points of potential debris accumulation should be checked after each significant rainfall event.

Overland flow always tends to converge as it flows through the VTA. Spreaders should be installed at regular intervals and other VTA design features included as discussed in section 6 to redistribute any concentrated flow within the VTA. Maintaining reasonably uniform flow through the length of a VTA will require regular VTA inspection and

- Maintenance of in-field spreaders
- Removal of solids accumulation near runoff inlets to a VTA
- Repair to areas of erosion or wheel tracks
- Reestablishment of vegetation in areas where it has been killed
- Repair of eroded areas in berms

Any equipment operations (mowing, baling) that take place in the VTA should be done when soil conditions are such that tracks or ruts, which can disrupt sheet flow, are not formed. Grazing should be avoided, as livestock hoof action can disrupt sheet flow.

Passive versus active management of liquid release

The risk of a discharge from a VTA is significantly greater if feedlot runoff enters the VTA simultaneously with rainfall directly falling on the VTA. The infiltration rate of the soil can be overwhelmed with the two simultaneous sources of water. Delay release of runoff liquids until after the storm or limit the release of runoff during the storm to reduce the potential of a discharge of feedlot runoff with pollutants from the feedlot. Three primary options for managing the release of liquids from a solids removal component to the vegetative component are possible. The latter two are designed to minimize the potential for a discharge from the vegetative component.

- *Unrestricted runoff release*—The outlet of the settling basin is not restricted, possibly because of limited or no storage capacity in the solids settling component. Runoff release is designed to match the peak flow rate of liquids into the settling basin when the basin is nearly full.
- *Active settling basin liquid release*—The outlet of the settling basin can be physically controlled. The manager determines the best timing for the release of basin liquids, presumably when the VTA soil conditions are most appropriate. This approach requires that the settling basin has sufficient capacity to handle a 25-year, 24-hour storm, as well as some additional capacity for normal runoff for some possible storage period (a few days to possibly months). The resulting settling basin volume is very similar to that of a standard holding pond. Its frequency of discharging will be essentially no different from the conventional basin and irrigation system. Many advantages of a VTA system including reduced cost, modest storage, and less risk of management errors are no longer realized with a system based upon active settling basin liquid release. However, the risk of a release from the VTA has been significantly reduced.
- *Passive settling basin liquid release*—The outlet of the settling basin can be controlled to deliver liquid slowly over a 36- to 72-hour period. The settling basin will need to be sized to handle a 25-year, 24-hour storm. Additional volume to store normal rainfall runoff would not be necessary since liquids would be released over a short period of time (<72 h). A passive system also does not rely upon the observation and decision making of a manager thus reducing potential problems due to infrequent inspections or poor management. Common advantages of a VTA system including reduced cost and modest storage will not be realized with a passive settling basin liquid release. However, as with active release systems, the risk of a release is substantially reduced. Design information for controlling liquid release from passive systems is presented in section 5.

Active versus passive management of flow from a solids settling component to a VTA is described in section 5.

Solids harvesting

Manure and other solids in the system must be managed to ensure the proper function of the treatment components. Solids should be harvested from earthen lots at least once after each pen of cattle is marketed (approximately twice a year) and every 180 days for dairy. More frequent solids removal will have value for animal management and odor and dust control and may have some value to reducing solids in runoff.

The maximum solids volume in a settling basin should be clearly identified (marked on a level gage) and solids should be removed in advance of solids accumulation to that point. As a minimum, the solids settling basin should be cleaned out once a year. The solids should be removed frequently from settling benches and siltation fences to maintain their effectiveness, possibly after each major runoff event.

Proper feedlot surface maintenance and solids settling should prevent the buildup of solids in a VTA. If solids begin to accumulate in a VTA, they can damage forage and contribute to channel flow. If solids accumulation within the VTA is observed, first attempt to reduce this problem with improved management of the feedlot surface and settling basin. If solids remain a concern in the VTA, a light tillage operation should redistribute the solids while allowing some grass to survive. If solids accumulation is a severe problem, a more aggressive tillage operation may be necessary followed by replanting of grass.

Vegetation inspection

The health and vigor of vegetation within a VTA or VIB should be checked regularly for potential developing problems. Some common concerns that can be monitored visually include:

- Indications of fertility deficiencies as identified by crop color
- Indications of ponding or solids accumulation causing loss or thinning of forage
- Indications of undesirable plant species
- Indications of high areas where infiltration is not occurring (plants may show signs of low fertility or drought)
- Indications of burrowing animals that would bypass infiltration role of soils

Form 3 of appendix F provides a sample inspection form for inspecting vegetation within a plant treatment system.

Standard operating procedures

When created for a specific, clear reason, written operating procedures save time and reduce the chances of mistakes. These procedures are generally referred to as a standard operating procedure (SOP). For some operation and maintenance, a written procedure may be advantageous if one or more of the following applies:

- The NPDES permit targets specific management expectations.
- The procedure is a condition of an environmental permit compliance.
- The procedure is difficult to commit to memory or is not done frequently enough to commit to memory.
- More than one person will be doing the procedure, and/or it must be done the same way each time.
- There could be serious environmental or safety consequences if the procedure is done incorrectly.
- In the manager's absence, someone else may need to do the procedure (vacations).
- New employees are regularly asked to complete a procedure.

A good SOP is written in simple language (including those languages native to all employees) that everyone can understand, includes all the steps involved in the procedure (even simple or obvious steps should be included, especially if they could have environmental consequences if skipped), is signed and dated, is reviewed, and is revised as needed by the responsible person.

Some key topics to be addressed by SOP for a vegetated treatment system include:

- VTA or VIB soil sampling procedure
- Solids removal from settling basin or other solids collection structure
- Runoff sampling procedures
- Forage harvesting procedures
- Liquid release from solids settling basin or storage (if release is actively controlled)
- Visual inspections for discharges following rainfall events
- Visual inspection of VTS components

- Mass nitrogen and phosphorus balance calculations on a VTA or VIB
- Other management procedures specifically identified within the NPDES permit

Records for monitoring performance

Sample records for VTA systems are provided in appendix F. A discussion of key issues to be addressed by these records follows.

CAFO regulation compliance

The NPDES permit issued to an individual CAFO will define the specific record keeping requirements and should be the final reference for establishing a recordkeeping and reporting program. Table 8–2 summarizes the three primary principles that should be addressed by a recordkeeping program for a conventional and a VTA system. State permitting authorities have the option of expanding the record and reporting requirements beyond those discussed in this section.

Of primary concern are the records and reporting requirements associated with a discharge event. Conventional runoff control systems must demonstrate their ability to limit surface water discharges resulting from a 25-year, 24-hour storm event or less. Larger storm events and possibly chronic (extended) wet periods can produce allowable discharges only if records demonstrate the quantity and timing of rainfall events and proper management of the manure management system prior to and during such events. Records commonly used to document attainment of this objective by a CAFO using a conventional system are summarized in table 8–2.

Alternative technologies such as a VTA system must perform at least as well as the conventional technology. Records will be necessary to verify the same precipitation and management related information. Table 8–2 summarizes a suggested set of records for documenting proper management of a VTA. Suggested records to document a VTA performance are included in appendix F for VTAs.

Releases of water from VTA **must** be observed, sampled, and reported to the permitting authority. To determine when a release occurs, a small reception basin with a spillway should be constructed at the outlet of the last component of the VTS. This small reception basin should be designed to provide a visual means of identifying when a discharge has occurred and a location for collecting a representative sample for later analysis of solids, nutrients, and fecal coliform concentration. An open livestock watering tank buried at ground level at the outlet may serve this purpose.

Table 8–2 Record expectations for a CAFO using a conventional or VTA system. *Suggested records for non-CAFOs are italicized.* [1]

Performance monitoring principle	Recommended records (reports) for a conventional system	Recommended records (reports) for a VTA system (see app. F for sample records)
1) What are the precipitation events that lead to the discharge? If a single storm event or a chronic rainfall period greater than the 25-year, 24-hour storm is the cause of a discharge, then the permitting authority will likely consider such a discharge as an acceptable discharge	– Daily onsite precipitation records	– Daily onsite precipitation records
2) Was good management practiced prior to a discharge? Producers must document key indicators of good (or poor) management	– Animal inventory – Pond liquid level – Pumping start and stop time and dates – Amount pumped – Daily visual inspections of water lines – Runoff effluent nutrient analysis – Weekly inspections of storm water collection/diversion components, runoff storage components, and pond depth readings	– Animal inventory – VTA inspection and maintenance for uniform flow – Crop harvest date and yield – Timing of solids harvest from solids settling system – Daily visual inspections of water lines – Runoff effluent nutrient analysis – Weekly inspections of storm water collection/diversion components – If a settling basin includes storage, follow recommendations for conventional system – VTA and VIB soil samples
3) When does a discharge occur? Any discharge from the runoff holding pond (or last stage of the VTA system) must be reported to the permitting authority within 24 hours by phone and 7 days by written report	– Livestock manure or related process water discharge report (Form 1 or equivalent) – Lab sample report on concentration of solids, nutrients, pH, and fecal coliform in discharge	– Discharge from VTA occurring as feedlot runoff is being applied to VTA (Form 1 or equivalent) [2] – Lab sample report on concentration of solids, nutrients, pH, and fecal coliform in discharge [2]

[1] State permitting authorities may add additional requirements to the NPDES program for individual states. The CAFO's NPDES permit will define the specific record and reporting requirements with which the CAFO must comply.

[2] Individual permitting authorities will define which releases of runoff from a VTA will qualify as a discharge and require reporting within 24 hours. Ask the permitting authority for this information. The producer also is encouraged to collect and analyze samples from releases from a VTA and create a history as to what releases are primarily clean water and what release contain feedlot runoff.

Example

Standard Operating Procedure (SOP) for
Sampling Open Lot Runoff Nutrient Concentration

Developed by: John Q Owner Revised by:

Date: September 1, 2004 Date Revised:

Filing Location: Clear Creek Feedlot business office

Posting Location: SOP manuals in feedlot office, employee break room, and all feedlot pickups

Purpose: Procedure ensures that runoff is regularly and accurately sampled for concentration of nutrients, solids, and potential contaminants.

Steps

1. Take samples in June and October.
2. Get rubber gloves, dipping can (coffee can on 8 ft pole), and a clean 5-gallon sampling bucket from the scale shed. Put the gloves on.
3. Collect 10 surface samples from perimeter of solids settling basin immediately following a rainfall event of 0.5 or more inches. Pour samples into 5-gallon bucket.
4. Stir the 5-gallon bucket sample in the bucket. Continue to stir until all the sample is mixed completely.
5. Get a clean quart plastic bottle from scale house. Fill the jar leaving 1-inch empty headspace.
6. Add lid and seal lid to jar with electrical tape.
7. Add a large mailing label to the jar. Record the farm name, your initials, and the date on the mailing label using a permanent marker.
8. Empty the remaining runoff from the bucket into settling basin.
9. Dispose of the gloves in the trash can and wash/disinfect hands thoroughly.
10. Take the sample to the office manager for immediate freezing or refrigeration.

Farm Personnel Training Needs

Employee	Training Topic	Date Completed	Dates Update
John Q. Owner	Sampling SOP and mailing to lab	Sept. 1, 2003	
Mary Rider	Sampling SOP	Sept. 4, 2003	9/04
Jim Crewchief	Sampling SOP	Sept. 4, 2003	
Chris Office	Mailing sample to lab	Sept. 10, 2003	

Standard Operating Procedure (SOP) for

____

Developed by: __________________________ Revised by: _________________________________

Date: ________________________________ Date Revised:______________________________

Filing Location: ____

Posting Location: ______

Purpose: ____

____

____

Steps:

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Farm Personnel Training Needs

Employee	**Training Topic**	**Date Completed**	**Dates Update**

Individual permitting authorities will define which releases of runoff from a VTA will qualify as a discharge and require reporting within 24 hours. **Ask the permitting authority for clarification on reportable discharges.** The producer also is encouraged to collect and analyze samples from releases from a VTA and create a history as to which releases are primarily clean water and which releases contain feedlot runoff. The presence of ammonium, volatile solids, or salts may provide some indication of presence or absence of feedlot runoff in the sample. A comparison sample from a field receiving no manure or feedlot runoff would be helpful in identifying if significant runoff pollutants from the feedlot are escaping the VTA.

Many of these records are essential for proper management of a VTA for all sizes of AFOs (not specifically CAFOs). Regular inspections and records for the VTA site and related components are essential for ensuring proper nutrient management and distributed flow of runoff over the VTA. Records detailing liquid levels in the settling basin and precipitation are essential for avoiding classification of an animal-feeding operation as a CAFO as a result of a discharge.

Ground water protection

Some states may regulate performance of animal production systems relative to their impact on ground water. For VTA systems, excess nitrogen application creates the potential for leaching of nitrate below a crop's root zone and is the primary opportunity for impact on ground water by a VTA. This issue is likely to be of greatest concern in the first 50 feet of a VTA. Possible indicators of ground water risk might include:

- End of growing season deep soil nitrate testing (24 to 36 in). This is only a fair measure because larger rainfall event can flush nitrate beyond sampling depth
- Crop nitrate levels
- Crop nitrogen removal (only estimates removal of nitrogen, not nitrogen additions to field):

$$\text{N removal (lb)} = \frac{\text{Tons of harvested crop} \times \%\text{ crop protein} \times 20}{6.25}$$

Records to document at least one of these three indicators of nitrogen utilization by the cropping system (and minimal nitrate leaching) are recommended for situations were ground water contamination is regulated or a priority neighborhood or regional issue.

Vegetation management

Table 8–2 contains a suggested set of records to document efforts to maintain a well-performing vegetation system.

Example:

In section 6, sizing calculations for a 2,000 head feedlot suggested the need for a VTA between 8 and 14 acres based upon the assumptions made the design phase. A 12-acre VTA was installed. In 2004, 4.5 tons per acre of tall fescue was harvested with an average protein content of 12.5 percent. Check the nitrogen balance for the VTA.

$$\text{N removal (lb)} = \frac{4.5\ \text{ton/a} \times 12\ \text{a} \times 0.125 \times 2{,}000\ \text{lb/ton}}{6.25} = 2{,}200\ \text{lbN/a}$$

Discussion: This value compares favorably with the two estimates of nitrogen in feedlot runoff in section 6 (1,600 and 2,800 lb N/yr) and the literature value from section 9 (table 9–4) of 0.68 lb N in runoff per finished animal (2,700 lb total N/yr, about half of which is crop available). Because of challenges with uniform distribution of nitrogen, deep soil sampling should be initiated near the runoff inlet into the VTA.

Record	Headlands (50 ft after effluent inlet)	Remainder of VTA
Soil nutrient profile		
Shallow (top 2 in) soil sample for P and pH	X	X[1]
• Plow layer sample for soil organic matter P, K, EC, and pH	X	X[1]
• Deep soil sample for nitrates (top 3 ft)	X	X[1, 2]
Crop production		
• Harvest timing and conditions	For entire VTA	
• Quantity of forage harvested	For entire VTA	
• Forage protein	For entire VTA	
• Forage nitrate	X	X
• Forage potassium (animal health)	For entire VTA	
• Pesticide application timing, rate, and product	For entire VTA	

1 Remainder of VTA may be divided into one or more zones.
2 Risk will be greatest in upper end of VTA. Sampling may not be warranted until headlands nitrate-nitrogen levels are observed to be high.

Section 9 Literature Review

Section 9 Literature Review

Contents

Introduction **9–2**

Feedlot runoff characteristics **9–3**

Runoff quality 9–3
Runoff quantity 9–4
Pollutant mass in runoff 9–5

VTS performance **9–9**

Performance models for VTS 9–9
Solids removal performance 9–10
VTA performance 9–11
Vegetative infiltration basin 9–27
Overall VTS performance 9–28

VTA maintenance **9–29**

References **9–30**

Tables

Table 9–1	Runoff holding pond effluent characteristics	9–3
Table 9–2	Average runoff characteristics from beef cattle feed yards in the Great Plains	9–4
Table 9–3	Unpaved beef cattle feedlot runoff characteristics	9–4
Table 9–4	Mass of solids and nutrients in runoff from beef cattle feedlot pens	9–6
Table 9–5	Performance of runoff control facility sized to hold runoff from an unsurfaced feedlot for a 25-yr, 24-h precipitation event as evaluated over a 30-yr period	9–7
Table 9–6	Performance of runoff control facility sized to hold runoff from an unsurfaced feedlot designed based upon Iowa Department of Natural Resource criteria and evaluated over a 50-yr period	9–8

Table 9–7	Relative size of runoff holding pond and land application system capable of pumping 2,850 L/min or 750 gpm during all seasons. Holding pond is sized to avoid all discharge based upon 25 years of weather data	9–8
Table 9–8	Summary of VTA performance when placed on commercial or research livestock facilities	9–12
Table 9–9	Summary of VTA performance under simulated conditions	9–16
Table 9–10	Summary of performance observations for VTA for past research and field demonstration projects	9–20
Table 9–11	Summary of contaminant concentration reductions	9–28
Table 9–12	Summary of design and management recommendations for VTA for past research and field demonstration projects	9–36

Figures

Figure 9–1	Precipitation-runoff relationships for beef cattle feed yards at seven locations in the Great Plains	9–5
Figure 9–2	Effectiveness of adding storage capacity to containment basin	9–8
Figure 9–3	Effect of VTA length on TKN and ammonia N reduction	9–26
Figure 9–4	Nutrient removal by VTA based upon VTA to feedlot drainage area (DA) ratio for references listed in tables 9–9 and 9–10	9–27

Section 9 Literature Review

Literature review summary

Runoff from open lot livestock systems (beef and dairy) defined as CAFOs must be controlled by systems designed and managed to prevent the release of manure contaminated runoff for storms equal to or less than a 25-year, 24-hour design storm. This performance standard has been attained for open lot systems with some combination of clean water diversion, settling basins, runoff collection ponds, and irrigation systems (baseline system).

An alternative approach is to rely on overland flow and infiltration into cropland with perennial forage or grasses for treatment of open lot runoff. Such vegetative systems have been researched since the late 1960s. This paper reviews the research literature on VTSs for managing open lot runoff summarizing available science on system performance, design, and management.

Based upon this review of literature, the following conclusions are drawn about the application of VTS to manage runoff from open lot livestock production systems.

- Substantial research (approximately 40 identified field trials and plot studies) provides a basis for understanding the performance of VTS. A superior research knowledge base exists for performance of VTS as compared to baseline systems for CAFO regulation compliance.
- The baseline systems for CAFO regulation compliance perform well in the High Plains regions of the United States where significant moisture deficits exist (rainfall minus evaporation). However, the performance of these baseline technologies drops substantially for decreasing moisture deficits found in the central and eastern Corn Belt states. These trends have been established through computer modeling processes but not confirmed with in-field performance measurements.
- The existing research targeting VTS is confined to non-CAFO applications, likely due to past regulatory limits. Unique challenges exist in adapting these results and recommendations to CAFO applications.
- The pollutant reduction resulting from a VTS is based upon two primary mechanisms: sedimentation, typically occurring within the first few meters of a VTS and infiltration of runoff into the soil profile. Systems relying primarily on sedimentation only are unlikely to perform equal or better than baseline technologies. System design based upon sedimentation and infiltration is necessary to achieve a required performance level for CAFO application.

Introduction

The terms Vegetative Treatment System (VTS) and Vegetative Treatment Area (VTA) are used. VTA applies to a cropped area with perennial grass or forage specifically designed to manage runoff from an open lot livestock facility. VTS refers to the combination of treatment components including a VTA or Vegetative Infiltration Basin (VIB) and other possible treatment components (solids settling).

Runoff from open lot livestock production systems continues to be a contributor to surface water impairment. This literature review summarizes past research on VTSs when applied to open lot systems. This alternative technology may potentially achieve the same pollution control that is achieved by current EPA NPDES technology-based standard. A VTS has the potential for providing control of pollution from feedlot runoff that is functionally equivalent to the conventional impoundment and land application system for CAFO. The 2003 final Federal rule for the NPDES Permit Regulation and ELG and Standards for CAFOs (Federal Register 2003) states that for large CAFOs with dairy cows or beef cattle:

> *"(a) there must be no discharge of process wastewater pollutants into waters of the U.S. from the production area.*
>
> *(1) Whenever precipitation causes an overflow of manure, litter, or process wastewater, pollutants in the overflow may be discharged into U.S. waters provided:*
>
> *a) The production area is designed, constructed, operated and maintained to contain all manure, litter, and wastewater including runoff and the direct precipitation from a 25-year, 24-hour rainfall event;*
>
> *b) The production area is operated in accordance with the additional measures and required by 412.37 (a) and (b) (note: defines management and record keeping expectations).*
>
> *(2) Voluntary alternative performance standards. Many CAFO subject to this Subpart may request the Director to establish NPDES permit effluent limitations based upon site-specific alternative technologies that achieve a quantity of pollutants discharged from the production area equal to or less than the quantity of pollutants that would be discharged under the standards as provided by paragraph (a)(1)…"*

Part (1) sets the 25-year, 24-hour storm technology standard for baseline systems (runoff holding facilities dewatered by irrigation systems). Part (2) opens the door for alternative technology (such as a VTS) if they can be proven to achieve equal or less discharge of pollutants than the baseline technology (runoff holding pond plus irrigation). The site-specific comparison provision will place the burden of proof on the individual producer for comparing the baseline and alternative technology for individual farms.

Feedlot runoff characteristics

Most research defining the characteristics of runoff from open livestock systems was completed in the 1960s through the 1980s. Based upon this, research common characteristics have been published in accepted references from NRCS (table 9–1), Texas Agricultural Extension Service (table 9–2), and Experiment Stations of the North Central Regions land grant universities (table 9–3). Original data for many of these reported values is from Linderman and Mielke (1975); Gilbertson et al. (1979); Swanson et al. (1971); Gilbertson and Nienaber (1973); Gilbertson et al. (1975); and Gilbertson et al. (1972).

Runoff quality

Some generalizations about characteristics of feedlot runoff can be based upon this previously cited research:

- The solids fraction is roughly 10 times greater in runoff from snowmelt as compared to runoff from rainfall (table 9–3). Fields (1971) reported 2 to 2.5 times higher solids in snowmelt runoff as compared to rainfall runoff.
- Volatile solids (VS) typically represent about 50 percent or less of total solids in runoff.
- Approximately 40 to 80 percent of solids in runoff will settle in settling basins designed with 30 minutes or greater retention capacity.
- Increasing rainfall intensity leads to higher solids loss from the feedlot surface and greater VS or chemical oxygen demand (COD) concentration. Rainfall duration does not affect solids content of runoff.
- Ammonium and nitrate contents in the runoff decrease with continuing precipitation, indicating rapid leaching of these compounds from the feedlot surface.
- Phosphorus removal is closely related to solids removal and directly affected by rainfall intensity.
- Salt concentrations are the primary constituent of concern for crop performance that should be reviewed when runoff is used in land application.

Table 9–1 Runoff holding pond effluent characteristics (Soil Conservation Service 1992)

Component	Units	Runoff pond supernatant	Sludge
Total solids	% w.b.	0.30	17.20
Volatile solids	kg/1,000 L	0.899	77.3
Fixed solids	kg/1,000 L	2.10	94.4
COD	kg/1,000 L	1.40	77.2
Nitrogen	kg/1,000 L	0.20	6.19
Ammonium-N	kg/1,000 L	0.18	–
Phosphorus	kg/1,000 L	–	2.10
Potassium	kg/1,000 L	0.90	1.70

	Nitrogen content (kg N/1,000 L) of feedlot runoff at holding pond for:		
Annual rainfall	**Below average conditions**	**Average conditions**	**Above average conditions**
<64 cm	1.6	0.49	0.26
64–89 cm	0.26	0.13	0.066
>89 cm	0.066	0.044	0.022

Below average: No settling facilities between the feedlot and pond. Feedlot topography and other characteristics are conducive to high solids transport. High cattle density—more than 620 head/ha (250 head/a).

Average: Sediment traps, low-gradient channels, or natural conditions remove appreciable amounts of solids from runoff. Average runoff and solids transport characteristics. Average cattle density—310 to 620 head/ha (125–250 head/a).

Above average: Highly effective solid removal, such as vegetated filter strips or settling basins that drain liquid waste through a pipe to storage pond. Low cattle density—less than 310 head/ha (125 head/a).

Table 9–2 Average runoff characteristics from beef cattle feed yards in the Great Plains (Sweeten 1991)

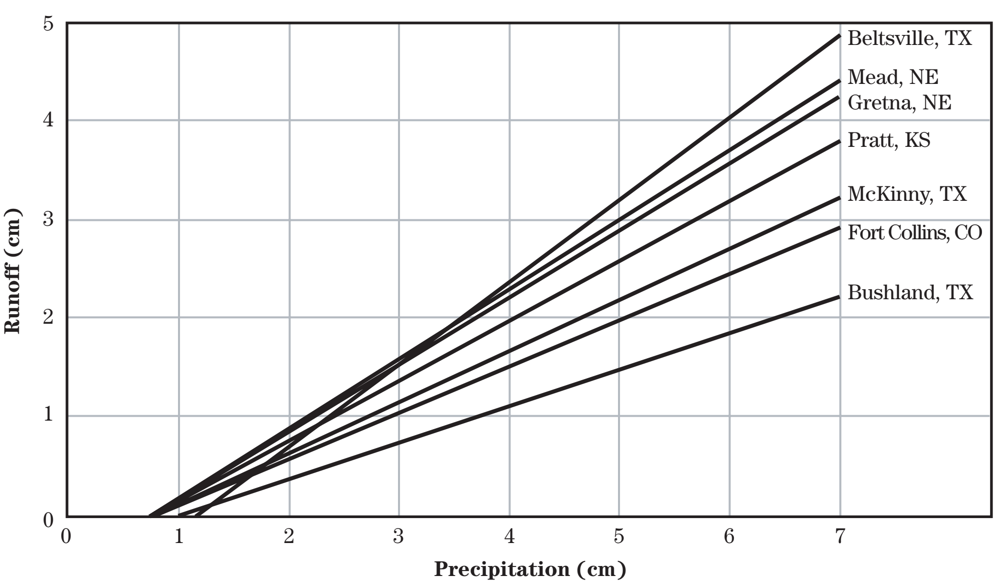
Source	Total solids (ppm)	Electrical conductivity (mmho/cm)	Chemical oxygen demand (ppm)	Total nitrogen (ppm)	Total phosphorus (ppm)	Sodium (ppm)	Potassium (ppm)
Feedlot runoff[1]							
Average	11,200	6,500	9,200	580	120	440	1,020
Range	3,000–17,500	3,200–8,600	2,200–17,800	80–1,080	50–300	230–590	340–1,320
Pond effluent							
South Texas	2,500	4,500	1,100	180	—	230	1,140
Texas High Plains	—	4,500	620	140	40	260	450

[1] Seven feed yards in TX, CO, NE, KS, and SD

Table 9–3 Unpaved beef cattle feedlot runoff characteristics (Gilbertson et al. 1981)

Source	Total solids (%)	Volatile solids (%)	Chemical oxygen demand (ppm)	TKN (ppm)	Total phosphorus (ppm)	Electrical conductivity (mmho/cm)
Nebraska						
Rainfall	0.24–3.3	0.12–1.5	1,300–8,200	11–8,593	4–5,200	—
Snowmelt	0.8–21.8	0.6 –14.3	14,000–71,000	190–6,528	5–917	3–19
Texas	0.5–1.5	0.9 –1.4	10,000–20,000	660–1,100	130–200	6–10
Kansas	0.8–1.9	0.36–0.96	800–16,000	165–1,580	9–242	2–13

Figure 9–1 Precipitation-runoff relationships for beef cattle feedyards at seven locations in the Great Plains (Clarke et al. 1975)



Runoff quantity

Maps for estimating design storm and average monthly runoff volumes are available from chapter 10 of the Agricultural Waste Management Field Handbook (Soil Conservation Service 1992). Some common observations relative to volume of runoff from open lots include the following:

- A linear relationship exists between runoff volume and rainfall (fig. 9–1). A rainfall event greater than 1 centimeter is necessary for runoff to occur. An average prediction equation was suggested by Clarke et al. (1975):

Runoff (cm) = 0.56 x Precipitation (cm) – 0.84

- A greater slope for the prediction equation should be used in regions with lower moisture deficit (rainfall – evaporation). This would suggest that higher rainfall regions should expect greater runoff volumes for the same size storm, a factor that is not included in current predictive equations (Clarke et al. 1975).
- Feed yard slope and stocking rates have little influence on runoff amounts (Gilbertson et al. 1970 and Clark et al. 1975).
- Lots that are wet the previous day have less runoff than dry lots due to depressions created by animal activity creating more opportunity for water retention on wet lots (Clarke et al. 1975).

The volume of runoff from a feedlot for a given storm is commonly estimated using the NRCS Curve Number method. This method is described in the NRCS National Engineering Handbook, part 630 (Monkus 1964). For the purpose of estimating the volume of storm runoff from a feedlot, the following equation is solved for Q:

$$Q = \frac{\left(P - 0.2\left(\frac{1000}{CN_1}\right) - 10\right)^2}{\left(P + 0.8\left(\left(\frac{1000}{CN_1}\right) - 10\right)\right)}$$

where:
Q = volume of runoff (in)
P = rainfall (in)
CN_1 = NRCS 1-d curve number

A CN_1 of 89 or 90 is commonly used for an unpaved feedlot, and a CN_1 of 97 or 98 is commonly used for a paved feedlot.

Pollutant mass in runoff

In addition to knowledge of volume and concentration, total mass of nutrient and solids in runoff can be useful in design of settling basins and land application sites. Nutrient mass balance data has been collected on a set of University of Nebraska research beef cattle feedlot pens over approximately a 5-year period (Erickson and Kissinger 2004) representing 120 separate pens of cattle over the entire finishing period. This data would suggest that runoff after settling will contain 27 kg total solids, 0.68 kg nitrogen and 0.32 kg phosphorus per finished animal (table 9–4). (Settling basins were designed to hold all runoff until after a storm event for the purpose of measurement of volume and collection of sample before release to a holding pond.)

Table 9–4 Mass of solids and nutrients in runoff from beef cattle feedlot pens (Erickson and Kissinger 2004)

	Volume (L/finished animal)	Nitrogen	Phosphorus	Volatile solids	Total solids
		- - - - (kg/finished animal) - - - -			
Runoff	3,600	0.68	0.32	13	27
Standard deviation	2,800	0.63	0.31	13	37
Estimated total excretion		25	3.3	290	360
% of excretion in runoff		2.7	9.8	4.6	7.6
Number of individual trials[1]	120	112	48	80	64

[1] One trial represents one pen of cattle entering the pen as calves or yearlings and fed to market weight. Feedlot is typically stocked at 30 m^2 per animal with an average slope of 6%..

Performance of runoff collection ponds

Since runoff from open lots is weather dependent, most in-field monitoring efforts are challenged to collect data over a sufficient time period to accurately predict the long-term performance of control technologies. The only efforts to predict runoff holding pond performance identified in the literature were based upon performance models. No field studies were identified that provided field measurements of performance for runoff holding ponds based upon a 25-year, 24-hour storm event design criteria or other related criteria. It would appear that once the EPA established their technology based ELG, no efforts have been made to document in-field performance of these design criteria.

Planning software titled Animal Waste Management (AWM) is maintained by NRCS and commonly used for sizing of manure storage and runoff holding ponds (Wilson et al. 2003). An evaluation of the storage sized by AWM was compared against a water-balance model for storages using 30 years of weather data for 10 United States sites (Moffitt et al. 2003). The comparison revealed that 0 to 73 percent of the 30 years produced events requiring land application at shorter intervals than the design critical storage to maintain an acceptable storage volume for a 25-year, 24-hour storm. If pump down during these periods did not occur, spillway flow would result during 0 to 40 percent of the modeled years. Management decisions during these periods when storage capacity was inadequate and sizing of the de-watering pump were two critical factors minimizing spillway flow.

A computer model developed by Kansas State University (Koelliker et al. 1975) predicts the portion of runoff controlled by a conventional runoff holding pond and irrigation system (sized to pump 10 percent of the holding pond volume per day). This model was used to evaluate a basin system for five Kansas sites and predicted that such systems perform better in more arid climates (table 9–5). Full (100%) control was predicted in southwest Kansas while only 93 percent control (and 47 days of discharge over 30 years) was predicted for northeast Kansas. Discharges most commonly resulted from a series of precipitation events less than the design storm over an extended period of time when land application of liquid was judged to be not feasible (saturated soil conditions in land-application site).

An Iowa State University application of the Kansas State model (Wulf et al. 2003, 2004) provides additional support for the Kansas State observations. Based upon Iowa Department of Natural Resources minimum design criteria, five alternative design and management scenarios were modeled with 50 years of weather data for six Iowa locations. The resulting predictions suggested that between 70 and 90 percent of runoff could be controlled based upon a 25-year, 24-hour storm design criteria with additional normal runoff storage requirement mandated by Iowa regulations. (States may require storage capacity in addition to the minimum Federal ELG requirement of a 25-year, 24-hour storm capacity. This additional capacity is typically sized to address average runoff over a pre-determined time. Iowa has established five methods for estimating this capacity based upon the planned schedule for dewatering of the holding pond.) The every event pump out results (table 9–6, col. 2 and 3) compare favorably with the Kansas State results.

Table 9–5 Performance of runoff control facility sized to hold runoff from an unsurfaced feedlot for a 25-yr, 24-h precipitation event as evaluated over a 30-yr period (Koelliker et al. 1975)

Location	Runoff control (%)	Years with overflow	Avg. number of days with overflow[1]	Number of days with discharge over 30 years
Northwest KS	98.6	2	1.5	3
Southwest KS	100.0	0	0	0
Central KS	97.9	3	2.3	7
Southeast KS	95.5	9	3.6	32
Northeast KS	93.0	9	5.2	47

[1] During years with overflow

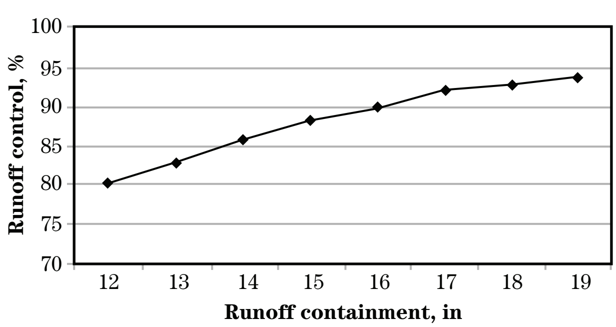
The predicted performance of the baseline system illustrated regular discharge occurrences for all scenarios evaluated. Northeast and East Central Iowa conditions produced the most frequent discharges and the lowest volume of runoff control. Land application systems that were not able to land apply runoff following each precipitation event were more likely to have discharge. Increasing volume of storage provided some reduction in runoff control but did not eliminate discharges (fig. 9–2). The baseline system currently defined in the ELG (Federal Register 2003) performs well under High Plains regional conditions, as found in western Kansas, but not nearly as well in regions with higher precipitation levels, extended wet periods, or less conducive to use of pivot irrigation systems.

To improve runoff control, it was further identified that extending the season for land application in the spring and fall produced the greatest benefits (extended pump out period results in table 9–6). Increasing pumping rate by 2.5 times or increasing storage capacity by 10 percent produced only minor improvements in increased runoff control (Wulf et al. 2003). Figure 9–2 illustrates the value of additional storage for a Central Iowa feedlot. Increasing total pond capacity from 30 to 48 centimeters (12–19 in) of total runoff produced a reduction in the runoff control, but did not eliminate discharges.

Table 9–6 Performance of runoff control facility sized to hold runoff from an unsurfaced feedlot designed based upon Iowa Department of Natural Resource criteria and evaluated over a 50-yr period (Wulf et al. 2004)

	Every event pump out		**April and Nov. pump out**		**Extended pump out period**	
	Runoff control	**Overflow**	**Runoff control**	**Overflow**	**Runoff control**	**Overflow**
Location	**(%)**	**(d/yr)**	**(%)**	**(d/yr)**	**(%)**	**(d/yr)**
Northwest IA	90.1	2.7	78.0	7.7	88.5	3.7
Southwest IA	88.5	4.1	72.4	10.4	83.7	6.7
Central IA	87.6	3.8	77.7	9.2	87.2	5.3
Southeast IA	90.1	3.9	79.2	8.8	83.7	6.7
East Central IA	82.3	6.1	64.5	13.4	80.3	7.8
Northeast IA	81.3	6.0	66.5	12.9	87.3	5.6
Basin capacity –						
Amount of runoff	**10–12 cm**		**20–25 cm**		**20–25 cm**	

Figure 9–2 Effectiveness of adding storage capacity to containment basin (Wulf et al. 2003)



A second Kansas State University study used the Koelliker model to estimate the baseline system volume necessary to provide 100 percent control of runoff based upon weather records for a 25-year period (Anschutz et al. 1979). The volume of the holding basin varies substantially with location, as illustrated in table 9–7. A holding pond for the same size feedlot will be between 3 and 6 times larger in the central and eastern Corn Belt as compared to western Kansas. This assumes that the all locations would have access to dewatering capacity equal to a pivot application system. Such systems are less commonly found in many regions outside of the High Plains states. With other land application methods, additional storage capacity would be needed to compensate for the slower dewatering rates. The study further observed a low correlation (r^2=0.33) between a 25-year, 24-hour storm design criteria for pond sizing and the estimated “no-discharge” pond size based upon 25-year weather records. Moisture deficit was better correlated (r^2=0.80) to the “no-discharge” pond size.

VTS performance

Performance models for VTS

An Iowa State University VTS software modeling tool is designed to predict the performance of a site-specific VTS to meet the Voluntary Alternative Performance Standards of the new EPA CAFO rules (Wulf et al. 2004). The VTS model performs site-specific modeling using daily weather inputs to estimate the performance of site-specific feedlots and VTS designs. The model is run for each of 25 weather years so that the performance of the alternative VTS (median outflow for 25-year period times pollutant concentration) can be compared to the performance of a baseline containment system at the same site following the procedures outlined by the Voluntary Alternative Performance Standards provisions of the CAFO regulations (Federal Register 2003). At the time this literature review was published, the model verification process was complete and the model was approved by the EPA.

Table 9–7 Relative size of runoff holding pond and land application system capable of pumping 2,850 L/min or 750 gpm during all seasons. Holding pond is sized to avoid all discharge based upon 25 years of weather data (Anschutz et al. 1979).

Location	Pond volume m^3 (10^6 gal)	Relative size to Garden City, KS	Location	Pond volume m^3 (10^6 gal)	Relative size to Garden City, KS
Garden City, KS	17,376 (4.6)	1.0	Wooster, OH	226,853 (60.0)	13.0
Sacramento, CA	57,760 (15.3)	3.3	Minneapolis, MN	56,374 (14.9)	3.2
Dublin, GA	110,936 (29.3)	6.4	Oklahoma City, OK	38,771 (10.2)	2.2
Boise, ID	19,980 (5.3)	1.1	Centerville, SD	51,478 (13.6)	3.0
W. Lafayette, IN	103,946 (27.5)	6.0	Hereford, TX	23,998 (6.3)	1.4
Urbana, IL	62,968 (16.6)	3.6	College Station, TX	54,761 (14.5)	3.1
Independence, KS	37,186 (9.9)	2.1			

Several Minnesota agencies have collaborated to develop a systematic procedure to identify appropriate applications of VTSs to feedlot runoff (Brach 2003; Minnesota Pollution Control Agency 2003). They have developed a standard identifying five levels of control (including VTA) and appropriate application of those five levels to individual situations based upon farm size and proximity to water. The team has developed a model, FLEVAL: An Evaluation System to Rate Feedlot Pollution Potential, to objectively evaluate feedlot pollution potential (*http://www.bwsr.state.mn.us/outreach/engineering/fleval.html*). Overcash et al. (1981) describes an additional model for predicting performance of a vegetative system located down-gradient from a manured land application site.

Solids removal performance

Solids removal via settling basins has been investigated for swine and bovine open lot runoff. Early studies of settling by Moore et al. (1973) using Imhoff cones showed that the majority of solids from beef feedlots settled within 10 minutes. From 10 minutes to 100 minutes only a slight improvement in settling was found. Fischer et al. (1975) concluded that the settling characteristics of hog manure are highly variable, but most settling occurs within the first 100 minutes. More recently Lott et al. (1994) examined solids in manure from Australian feedlots and differentiated two components: large particles that settled within 10 minutes and small particles that required extremely long settling times. The rapidly settling portion varied from 45 to 75 percent of the total solids. Sedimentation basin design based upon a maximum settling velocity of 0.003 m/s was recommended by Lott et al. (1994).

A 2-year study of settling basin performance below a swine facility and a beef feedlot in Iowa was conducted in the early 1990s (Lorimor et al. 1995). Solids in the swine runoff were reduced 29 percent from 3.1 percent to 2.2 percent wet basis. Solids concentration in the retained solids within the basin increased to an average of 12.7 percent. On a mass basis, the settling basin below the swine lot retained an average of 46 percent of the solids, 31 percent of the total Kjeldahl nitrogen (TKN), and 31 percent of total phosphorus (P) over the 2 years of monitoring. Settling below the earthen beef feedlot in this study removed a mean of 64 percent of the total solids, 84 percent of the TKN, 80 percent of the total P, and 34 percent of potassium (K).

Woodbury et al. (2003a) reported total nitrogen mass reduction of about 45 percent for a settling basin on a central Nebraska beef cattle feedlot over a 2-year period. Gilbertson and Nienaber (1973) observed that 71 percent of total solids that eventually settle will do so in the first 15 minutes representing 40 percent of total solids in runoff (Gilbertson et al. 1972).

Gilbertson et al. (1971) reported on performance of a batch system and a continuous-flow system for feedlot runoff. The batch system was more efficient in solids removal but suffered from management challenges including removal of settled solids. Dual settling basins were recommended to encourage greater drying and simplified solids management with solids-handling equipment. A continuous-flow system consisting of three porous dams in a settling channel recovered 50 percent of the total solids with 80 percent settling behind the first damn. Cold-weather solids settling proved a greater challenge, with solids remaining in a suspended form for longer periods at near-freezing temperatures. Only 42 percent of total solids were captured by the continuous-flow system during winter thaws.

Over a 2–1/2 year period, Swanson and Mielke (1973) monitored a broad, flat channel with two or three galvanized hardwire meshes installed to settle solids from runoff. It was estimated that 80 percent of the total solids were removed during the period observed. Key design recommendations included:

- channel length at least 6 times the channel width
- channel depth should exceed screen height to permit emergency overflow
- first screen placement at to half the length of channel from the inlet with additional screens equally spaced
- solids depth maximum of 38 centimeters (15 in)
- inclusion of a hard-surface channel bottom to facilitate equipment operation

The first component of any open feedlot runoff treatment system, whether it is total-containment system or alternative technology, should be solids settling, as is currently required by many state laws. Properly designed and managed solids settling basins should remove about 30 percent of the N and P from the runoff from swine lots and up to 80 percent of each from bovine lot runoff. Design recommendations for solids settling basins are available from MWPS (1985); Gilbertson and Nienaber (1973); and Sweeten (1991).

VTA performance

The author uses the terms VTA or vegetative treatment areas to represent the same technologies often referred to by other authors as vegetative filter strips. The author's choice of terminology differentiates VTAs applied to open lot livestock facilities from vegetative filter strips commonly used down gradient of cropland. Although both technologies share some similarities, there are distinctive differences in design and management.

This review of the literature assembled performance data from 16 research citations reporting 40 sets of performance data under field conditions (table 9–8) and an addition 17 research citations reporting 61 sets of performance data under simulated conditions (table 9–9). These research results are for both VTAs and VIBs. The preponderance of the performance data is for a VTA. VTA efficiency is estimated in the literature by comparing the reduction of pollutant concentration and/or mass entering and leaving the VTA. Pollutants of concern in livestock runoff include solids, nitrogen, phosphorus and pathogens. In addition, summaries of performance observations beyond specific pollutant reductions are reported in table 9–10.

Ikenberry and Mankin (2000) defined a VTA as a band of planted or indigenous vegetation situated downslope of cropland or animal production facilities that provides localized erosion protection and contaminant reduction. Planted or indigenous vegetation is defined as pasture, grassed waterways, or cropland that is used to treat runoff through settling, filtration, adsorption, and infiltration. Murphy and Harner (2001) identified four primary approaches used in VTAs:

- VTAs should be designed with a 1 to 4 percent slope and 61 meters (200 ft) of filtering length per 1 percent slope. Total area should be designed to match crop nitrogen uptake with estimated N in runoff. Uniform flow across filtering slope is necessary, typically requiring laser-guided land leveling equipment.
- Constructed wetlands have been applied to open lot runoff. Design and management is challenged by the intermittent flow from open lots. The authors suggests that seasonal open lots used for winter livestock housing and empty during the summer may be a preferred system for constructed wetlands.
- Infiltration basins are a containment type of system with a 30 to 60 centimeters (12–24 in) berm place around the vegetated area. They can be designed as discharge or non-discharge systems. Infiltration area necessary to infiltrate design runoff within 30 to 72 hours must be considered in sizing of infiltration basin area.
- Terraces, similar to infiltration basins, have been used to contain runoff on sloped areas. Both overflow and cascading terraces have been used. Overflow terraces move runoff from one terrace to an adjacent terrace at a lower elevation 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.

VTAs provide an opportunity for reduction of pollutants in runoff through two primary mechanisms: sedimentation, typically occurring within the first few meters of a VTA, and infiltration of runoff into the soil profile (Pope and Stolenberg 1991). The soil system also provides a physical structure and biological environment for treatment of pollutants including filtration (restricting movement of most protozoa and bacteria), immobilization (soil cations immobilizing ammonium), aerobic processes (conversion of organic compounds to water and carbon dioxide), and anaerobic process (conversion of nitrates to nitrogen gas). The VTA also allows the recycling of nutrients by plants (Fajardo et al. 2001).

VTA flow can be classified as either channelized or uniform flow (Dickey and Vanderholm 1981a). Their work showed that "the channelized flow system required a flow length over five times longer than the overland flow systems to achieve a similar concentration reduction." Dillaha et al. (1988) studied concentrated flow effects on removal efficiencies and found that lower removal efficiencies occurred in VTAs with concentrated flows than in VTAs with shallow, uniform flow.

Surface flow in channelized-flow VTAs concentrates into channels. One can more clearly define these as gullied or preferential-flow systems. If gullied or preferential flow develops, non-uniform loading of VTA will reduce performance of the system due to soil erosion and reduced utilization of the VTA area. Uniform-flow systems allow a uniform loading of waste (across the width of the VTA) at a relatively shallow depth (<4 cm). Uniform depth across the entire width of the VTA results in a slower velocity through the system, allowing sediment and nutrients to be trapped by the vegetation and adsorbed by the soil, and ultimately more efficient removal of nutrients and sediment from the waste stream.

Dickey and Vanderholm (1981b) showed progressively better removal of N and ammonium (NH_4^+) over 100 meters (300 ft) of overland flow in a VTA for a 100 head dairy and 500 head beef lot as shown in figure 9–3. Lim et al. (1997) and Chaubey et al. (1995) demonstrated a first-order exponential relationship better described the interaction between VTA length and pollutant transport. Data from 10 separate studies conducted over the last 25 years (fig. 9–4) show that 80 percent reductions of TKN and total P are achievable as a function of the ratio of VTA area to the feedlot drainage area.

Solids removal—Extensive research has been conducted on solids removal by VTA. Total solids are commonly reduced by 70 to 90 percent (tables 9–8 and 9–9). Variations occur due to site-specific conditions such as vegetation; slope; soil type; size and geometry of filter strip; and influent solids concentration. When receiving runoff directly from a feedlot, VTAs remove most solids within the first few meters of the filter strip. Coyne et al. (1998) found most reductions in concentration occurred in the first 4.5 meters. Chaubey et al. (1995) showed improved P removal effectiveness from swine lagoon effluent with increased VTA length up to 9 meters (30 ft). Solids reduction would likely perform in a similar manner. Chaubey et al. (1995) noted that removal of total suspended solids and chemical oxygen demand in VTA increased for lengths up to 3.1 meters. This quick reduction can be attributed to a significant reduction in flow velocity due to vegetation retarding the flow and soil conditions conducive to infiltration.

Fecal coliform removal—More research on fecal coliform (FC) removal by VTAs is needed. Reported values vary greatly and few studies have been conducted on large scale VTAs. Fajardo et al. (2001) report FC removal rates between 64 percent and 87 percent when using small-scale simulated runoff events with stockpiled manure. Lim et al. (1997) found that all FC were removed in the first 6.1 meters of a VTA used to treat runoff from a simulated pasture. Average FC removal in the studies reported was 76.6 percent (Ikenberry and Mankin 2000). A model for describing fecal pathogens in vegetative filter strips was being assembled by Zhang et al. (2001) and linked to an existing model of VTA hydrology and sediment transport, although data were not available to test the model at the time this research paper was prepared.

Figure 9–3 Effect of VTA length on TKN and ammonia N reduction (Dickey and Vanderholm 1981a)

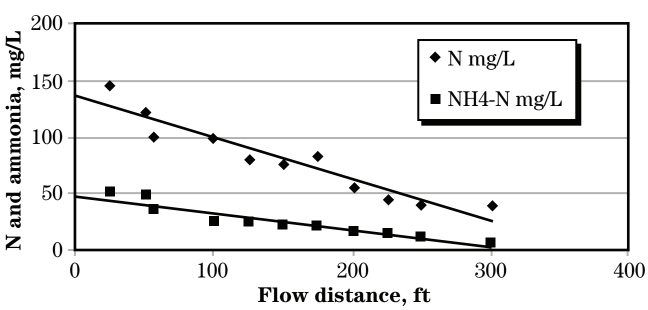


Figure 9–4 Nutrient removal by VTA based upon VTA to feedlot drainage area (DA) ratio for references listed in tables 9–8 and 9–9

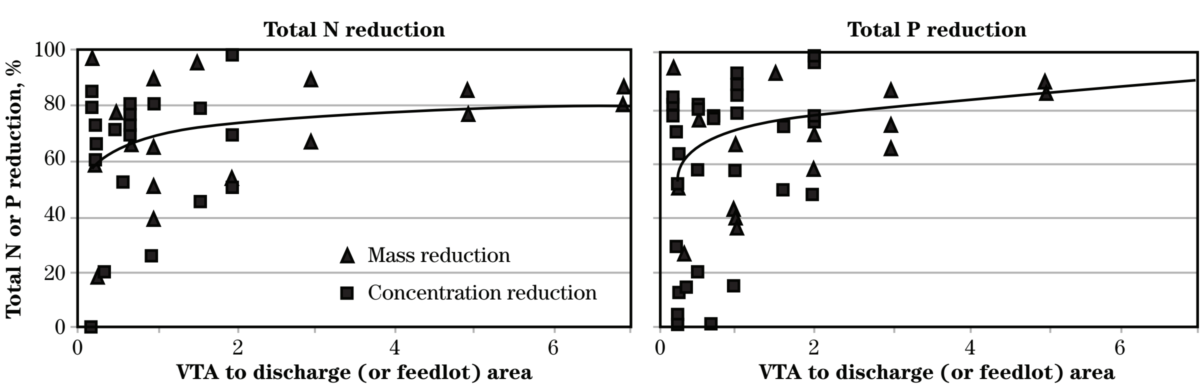


Table 9–8 Summary of VTA performance when placed on commercial or research livestock facilities

Study description					VTA information				
Reference	**Summary**	**Study period**	**Pollutant source**	**Settling basin**	**Length (m)**	**AR** [1/]	**Slope (%)**	**Vegetation**	**Soil**
Baker and Young 1984	Milking center wastewater and open lot runoff from a 54 cow dairy was directed to settling basin and VTA. Four earthen berms located at 9 m intervals were designed to create a cascading type system. System was monitored over 2 yr	5/82 – 5/84	Milking center wastewater only	Yes	91 x 23		10	Orchardgrass and foxtail at upper end. Hairy crabgrass in drier areas	VTA only VTA+basin VTA only VTA+basin
			Milking center wastewater and paved dairy lot runoff	Yes	91 x 23		10	Orchardgrass and foxtail at upper end. Hairy crabgrass in drier areas	VTA only VTA+basin VTA only VTA+basin
Dickey and Vanderholm 1981a	Four different VTA systems after settling basins at actual feedlots	17 mo	Dairy farm	Yes	91	1.00	0.5	Reed canary, bromegrass, and orchardgrass	
*Influent concentrations estimated from a similar site			450 head beef feedlot	Yes	61	0.70	2	Fescue-alfalfa mix	sandy
*Channelized flow VTA (serpentine terrace channel)			500 head beef feedlot	Yes	533	– –	0.25	– –	– –
*Vegetated terrace channel and grassed waterway			480 head swine finishing facility	Yes	148	– –	0.25	Garrison creeping foxtail	– –
Fausey et al. 1988	Infiltration basin used with 56 head of beef cattle on concrete lot	3 yr	56 head beef feedlot	Yes	6 x 27.5	0.7	1	Reed canarygrass 1) Drain tile with slope 2) Drain tile across slope	silt loam
Edwards et al. 1986	Infiltration basin used with 56 head of beef cattle on concrete lot	3 yr	56 head beef feedlot	Yes	6 x 27.5	0.7	1	Reed canarygrass, 1) VTA and settling basin 2) VTA only	silt loam
Harner and Kalita 1999; Keaton 1998	300 head feedlot runoff is directed to settling basin and VTA,	2 yr	300 head beef feedlot	Yes	427	0.97	0.3–4	Bromegrass	silty clay loam
	300 head beef feedlot discharges to VTA Both facilities are in Kansas	2 yr	300 head beef feedlot	Yes	239	0.23	0.5–2	Bromegrass	sandy loam

Table 9–8 Summary of VTA performance when placed on commercial or research livestock facilities—Continued

Percent reduction

TS	TSS	BOD5	COD	Total N	TKN	NH_4-N	NH_3-N	NO_3-N	Total P	Ortho-P	FC [2/]	FS [2/]	E. Coli	**
90			96	97	97		99	82	98					c [3/]
95			98	99	99		98	81	98					c
99			100	100	100		100	99	100					m
100			100	100	100		100	99	100					[3/] m
45			56	46	46		55	–68	68					c
65			65	60	60		40	–17	68					c
97			98	97	97		98	92	98					m
98			98	98	98		97	94	98					m
73.1			85.4	– –	80.1	– –	86.2	– –	78.2	– –	– –	– –	– –	c
63.1			81.2	– –	71.1	– –	71.5	– –	– –	– –	– –	– –	– –	c
79.7			86	– –	83.1	– –	83.4	– –	– –	– –	– –	– –	– –	c
78.7			92.1	– –	88.9	– –	85.2	– –	– –	– –	– –	– –	– –	c
61–81			69–87	Org N 69–85		69–92	NO_3-N before: 1 ppm		62–91	73–93				c
55–83			59–86	59–87		56–89	After 1 and 2: 76 and 64 ppm		63–89	67–90				c
82			85	Org N 80		50		–643		80				c
80			83	78		50		–940		74				m
66			69	70		73		–733		77				c
61			65	66		72		–1150		70				m
	65			26		44		2	14	18				c
	76			50		63		34	42	45				m
	78			73		74		95	71	64				c
	83			59		74		87	52	44				m

Table 9–8 Summary of VTA performance when placed on commercial or research livestock facilities—Continued

Study description				VTA information					
Reference	**Summary**	**Study period**	**Pollutant source**		**Length (m)**	**AR**	**Slope (%)**	**Vegetation**	**Soil**
Komor and Hansen 2003	Settling basin and VTA were placed below two cattle feedlots and monitored for seven storm events	1995–96	200 head capacity lot (35 cattle during test)	Yes	79	0.2	1.2	Grass	silt loam
			225 head feedlot	Yes	58	0.2	0.5	Grass	loam
Lorimor et al. 2003	Runoff from concrete open lot beef facility is directed to settling basin, totally bermed infiltration basin (IB), and constructed wetland (CW)	1997 to present—data based upon 5 yr	380 head concrete beef cattle facility	Yes	108	0.18	0	IB - Reed canarygrass CW–Com-mon cattails	Loam IB: IB + CW: IB + CW:
Mankin and Okoren 2003	300 head heifer feedlot with runoff directed to settling basin (stage 1) and VTA (stage 2)	May 2001–May 2002	300 head dairy heifer feedlot	Yes	150		2	Fescue	silt loam
								Mass reductions at: 30 m 150 m	
Paterson et al. 1980	Milking center waste and barnyard runoff from 70 cow dairy studied for a 5-yr period	5 yr	Natural rainfall	Yes	36		3.4	Tall fescue	Silt loam
			Snow melt						
			Perched water table						
Schellinger and Clausen 1992	Runoff from paved dairy lot to detention pond then VTA subject to natural rainfall	18 mo	Dairy barnyard	Yes	22.9	0.27	2	Fescue, bluegrass, and ryegrass mix	
Williamson 1999	Describes and compares design and performance of four VTAs in Kansas for feedlot	5 mo 5/98	350 head beef feedlot	Yes	239	0.23	1.2	Bromegrass	Sandy loam
*Same study, different VTA location and design		11/98 for all sites	300 head beef feedlot	Yes	427	0.97	0.75	Bromegrass	Silty clay loam
*Same study, different VTA location		11/98 for all sites	300 head beef feedlot	Yes	213	0.36	2	Fescue	Silt loam
*Same study, different VTA location		11/98 for all sites	200 head beef feedlot	Yes	137	0.59	0.6	Bromegrass	Loam
Woodbury et al. 2002; Woodbury et al. 2003a; Woodbury et al. 2003b	Settling basin and VTA collects open lot runoff from beef cattle facility	1997–2003	600 head beef feedlot	Yes	200	3	0.5	Brome grass	

$$\text{*AR = area ratio} = \frac{(\text{VTA area})}{(\text{feedlot drainage area})}$$

**m = reductions calcuated on a mass basis c = reductions calculated on a concentrated basis

Table 9–8 Summary of VTA performance when placed on commercial or research livestock facilities—continued

Percent reduction														
TS	**TSS**	**BOD5**	**COD**	**Total N**	**TKN**	**NH_4-N**	**NH_3-N**	**NO_3-N**	**Total P**	**Ortho-P**	**FC**	**FS**	**E. Coli**	******
1.5 cm rainfall on 5/14/96					85	62			83	25	60			
									Suspended P					
9.1, 3.6, and 0.6 cm rainfalls on 7/27/96, 6/2/96, and 6/27/98					35–75	35–80			25–75	15–75	20 to 80%			
65				80			81	–87	77					c
								–43	83					c
71				85			83	86	95					m
93				97			98							
			Most mass flow reduction occurred in infiltration basin											
		TDS												
	93	74		77					84		84		91	m
	95	68		81					79		85		90	m
	71	42				38		increase	7					c
	84	77				78		40	32					c
		99				97		increase	98					c
–	33	–	–	--	18	15	--	--	12	6	--	–	--	m
–	--	–	–	61.5	--	--	--	--	28.6	–	78.9	–	79.3	c
–	--	–	–	63.7	--	--	--	--	56.8	–	76.5	–	78.2	c
–	--	–	–	19	--	--	--	--	13	–	36	83	--	c
–	--	–	–	52.8	--	--	--	--	74.2	–	90.3	–	88.4	c
No observed discharge of water below root zone for 2 yr or as surface water from VTA for 5 yr														m

Table 9–9 Summary of VTA performance under simulated conditions

Study description			VTA information				
Reference	**Summary**	**Intensity**	**Length (m)**	**AR [1/]**	**Slope (%)**	**Vegetation**	**Soil**
Coyne et al. 1998	Four VTA plots placed after poultry manure amended pasture area	64 mm/h	4.5	0.25	9	Tall fescue and Kentucky bluegrass	Silt loam
		64 mm/h	9	0.66	9	Fescue-bluegrass mix	Silt loam
Chaubey et al. 1994	Swine manure applied to VTA subject to simulated rainfall	50 mm/h	3	1	3	Fescue	Silt loam
		50 mm/h	6	2	3	Fescue	Silt loam
		50 mm/h	9	3	3	Fescue	Silt loam
		50 mm/h	15	5	3	Fescue	Silt loam
		50 mm/h	21	7	3	Fescue	Silt loam
Chaubey et al. 1995	Poultry manure applied to VTA subject to simulated rainfall	50 mm/h	3	1	3	Fescue	Silt loam
		50 mm/h	6	2	3	Fescue	Silt loam
		50 mm/h	9	3	3	Fescue	Silt loam
		50 mm/h	15	5	3	Fescue	Silt loam
		50 mm/h	21	7	3	Fescue	Silt loam
Dillaha et al. 1988: Dillaha et al. 1986	Simulated feedlot and rainfall	50 mm/h	4.6	0.25	11	Orchardgrass	Silt loam
		50 mm/h	9.1	0.50	11	Orchardgrass	Silt loam
		50 mm/h	4.6	0.25	16	Orchardgrass	Silt loam
		50 mm/h	9.1	0.50	16	Orchardgrass	Silt loam
	*concentrated flow	50 mm/h	4.6	0.25	5	Orchardgrass	Silt loam
	*concentrated flow	50 mm/h	9.1	0.50	5	Orchardgrass	Silt loam
Edwards et al. 1983	VTA test plots after settling basin, natural rainfall, 56 head of beef cattle on concrete lot		2 x 30		2	Fescue	Silt loam
Fajardo et al. 2001	Plot study comparing fallow vs. vegetated filter strip	17 mm/h for fallow 110 mm/h for VTA	30		4.3–5.1	Tall fescue	Fine silt
Goel et al. 2004	A dairy slurry and water mix was applied to upper end of three lengths of VTA and three vegetative covers were tested	1.2 L/s applied to upper end of filter strip	5 10 5 10 5 1 5 10 5 10 5 10	Width = 1.2 m	3	Perennial rye Mixed grass species Kentucky bluegrass Perennial rye Mixed grass species Kentucky bluegrass	Guelph loam

Table 9–9 Summary of VTA performance under simulated conditions—Continued

Percent reduction

TS	TSS	BOD5	COD	Total N	TKN	NH_4-N	NH_3-N	NO_3-N	Total P	Ortho-P	FC [2/]	FS [2/]	E. Coli	
96											75	68		c [3/]
98											91	74		c
					65		71		67	65				m [3/] pt
					69		83		71	71				m
					89		96		87	89				m
					86		99		91	93				m
					87		99		92	94				m
					39		47		40	39				m
					54		70		58	55				m
					67		78		74	71				m
					76		94		87	85				m
					81		98		91	90				m
	87			61	64	34		-36	63	-20				c
	95			77	80	69		4	80	30				c
	76			67	69	-21		3	52	-108				c
	88			71	72	-35		17	57	-51				c
	31			0	1	1		-82	2	-3				c
	58			7	9	-11		-158	19	31				c
87		81	89	83					84					m
							94–99				No change			c
	86			91				-	88	50	61		66	c
	86			90				45	88	44	53		36	c
	87			87				25	87	44	15		-26	c
	91			84				16	86	48	52		58	c
	89			92				13	89	50	68		-130	c
	91			95				35	92	58	74		77	c
	90			94				3	91	64	71		67	
	94			95				67	95	77	77		64	m
	91			89				49	90	66	56		58	m
	95			91				52	92	75	75		82	m
	97			98				75	97	85	91		39	m
	99			100				96	100	97	99		99	m

Table 9–9 Summary of VTA performance under simulated conditions—Continued

Study description			VTA information				
Reference	**Summary**	**Intensity**	**Length (m)**	**AR***	**Slope (%)**	**Vegetation**	**Soil**
Hawkins et al. 1998	WW pumped from swine lagoon to VTA; runoff and percolate analyzed		6.1		5 11	Bermuda and ryegrass mix	Loamy sand
Lim et al. 1997	Simulated pasture and rainfall	10 cm/h	6.1	0.50	3	Fescue	Silt loam
		10 cm/h	12.2	1.00	3	Fescue	Silt loam
		10 cm/h	18.3	1.5	3	Fescue	Silt loam
Prantner et al. 2001	Lab scale study of raw swine manure applied to soil infiltration areas					None	Clarion loam soil
Sanderson et al. 2001	Manure application to grassland with VTA down gradient		16.4	1.0	1	Switchgrass	Fine sandy loam
Schwer and Clausen, 1989	VTA test plot, natural rainfall, milk house waste water pumped to VTA		26	--	2	Fescue, ryegrass, bluegrass mix	Sandy loam
	Same VTA, subsurface flow analysis	High rate: 20–27 cm/wk Low rate: 6–16 cm/wk				Fescue low rate high rate	Loam (surface); clay loam (subsurface)
Srivastava et al. 1996	Nine control VTA plots placed after manure amended pasture		3.1–18.3	3 1 0.33	3	Fescue	Silt loam
Young et al. 1980	Rainfall simulator applied 25-yr, 24-h storm to VTA plots containing corn, orchardgrass, sorghum-Sudangrass mix over 2-yr test period	6.35 cm/h for 71 min					Runoff volume reduction
			27	2	4	Corn	98%
			27	2	4	Orchardgrass	81%
			27	2	4	Sorghum-Sudangrass mix	61%
			21	1.6	4	Corn	66%
			21	1.6	4	Oats	41%
Willrich and Boda, 1976	VTA test plots, natural rainfall, swine lagoon effluent pumped to VTA		30.5	--	3	Fescue	Clay loam
			6.1	--	5	Bermuda and ryegrass mix	Loamy sand
*Same source of wastewater pumped to VTA with different slope			6.1	--	11	Bermuda and ryegrass mix	Sandy loam
			6.1	--	11	Bermuda and ryegrass mix	Sandy loam

1/ AR = area ratio = VTA area/feedlot drainage areas

2/ FC = fecal coliform; FS = fecal streptococci

3/ c = reductions calculated on a concentration basis; m = reductions calculated on a mass basis

4/ Data represents total organic carbon as measured by Srivastava et al.1996

Table 9–9 Summary of VTA performance under simulated conditions—Continued

Percent reduction

TS	TSS	BOD_5	COD	Total N	TKN	NH_4-N	NH_3-N	NO_3-N	Total P	Ortho-P	FC	FS	E. Coli	**
14	--	--	52	--	3		1	47	22	--	--	--	--	c
5			81		60		58	54	75					m
-557			14		33		33	-834	-11					c
37			92		93		93	-59	92					m
23.6	70				78		18.6	-498.2	76.1	74.5	100			m
40.8	89.5				89.5		52.8	-140.1	90.1	87.8	100			m
69.8	97.6				95.3		68	-96.7	93.6	93	100			m
1998 Undiluted swine manure					94			Inc.	85					c
3 parts manure + 1 part water					87			from	78					c
1999 Undiluted swine manure					96			1–77	98					c
3 parts manure + 1 part water					94			mg/L	97					c
			25–44							4–76				m
	92				83	46			86	82				c
	97				93	70			92	90				c
Turbidity 31		31	15				26		14		13			c
			67			62			62					m
			50			43			46					m
			30		67		75		66					
			11		44		39		36					
			13[4/]		21		27		26					
													Total coliforms	
Sediment														
93					98	98		95	98	100			53	
66					69	65		9	76	77	55	72	81	
82					50	47		-81	48	42	83	68		
													71	
81					79	78		-441	74	41			70	
75					45	33		-1130	50	-3				
		31	15				26			14	31			
59			81		60	58		54	75					
-557			14		33	33		-834	-11					
37			92		93	93		-59	92					

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects

Reference	Type of system
Barker and Young 1984	Milking center wastewater and open lot runoff from a 54 cow dairy was directed to settling basin and VTA. Four earthen berms located at 30-in intervals were designed to create a cascading type system. System was monitored over 2 yr
Coyne et al. 1998	Controlled replicated research trials were conducted on VTA of 4.5 m and 9.0 m in length below a simulated pasture area with poultry manure added. A 64-mm/h rainfall was applied
Chaubey et al. 1995	Poultry manure applied to established grass area with VTA located below area of land application. Site is subject to simulated rainfall
Dickey and Vanderholm 1981a; Vanderholm and Dickey 1980; Dickey and Vanderholm 1981b	Papers review design and performance of four VTA, two functioning as overland flow (100 cow dairy and 450 beef feedlot) and additional two as channelized flow (500 head beef feedlot and 480 swine operation)
Dillaha et al. 1988; Dillaha et al. 1986	Controlled replicated research trials were conducted on VTA of 4.6 m and 9.1 m in length below a simulated dairy open lot of 18.3 m on a silt loam soil. A 50-mm/h rainfall was applied for 2 h on soils described as “dry,” “wet,” and “very wet”
Edwards et al. 1983	VTA test plots after settling basin, natural rainfall, 56 head of beef cattle on concrete lot. Two grass filter cells were used in series, each representing approximately 50% of the concrete lot area
Edwards et al. 1986	VIB used with 56 head of beef cattle on concrete lot. VIB was preceded by solids settling basin
Fausey et al. 1988	
Fajardo et al. 2001	VTA and fallow plots are placed below area of manure application. Sufficient simulated rainfall was applied to achieve 1-h runoff event. Much greater volumes were applied to VTA plots
Harner and Kalita 1999	VTA established on several open lot beef systems in three watersheds, three of which were monitored for performance

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects—Continued

Performance observations (in addition to % reductions reported in tables 9–8 and 9–9)
• Effluent leaving the VTA effluent was only 5% of VTA influent volume resulting is high pollutant mass reductions • Increased soil nitrates were observed in deep soil samples in sections prior to first two berms. Increased soil P levels were also observed ahead of first two berms. No other soil samples showed increases • Soluble salt concentration showed increases in all soil samples ahead of first two berms. Total cations remained relatively constant with exception of shallow soil samples taken ahead of first berm • VTA distribution pipe at upper end of field with four separate outlets produced channel flow concerns. Increasing number of outlets to seven appeared to reduce channel flow concerns
• 85% and 76% of total water runoff infiltrated into the 9.0 m and 4.5 m VFA plots, respectively • The 4.5-m VTA trapped most of the sediment in runoff • VTA of this length trapped most of the fecal bacteria that moved onto the site. However, the concentration of fecal bacteria in runoff remained high and exceeded water quality standards
• First order linear regression describes reduction in mass transport of litter constituents with VTA length • Removal of contaminants in VTA increased for lengths up to 15.2 m (ammonia and dissolved phosphorus), 9.2 m (total Kjeldahl nitrogen and total phosphorus), and 3.1 m (total suspended solids and chemical oxygen demand) • VTA holds promise for improving quality of runoff from land application sites treated with poultry litter
• VTA reduces nutrients, solids and organic matter from feedlot runoff by more than 80% on a concentration basis and 95% on a weight basis • Additional removals are impractical due to quality of runoff approaching that of agricultural land that is not exposed to feedlot runoff. Discharge did not meet stream quality standards • Fecal coliform levels from the VTA with feedlot runoff addition were one log higher than runoff from a control VTA with no manure addition. Both were high in relation to stream standards • Most runoff events infiltrated completely, resulting in no discharge. Sizing procedures used for project resulted in runoff only during large precipitation events and high stream flows
• VTA are effective for removal of sediment and suspended solids with filters of 9.1 m or less if flow is shallow and uniform • Some decline in effectiveness is noted with time as sediment accumulates • Total N and P are not removed as effectively as sediment for the lengths tested • VTA lengths used in this research were not effective in removing soluble N and P. Soluble P was often higher in outflow than inflow, presumably due to release of P previously trapped in the VTA • VTA with concentrated flow were significantly less effective than were uniform flow plots
• Settling basin and filter strips reduced contaminant mass transport by 81–89% • The settling basin was more effective in large storm events • The grass filter strip was more effective when the basin was slowly drained 1 day following a storm event
• Infiltration basin approach eliminated all overland flow runoff to receiving stream • Infiltration basin produced greater nutrient transport reduction than a 33-m grass filter strip but was less effective than a 66-m grass filter strip • Reed canarygrass thrived in the infiltration basin • Drain tile placed across the slope in the infiltration basin produced greater discharge volumes and greater pollutant transport from the drain tiles than a single drain tile placed parallel with the slope of the infiltration basin
• Bacterial contamination in runoff water was not reduced when comparing tall fescue and fallow filter strips. Presence of bacterial organisms on the soil surface is ubiquitous. Manure addition did not significantly impact source of bacterial organisms • Dilution due to substantially greater water application in VTA to achieve similar runoff many also be partial explanation for reduced nitrates and unchanged coliform concentration (Author's note: all comparisons are based only on concentration)
• VTA effectively reduces nuitrient, sediment, and bacteria from open lot livestock systems • Quality of vegetation impacts nutrient uptake capacity of VTA

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects—Continued

Reference	Type of system
Hawkins et al. 1998	Effluent pumped from swine lagoon to VTA; runoff and percolate analyzed
Hubbard et al. 1994	Pre-treated swine lagoon effluent was applied at a rate of 450 and 900kg/ha/yr to three VTA consisting of 1) 10-m wide grass (bermuda and tall fescue) followed by 20-m riparian zones, 2)10-m grass and 20-m maidencane zones and 3) 20-m grass and 10-m riparian zones
Hubbard et al. 1999	Pre-treated swine lagoon effluent was applied at a rate of 800 kg N and 150kg P per ha per yr to six different wetland and riparian plant species to evaluate plant response.
Komor and Hansen 2003	A settling basin and VTA is applied to two small feedlot sites in Minnesota (200 and 225 cattle capacity). Data was collected for seven rainfall events ranging from early May to late October. VTAs were sized to represent approximately 20% of the feedlot runoff area
Lim et al. 1998	Cattle manure was applied to upper 12.2 m of grassed plots. Runoff was collected at 0, 6.1, 12.2, and 18.3 m below area of manure application for simulated rainfall of 100 mm/h
Lorimor et al. 2003	Runoff from 380 head concrete feedlot passes through settling channel (stage 1), infiltration basin (stage 2), and wetlands (stage 3).
Mankin and Okoren 2003	300 head heifer feedlot with runoff directed to settling basin (1st stage) and VTA (stage 2)
Nienaber et al. 1974	Settling basin, holding pond, sprinkler irrigation on grassed treatment area. Fresh water application compared with beef feedlot runoff
Paterson et al. 1980	Milking center waste and barnyard runoff from 70 cow dairy was directed through settling basin (stage 1), holding tank with lift pump, and VTA (stage 2).
Prantner et al. 2001	Undiluted swine manure, 3 to 1 swine manure and water, and water applied to buried containers with grass (first stage) followed by wetland plants (stage 2). Sufficient manure or water volume applied at 2-wk intervals to saturate soil column

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects—Continued

Performance observations (in addition to % reductions reported in tables 9–8 and 9–9).
• Significant nitrification occurred on the steeper slope and elevated soil nitrate levels were a concern
• Intense monitoring of nitrogen in soil, ground water, and surface water runoff was reported for a 9-month period with no differences in treatments observed at this time • All three treatments were effectively filtering N from applied swine manure at both rates • Significant reductions in ammonium in surface runoff were noted with down gradient distance from point of swine manure application. Nitrate concentration increased from less than 1 mg/L to between 1 and 15 mg/L • All species responded well to swine effluent application with buttonbush and saltmeadow cordgrass showing the greatest growth response
• Significant variation occurred in performance of VTA for different rainfall events. Greatest attenuation occurred on October and May when mats of wilted, flat-lying grass covered the filter strips. Attenuation was least during the summer when tall growing grass covered the filter strips • On one site, runoff volume was reduced from 47% for a 2.3-cm (spring rainfall) to 100% for a fall 1.5-cm fall rainfall event. On the second site, runoff volumes were reduced by 83% for a 3.6-cm fall event, 85% for a 9.1-cm summer event, to 98% for 0.6-cm summer rainfall event • Ground water degradation was observed where shallow water table exists (1.3 m and 0.8 m below ground surface at two sites)
• No concentration reductions were observed after first 6.1 m • Concentration and mass transport reductions of the analyzed parameters followed a first-order exponential reduction relationship with length of VTA
• Overall mass flow reductions have been between 86 and 98% for this system, with most significant reductions due to VIB • After 5-yr use, soil phosphorus levels within the infiltration basin have not shown signs of buildup • Although the flow out of the infiltration basin is not continuous, it has a substantially lower peak and extended period of flow as compared to the runoff flow from the feedlot. The infiltration basin also stores significant quantities of water subsequently used by plant growth thus reducing total volume. This change in flow pattern is beneficial to secondary treatment systems
• Mass reduction of constituents occurred in first 30 m. Little or no reduction occurred in last 120 m • Fecal coliform concentration was reduced below accepted water quality standards
• Application rates of 64 cm (25 in) in 1971 and 91 cm (36 in) in 1972 did not result in runoff (applied mid spring through late fall) or accumulation of nitrogen, phosphorus, or chlorides
• Four pollutants (BOD, NH4, PO4, and suspended solids) decreased in concentration by passing though VTA • Four pollutants were reduced by 97% or more in perched ground water while nitrate increased • Nitrate increased during passage through VTA except during winter where nitrate was reduced in concentration
• Systems were designed to encourage nitrification followed by denitrification processes and soil absorption and settling of phosphorus. The 2-yr study produced 99.5% and 99.9% reduction in ammonium-N, 98.5% and 99.8% reduction in total P and ending nitrate concentrations of 0.2 mg/L (1998) and 7–9 mg/L (1999). Similar percentage of reduction of ammonium and phosphorus were observed in the infiltration and wetland zones. Soil P accumulation was a concern but not observed in the 2-yr study

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects—Continued

Reference	Type of system
Sanderson et al. 2001	Solid dairy manure (1995) and dairy lagoon effluent (1996 and 1997) was applied at rates ranging from 0–600 kg N/ha in a replicate plot design. Manure was applied to a switchgrass area with a VTA consisting of switchgrass below the manured plots
Scheilinger and Clausen 1992	Concrete dairy barnyard runoff flows through a detention pond and into a 22.9 m by 7.6 m VTA with 2% slope
Schmitt et al. 1999	Alternative lengths of VTA and types of vegetation were evaluated for agricultural field runoff
Schwer and Clausen 1989	VTA was designed to treat milk house wastewater on a Vermont dairy
Srivastava et al. 1996	Nine control VTA plots, ranging from 3–18.3 m, were placed after poultry manure amended pasture
Willrich and Boda 1976	Anaerobic lagoon swine effluent is applied to upper end of six plots
Woodbury et al. 2002; Woodbury et al. 2003a; Woodbury et al. 2003b	Runoff from eight open lot beef cattle pens (about 600 cattle) moved from the pens through a grass approach, settling basin (created by a 300-m long terrace below the pens), and a 6-ha VTA
Young et al. 1980	Rainfall simulator applied 25-yr, 24-h storm to VTA plots containing corn, orchardgrass, sorghum-Sudangrass mix, oats over a 2-yr test period
Younos et al. 1998	18-m wide VTA placed down gradient from open lot for 60 head dairy

Table 9–10 Summary of performance observations for VTA for past research and field demonstration projects—Continued

Performance observations (In addition to % reductions reported in tables 9–8 and 9–9)
• VTA effectively reduced total reactive P and COD concentrations in surface runoff • Runoff concentration of N, P, and COD decreased as greater time lapsed between manure application and precipitation event. To minimize N and COD runoff concentrations, 3–4 days was suggested. To minimize P concentrations, then 1 day was necessary
• 65% of barnyard runoff exited from VTA. Retention of solids, N, P, K, and bacteria was considered poor • Average hydraulic retention time of 15 min was observed • Inadequate detention time and excessive hydraulic detention times were identified as reasons for poor performance
• VTA performance is strongly dependent upon type of contaminants. VTA are most effective for sediment related contaminants and least effective for dissolved contaminants • Doubling filter strip from 7.5–15 m does not improve sediment settling, increases infiltration, and increases dilution of runoff • Incorporating trees and shrubs into the lower half of filter strips does not affect performance • Contour sorghum strips of equal width are not as effective at reducing contaminants as perennial vegetation
• Retention was greatest during the growing season and least during snowmelt • Retention of N and P in harvested crops accounted represented only a small portion of input nutrients
• Pollutant concentration of water exiting litter treated areas is not dependent on litter treated length, suggested rapid equilibrium being reached • Pollutant concentrations decreased with increasing VTA length for all pollutants • Mass transport was not affected by VTA length with large portion of the mass removal occurring within the first 3 m of VTA
• Overland flow treatment of swine lagoon effluent caused significant concentration attenuations and mass reductions of its polluting properties • BOD and turbidity removal became effective with time whereas treatment effectiveness for COD, phosphorus, salinity and ammonia decreased with time • Changes in application rate impacted runoff volumes but did not significantly change concentration of most contaminants • Significantly greater attenuation occurred during cool, wet months for turbidity and fecal coliform and during warm, dry months for phosphorus. Nitrification was also greater during warn, dry months.
• The settling basin removed 80,67, 59, and 47% of the total suspended solids, volatile suspended solids, chemical oxygen demand, and total nitrogen • Distribution of settling basin water to a VTA was not uniform resulting in soil nitrate accumulation in upper 30 cm (1 ft) • No water was measured exiting the VTA below the root zone or at the down gradient end of the VTA over a 3-yr period suggesting hay crop utilization of all applied water • Mass nitrogen removal by harvesting exceeded mass nitrogen addition with feedlot runoff • Migration of nitrate below the settling basin is a problem, possibly exacerbated by solids removal and basin cleaning
• Significant reductions on nitrogen forms (with exception of nitrate), phosphorus, and microorganisms were observed for 36 m VTA • Nonstructural control practices are a promising alternative method for controlling feedlot runoff
• Stream loads for total runoff, orthophosphate and dissolved phosphorus, total phosphorus, and total nitrogen were lower after VTA installation as compared to a pre-VTA installation. However, due to the relatively short monitoring (6 mo prior and after installation), differences were statistically inconclusive • Although the water quality upstream of the sacrifice lot is already degraded, the installation of the VTA may prevent a further degradation of the water quality downstream of the sacrifice lot

Nitrogen removal—The most common gauges of nitrogen content in surface runoff include total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonium and ammonia nitrogen (NH_4 and NH_3, respectively), and Nitrate (NO_3) (Ikenberry and Mankin 2000). Removal of TN, TKN, NH_4, and NH_3 by VTA, has been shown to exceed 85 percent. Nitrate (NO_3) removal has typically been much lower, although Fajardo et al. (2001) reported 97 and 99 percent reductions in simulated VTA studies. In some studies, NO_3 increased from near-zero levels typical of most anaerobic feedlot runoff, to sub-health-limit levels during flow through the VTA. Chaubey et al. (1995) noted that removal of ammonia and TKN in VTA increased for lengths up to 15.2 and 9.2 meters, respectively. Overall properly designed and managed VTAs are very effective, averaging approximately 70 percent nitrogen removal (Ikenberry and Mankin 2000).

Phosphorous removal—Because the majority of the phosphorous in feedlot runoff is adsorbed to solids particles, total phosphorous removal is directly related to solids removal efficiencies. Phosphorous removal rates have ranged from 12 to 97 percent, averaging about 70 percent. Chaubey et al. (1995) also noted that removal of dissolved and total phosphorus in VTA increased for lengths up to 15.2 meters and 9.2 meters, respectively.

Vegetative infiltration basin (VIB)

Some vegetative systems force infiltration of runoff through a soil filter and provide an alternative approach that prevents surface water discharges. Lorimor et al. (2003) operated a bermed infiltration area that allowed discharges only through subsurface drain tiles placed 1.8 meters (6 ft) below the surface of this basin. All runoff must move through a soil filter prior to discharge. Smaller footprint for the VTA (1/6 to 1/12 of most standard VTA designs) and no direct surface-water discharge are two advantages. After 5 years of experience, soil P levels have not shown signs of buildup. Preferential flow through the soil filter may be a potential concern over time. Infiltration basins represent an alternative VTA design that out-performs most grass filters but may be acceptable only for sites with low-infiltration clay layer below the drain-tile. Edwards et al. (1986 and 1988) have reported operation of an infiltration basin below a small open lot cattle facility (table 9–8).

As wastewater infiltrates the soil, aerobic nitrification occurs, converting ammonium to nitrate by the aerobic bacteria *Nitrosomonas* and *Nitrobacter* (Prantner et al. 2001). In addition, phosphorus interacts and becomes attached to soil particles in the profile. Field drainage tile is used to intercept the filtrate and carry it to a secondary form of treatment such as a constructed wetland or VTA.

Two recent infiltration studies at Iowa State University have shown significant water quality improvements. Using liquid swine manure, Prantner et al. (2001) showed over 93 percent reductions in NH_4–N, and 89 percent reduction in phosphorus. Yang and Lorimor (2000) reported a field infiltration system down gradient of a 380-head concrete beef feedlot. Over 2 years of sampling, they found an 81 percent reduction in suspended solids, 83 percent reduction in TKN, 85 percent reduction in NH_4–N, and a 78 percent reduction in P. Nitrate levels have increased by 87 percent, suggesting a need for nitrate utilization or treatment downstream of an infiltration system.

Infiltration basins based upon soil filters are limited to sites conducive to tile drainage where a restrictive soil layer exists below the surface restricting water and contaminant movement to ground water. Alternative infiltration systems, such as a constructed infiltration bed of sand, biosolids, and wood chip mixtures laid over a gravel layer with a tile drain used to treat runoff from paved parking lots (Culbertson and Hutchinson 2004), may have application to livestock systems.

Another advantage of an infiltration basins is its ability to alter the flow rate and timing of liquid (hydrograph) exiting the infiltration basin (Lorimor et al. 2003). Slowing the flow from the infiltration basin during the storm event and delaying much of the discharge until after the storm event enhances the potential for successful treatment in later treatment components such as a VTA.

Overall VTS performance

By coupling various combinations of treatments into a treatment system, the quality of feedlot runoff can be significantly improved to the point of achieving functional equivalency to baseline technologies to complete elimination of surface water runoff. Although the particular combination of treatments selected for any feedlot will be site specific, essentially all should begin with solids settling. Table 9–11 shows a summary of the anticipated contaminant reductions for various treatment components associated with a dairy or beef open lot facility. Reductions for two or more components can be estimated by multiplying remaining contaminants (one reduction) for each component. A settling basin and VIB will reduce total solids concentration by 92 percent or 100-[(100-60) x (100-80)].

VTA design

The literature provided illustrations of a number of critical design considerations for VTAs (table 9–12). Based upon this literature, there are several design considerations that are generally accepted for VTAs:

- A need exists for some degree of pretreatment. Solids settling is commonly used with VTAs to minimize solids accumulation at the front end of a VTA. This pre-treatment minimizes vegetation damage and reduces the potential for channel flow paths and vegetation damage where runoff first enters the VTA.
- Uniform sheet flow of liquid is essential for optimum VTA performance. Design of inlets and headlands is critical to initiating sheet flow. Field management is critical to minimizing concentrated flow. Even with the best inlet design and management, concentrated flow is likely to occur within a VTA and may requiring additional structures to redistribute flow.
- For VTS on CAFOs, minimizing potential for discharge will be critical for achieving equal or better performance than baseline technologies. Combinations of treatment components into systems, attention to sizing, and modification of hydrograph of flow into a VTA are important considerations for minimizing discharge potential.
- Siting criteria is critical to the appropriate application of VTAs. Iowa Department of Natural Resources has established nine evaluation criteria used to initially judge a site including available area, soil permeability, depth to water table, subsoil and geology, slope, spreaders for uniform distribution, berming for inflow water protection, flooding potential, and proximity to waters of the state (Iowa Department of Natural Resources 2004).

Multiple approaches have been suggested for VTA sizing:

- Dickey and Vanderholm (1981a) recommended a minimum VTA width of 61 meters (200 ft) and a length adequate to completely infiltrate the feedlot runoff and rainfall from a 1-year, 2-hour storm. They calculated minimum flow lengths to provide 2-hour contact times. Based on their model, minimum lengths varied from 91 meters (300 ft) for a 0.5 percent slope up to 262 meters (860 ft) for a 4 percent slope. They also recommended that an infiltration area be designed to allow infiltration for all runoff from a 1-year, 2-hour storm.
- Nienaber et al. (1974) suggested a disposal area of a half hectare per hectare of feed lot is needed. Data in figure 9–4 suggest that a ratio of 1 to 1 (disposal to feedlot area) or greater is necessary to achieve peak performance. Lorimor et al. (2003) has achieved high contaminant removal rates with a ratio of 1 to 6 (infiltration basin to feedlot area) for a bermed infiltration area that allows discharges only through subsurface drain tiles.

Table 9–11 Summary of contaminant concentration reductions

	Total solids	TKN	Ammonium- N	Total P	BOD
Settling	60	80	80	80	—
VTA	60	70	70	70	75
VIB	80	80	85	80	
Wetland	60	50	50	50	60

Table 9–12 Summary of design and management recommendations for VTA for past research and field demonstration projects

Reference	Type of system
Barker and Young 1984	Milking center wastewater and open lot runoff from a 54 cow dairy was directed to settling basin and VTA. Four earthen berms located at 30 ft intervals were designed to create a cascading type system
Dickey and Vanderholm 1981a; Vanderholm and Dickey 1980; Dickey and Vanderholm 1981b	Papers review design and performance of four VTA, two functioning as overland flow (100 cow dairy and 450 beef feedlot) and additional two as channelized flow (500 head beef feedlot and 480 swine operation)
Dillaha et al. 1988; Dillaha, et al. 1986	
Edwards et al. 1983	• VTA test plots after settling basin, natural rainfall, 56 head of beef cattle on concrete lot. Two grass filter cells were used in series, each representing approximately 50% of the concrete lot area
Ikenberry and Mankin 2000	Review of literature

Table 9–12 Summary of design and management recommendations for VTA for past research and field demonstration projects—Continued

Design recommendations	Management recommendations
• Initial seeding of fescue and reed canarygrass was used due to tolerance to wet conditions • Four distribution points at upper end of VTA proved inadequate to create uniform flow. Later expansion to seven distribution points reduced problems of channel flow	• At conclusion of study, orchardgrass and foxtail grass were dominant species at upper end of filter strip and hairy crabgrass dominated in drier areas. • Four grass cuttings were made per year with an attempt to hold grass height near 6–12 in high.
• Solids settling in advance of a VTA minimizes vegetation damage and maintains VTA effectiveness • Overland or sheet flow within VTA • Minimum recommend contact time for runoff with a VTAis 2 h • Overland VTA do not require longer contact time as lots increase in size • Infiltration area should be designed to allow infiltration for all runoff from a 1-yr, 2-h storm. Additional area provides little improvement • Slope and soil infiltration rate are important considerations in VTA sizing Channelized flow systems will: • Require flow distances at least 10 times greater that sheet flow design • Require one additional hour of contact time beyond the 2-hour minimum for each 465 m^2 (5,000 ft^2) of open lot greater than 929 m^2 (10,000 ft^2) • Require large areas for open lots of more than 0.4 ha (1 a)	• Dormant residues in VTA have proven to be an effective filter and settling mechanism. Management practices that contribute to a strong fall growth and well-established dormant residue through winter has value in pollutant removal from winter precipitation and snowmelt runoff
• Effectiveness of VTA is dependent upon design and management measures that create shallow uniform flow and prevent concentrated flow • VTA site selection should target flat areas and avoid hilly terrain	• See first bullet under design recommendations
	• The grass filter strip was more effective when basin release was actively managed and slowly drained one day following a storm event and after settling of solids
	Key management considerations recommended: • Soil testing to determine fertilization requirement at time of planting of vegetation • Reseeding and fertilization to maintain dense stand • Repairing of gullies soon after their development • Regular moving and harvesting of plant material to remove nutrients and maintain dense vegetation stand • Restriction of field traffic and grazing during wet periods to avoid development of ruts leading to channel flow and damage to vegetation

Table 9–12 Summary of design and management recommendations for VTA for past research and field demonstration projects—Continued

Reference	Type of system
Lorimor et al. 2003	Runoff from concrete open lot beef facility is directed to settling basin, totally bermed infiltration basin, and constructed wetland
Murphy and Bogovich 2001	Summarizes NRCS design recommendations for application of VTA to open lot dairies in PA for handling runoff and milking center effluent
Nienaber et al. 1974	Settling basin, holding pond, sprinkler irrigation on grassed treatment area. Fresh water application compared with beef feedlot runoff
Norman and Edwards 1978	Ohio NRCS recommendations for sizing of buffer strip dimensions for cattle feedlots
Paterson et al. 1980	Milking center waste and barnyard runoff from dairy was directed through settling basin (first stage), holding tank with lift pump, and VTA (second stage)
Murphy and Harner 1999; Harner and Kalita 1999	VTA established on several open lot beef systems in three watersheds, three of which were monitored for performance
Murphy and Harner 2001	
Scheilinger and Clausen 1992	Runoff from dairy barn yard is directed through a detention pond and then to a VTA
Woodbury et al. 2002; Woodbury et al. 2003a; Woodbury et al. 2003b	Runoff from eight open lot beef cattle pens (about 600 cattle) moved from the pens through a grass approach, settling basin (created by a 300-m long terrace below the pens), and a 6 ha VTA

Table 9–12 Summary of design and management recommendations for VTA for past research and field demonstration projects—Continued

Design recommendations	Management recommendations
• Infiltration basin was bermed to provide total containment of 25-yr, 24-h storm • Infiltration basin was size to provide a land area that was 1/6 of the drainage area of the concrete open lot • Three parallel buried tile lines ran the length of the infiltration basin to move filtrate from the basin to a constructed wetland	
• Determines hydraulic characteristics that provide a minimum 15 min flow through time for sheet flow at depths of 1.3 cm and less for various flow rates and slopes • Pretreatment settling basin volume was recommended to be 2-yr peak flow times 15 min	
$\text{VTA size} = \dfrac{\text{Annual feedlot runoff (a-in)}}{\text{Max. annual crop water tolerance} - \text{annual precipitation (in)}}$ • Minimum disposal area of one-half ha per ha of feed lot with a suggested sizing procedure of:	• Applied effluent to a grassed disposal area planted with a mixture of nine cool and warm season grasses. Bromegrass and intermediate wheatgrass became the dominant species, not necessarily due to effluent application. Grazing cattle did not discriminate between areas receiving effluent and area receiving only water for irrigation
• Travel time should be proportional to BOD concentration	
• Distribution lines longer than 30 m created challenges with uniform flow • Filter area designed for flow of 4.5 L/m^2 VTA/day was a safe load for high rainfall and snowmelt events. Discharge from VTA was common	• Daily application of waste resulted in tall fescue being replaced by barnyard grass in early season and crabgrass later in the season • Mechanical harvesting and removal of grass on a monthly basis was preferable to pasturing • Duplicate VTA area was needed to allow soil drying and harvesting due to daily effluent additions • High rate "dosing" with a pump was found to be preferable for even distribution and to avoid freeze up problems during winter operation
• VTA should be located at least 3 m (10 ft) above ground water or seasonal perched water table and 30 m (100 ft) from wells • Sedimentation structure must preceed VTA • 61 m (200 ft) of length minimum per 1% slope • For finishing cattle, 1 ha of VTA is suggested per 200 head. For calves confined for 150 d/yr, 1 ha of VTA is suggested per 1,000 head	• Quality of vegetation impacts nutrient removal of vegetation. Establishment procedures and harvesting frequency is important to establishing lush forage growth
• VTA systems should be sized by matching normal nutrient runoff and crop nutrient utilization	
• USDA SCS design specification to pass the peak discharge of a 2-yr, 24-h storm at a maximum flow depth of 1.3 cm with a detention time of 15 min was inadequate	Preferential flow path from the lip spreader through the VTA was another identified cause of poor performance
• A mean hydraulic retention time of 5–8 min within the settling basin was used for peak runoff rates • Earth bottom settling basin was designed to be cleaned with front–end loader. For wet years, a settling basin slope (6 to 1) was selected to allow box scraper to be backed into settling basin while keeping tractor on dry ground • Settling basin drainage to minimize liquid depth was recommended to minimize seepage below the basin • Settling basin outlets were installed to place and maintain all outlets on an equal elevation (reinforced concrete pads set outlet elevation • Settling basin drain pipes (separate from normal outlets) were installed to allow complete basin drainage and solids drying prior to solids removal	• Cross drainage across lots should be avoided to prevent one area of settling basin collecting most solids. Berms or wooden planks at the fence line between pens were suggested • Solids accumulation at the bottom end of the pens (due to animal traffic and solids settling) created problems with uneven flow into the settling basin. Periodic solids removal from under the fence line at the lower end of the feedlot is needed • One to two harvests per year of bromegrass was considered adequate • Herbicides were used for broadleaf weed control on the VTA and settling basin berm

- A design procedure was developed by NRCS in Pennsylvania suggesting that the VTA be designed for the peak discharge resulting from a 2-year, 24-hour storm event at a maximum flow depth of 1.3 centimeters with a minimum flow through time of 15 minutes (Murphy and Bogovich 2001). A design procedure based upon a sheet flow equation was proposed:

$$T = \frac{0.07(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

where:
T = travel time (h)
n = Manning's roughness coefficient (0.24 for dense grass)
L = flow length (ft)
P_2 = 2-yr, 24-h storm
s = land slope (ft/ft)

Scheilinger and Clausen (1992) used this design standard for Vermont applications and observed poor performance results. Additional design criteria have been assembled by other NRCS state offices including the Montana Supplement to chapter 10 of the Agricultural Waste Management Field Handbook (Montana NRCS 2003). All of these practice standards have typically targeted non-CAFO units. For example, the Montana practice standard states that final designs for feedlots larger than 3 acres (about 600 cattle) should not be designed with the simplified method (Montana practice standard).

- Murphy and Harner (2001) suggested sizing a VTA area based upon normal nitrogen runoff balanced against nitrogen removal as harvested hay. Procedures for estimating mass of nitrogen runoff from the feedlot and example design calculations are provided in section 6.

- Black (1984) proposed a design procedure based on a maximum allowable hydraulic load to the filter.

$$R_w = P + \left(\frac{D}{10}\right) + SR$$

where:
R_w = maximum allowable wastewater hydraulic load in cm/yr
P = soil permeability in cm/yr
D = soil water deficit in mm/yr
SR = seasonal runoff rate in cm/yr

After calculating R_w, a required VTA area can be calculated by dividing the total flow expected, which includes wastewater, runoff, and direct precipitation, by R_w.

- Overcash (1981) proposed a design equation based on influent and effluent concentrations.

$$C_X = C_B + (C_O - C_B) \times e^{\left\{\left[\frac{1}{(1-D)}\right] \times \ln\left[\frac{1}{(1+K)}\right]\right\}}$$

This procedure requires knowledge of the influent contaminant concentrations, C_O, to the VTA. A desired VTA effluent concentration, C_X, can then be selected. C_B represents the background concentration, D is the ratio of infiltration to runoff, and K is the ratio of VTA length to waste area length. Once C_X, C_B, C_O, and D have been determined, the equation must be solved for K to size the filter strip. This calculation should be made for all contaminants of concern, and filter strip length be selected based on the limiting contaminant.

VTA maintenance

Several maintenance issues are critical in VTA function (table 9–12):

- A good stand of dense vegetation is needed. Dickey and Vanderholm (1981) noted that dormant residues are effective for filtering and settling pollutants. Management practices that contribute to strong fall growth and well-established winter vegetative cover are critical. Regular harvesting (including hay removal), prevention of channel flow, and minimizing solids accumulation in the VTA are of value in achieving dense fall vegetation. Soil testing to determine fertilization will be of value.
- Uniform flow conditions are essential to VTA performance. Minimal animal traffic and limiting of vehicle traffic to dry conditions are critical.
- Prevention of nutrient accumulation in VTA is important. Regular harvesting with crop removal to encourage a balance of nutrients of nutrients is necessary. Animal grazing is not an acceptable harvesting option. Regular soil testing for residual soil nitrates and phosphorus is suggested at the upper end of the VTA. Higher nutrient deposition is anticipated in the first few meters of the VTA suggesting a potential for nitrate leaching and increased soil P.

Conclusions

Based upon this literature review, the following conclusions are drawn about the application of vegetative treatment areas to runoff from open lot livestock production systems:

- Substantial research (approximately 40 identified field trials and plot studies) provides a basis for understanding the performance of VTS. A superior research knowledge base exists for performance of VTS as compared to baseline systems for CAFO regulation compliance.
- The baseline systems for CAFO regulation compliance perform well in the High Plains regions of the United States where significant moisture deficits exist (rainfall minus evaporation). However, the performance of these baseline technologies drops substantially for decreasing moisture deficits found in the central and eastern Corn Belt states. These trends have been established through computer modeling processes. In-field performance measurements do not exist for baseline systems established by CAFO regulations.
- The existing research targeting VTS is confined to non-CAFO applications, likely due to past regulatory limits. Unique challenges exist in adapting these results and recommendations to CAFO applications.
- The pollutant reduction resulting from a VTS is based upon two primary mechanisms: sedimentation, typically occurring within the first few meters of a VTS, and infiltration of runoff into the soil profile. Systems relying primarily on sedimentation only are unlikely to perform equal or better than baseline technologies. System design based upon sedimentation and infiltration is necessary to achieve a required performance level for CAFO application.

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Appendix A Sources of Topographic Maps

Ordering USGS topographic maps

To locate or order USGS topographic maps, refer to the following sources of information:

- Call 1-888-ASK-USGS (1-888-275-8747).
- Write to USGS Information Services, Box 25286, Denver, CO 80225.
- Contact any state-affiliated USGS Earth Science Information Center, typically located within state government or at a land-grant university. Your local NRCS or Soil and Water Conservation District office should be able to help you identify the appropriate state contact.
- In some locations, the local NRCS or Soil and Water Conservation District may be a source of USGS topographic maps.

Finding USGS topographic maps online

There are many options for obtaining topographic maps. A general site that offers a range of information is at:

http://topomaps.usgs.gov/

Topopgraphic maps may be viewed at:

http://www.topozone.com/default.asp

or

http://www.terraserver.microsoft.com

Electronic files for much of the United States may be downloaded from:

http://data.geocomm.com/catalog/index.html

The files downloaded from this site are TIFF files. They can be inserted into most word processing (Corel® WordPerfect® or Microsoft® Word) or presentation software (Microsoft® PowerPoint) that contain simple drawing tools for identifying farm locations, field boundaries, and adding labels. There are also other image-viewing software options that enable you to view and work with the TIFF image directly.

Local sources of aerial or topographic maps:

- Local NRCS center
- Soil and Water Conservation District office
- County planning/zoning office

Appendix B How Much Runoff Will Come from the Feedlot?

Single storm event

The volume of runoff from a feedlot for a single storm event is commonly estimated using the NRCS Curve Number method. This method is commonly use to estimate the storage volumes required for design storm events such as a 25-year, 24-hour storm (fig. B–1). It is described in the NRCS National Engineering Handbook, Part 630, Chapter 10. For the purpose of estimating the volume of storm runoff from a feedlot, the following equation is solved for Q:

$$Q = \frac{\left[P - 0.2\left(\left(\frac{1000}{CN_1}\right) - 10\right)\right]^2}{P + 0.8\left\{\left(\frac{1000}{CN_1}\right) - 10\right\}} \quad (1)$$

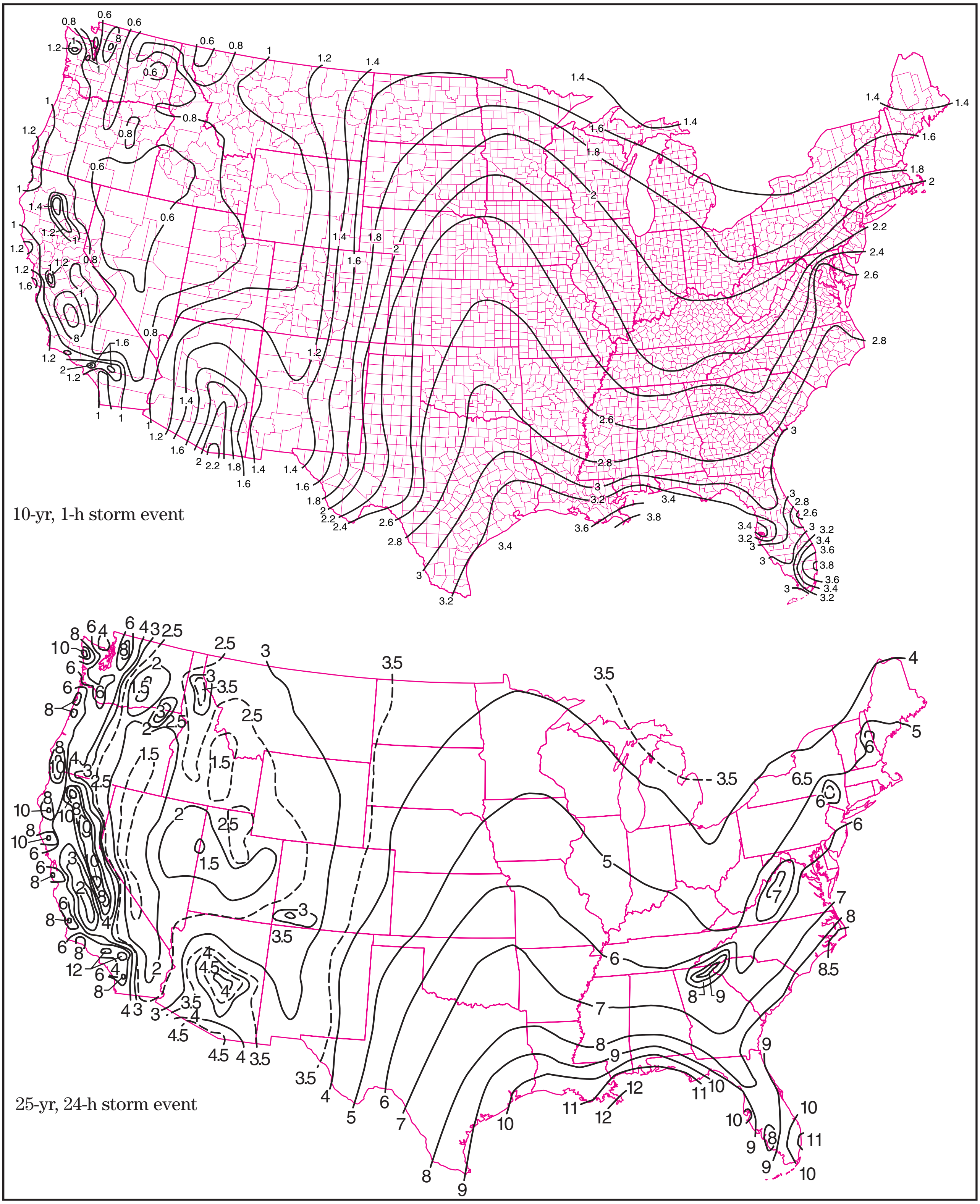
where:
Q = volume of runoff (in)
P = rainfall (in)
CN_1 = NRCS 1-day curve number

A CN_1 of 89 or 90 is commonly used for an unpaved feedlot, and a CN_1 of 97 or 98 is commonly used for a paved feedlot. The volume of rainfall for this application is usually the volume of a 25-year, 24-hour or a 10-year, 1-hour (fig. B–1) storm event. Estimates of runoff for four different surfaces are illustrated in table B–1.

Table B–1 Volume of runoff in inches associated with an individual storm event for four surfaces based upon equation 1

	Surfaces			
Rainfall event (in)	Concrete lot or compacted surface (CN_1 = 98)	Earthen feedlot surface (CN_1 = 90)	Medium texture cropland (CN_1 = 75)	Medium texture grassland (CN_1 = 70)
2.0	1.8	1.1	0.4	0.2
2.5	2.3	1.5	0.7	0.5
3.0	2.8	2.0	1.0	0.7
3.5	3.3	2.4	1.3	1.0
4.0	3.8	2.9	1.7	1.3
4.5	4.3	3.4	2.1	1.7
5.0	4.8	3.9	2.4	2.0
5.5	5.3	4.4	2.9	2.4
6.0	5.8	4.8	3.3	2.8
6.5	6.3	5.3	3.7	3.2
7.0	6.8	5.8	4.1	3.6
7.5	7.3	6.3	4.6	4.0
8.0	7.8	6.8	5.0	4.5

Figure B–1 Precipitation (in) resulting from a single storm event



Monthly runoff

Monthly runoff is of used to estimate the storage requirements between periods of land application (storage period). Monthly runoff may be estimated using the thirty day curve number (CN_{30}). Using this method the CN_1 is converted to a CN_{30} using the following equation:

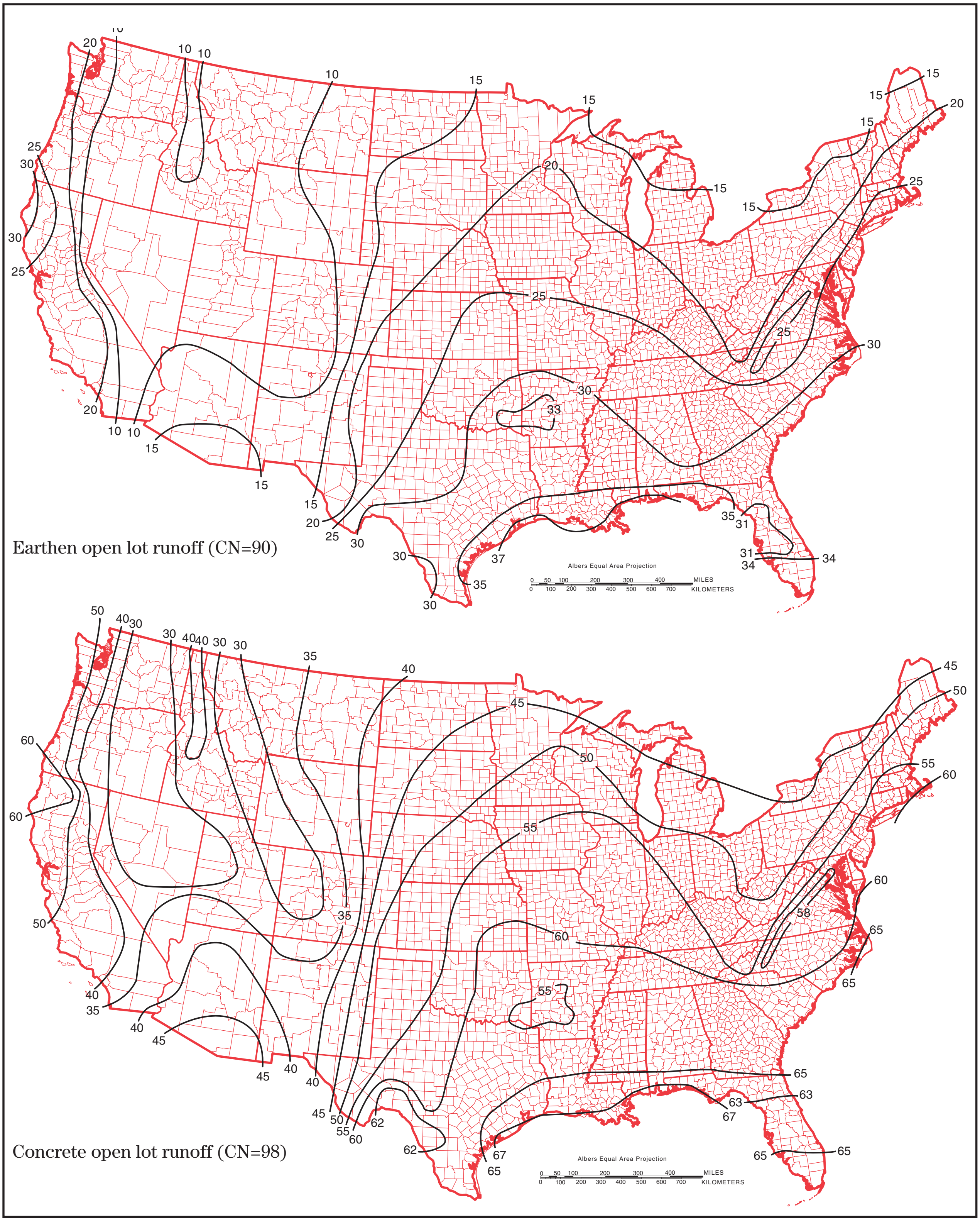
$$CN_{30} = CN_1 - \left\{ CN_1 - \left[\left(\frac{CN_1^{2.365}}{631.79} \right) - 15) \right] \right\} \log 30 \qquad (2)$$

A CN_{30} for an unpaved feedlot is commonly 73 to 76, and a CN_{30} for a paved feedlot is commonly 95 to 98. The monthly runoff from a feedlot is computed by substituting CN_{30} for CN_1 in equation 1. In this application, P would be the average rainfall for a given month. If a storage period is required for the months of December through March to avoid winter application, then a CN_{30} is calculated and used with monthly precipitation values to estimate runoff for each of the 4 months. The summation runoff for the 4 months would represent the volume required for the storage period. The volumes computed using CN_{30} is typically high when compared with actual data. They work better on smaller watersheds than on larger watersheds. National maps showing average monthly runoff percentages are also available from chapter 10 of the NRCS Agricultural Waste Management Field Handbook (see *http://www.wcc.nrcs.usda.gov/awm/awmfh.html*).

Annual runoff

Annual totals for feedlot surfaces are summarized in figure B–2. Annual runoff values might be used in planning nutrient runoff from feedlot for sizing of a land application area (sec. 6) or other planning roles.

Figure B–2 Annual runoff from open lots as a percent of mean annual precipitation (NRCS Agricultural Waste Management Field Handbook, ch. 10 (*http://www.wcc.nrcs.usda.gov/awm/awmfh.html*))



Example—Calculation of runoff

Determine the runoff for a 2,000 head capacity dirt feedlot (finishing 4,000 head of cattle per year) located in central Iowa. The feedlot is 11.5 acres in area an additional 8 acres of roads, drainage ditches, feed storage and preparation areas, and compost site drains into the settling basin. Annual precipitation is assumed to be 34 inches.

10-year, 1-hour storm runoff: 2.3 inches of rainfall (from fig. B–1) which produces 1.4 and 2.1 inches of runoff from feedlot (table B–1, CN=90) and additional drainage area (assumed to be primarily compacted surfaces, thus selecting CN=98 from table B–1), respectively. This single event would produce:

$$= (1.4 \text{ in} \times 11.5 \text{ feedlot a}) + (2.1 \text{ in} \times 8 \text{ additional a})$$
$$= 33 \text{ a-in of runoff}$$

25-year, 24-hour storm runoff: 5.5 inches of rainfall (from fig. B–1) which produces 4.4 and 5.3 inches of runoff from feedlot (table B–1, CN=90) and additional drainage area (assumed to be primarily compacted surfaces, thus selecting CN=98 from table B–1), respectively. This single event would produce:

$$= (4.4 \text{ in} \times 11.5 \text{ feedlot a}) + (5.3 \text{ in} \times 8 \text{ additional a})$$
$$= 93 \text{ a-in of runoff}$$

Monthly runoff: Estimate runoff for the month of June when average precipitation is 3.5 inches. The CN_{30} value is estimated using equation 2 as follows:

$$\text{Feedlot: } CN_{30} = 90 - \left\{ 90 - \left[\frac{\left(90^{2.365}\right)}{631.79} \right] - 15 \right\} \log 30 = 77$$

$$\text{Additional area: } CN_{30} = 98 - \left\{ 98 - \left[\frac{\left(98^{2.365}\right)}{631.79} \right] - 15 \right\} \log 30 = 95$$

Monthly runoff is calculated from equation 1 as follows:

$$\text{Feedlot: } Q = \frac{\left\{ 3.5 - 0.2\left[\left(\frac{1,000}{77} \right) - 10 \right] \right\}^2}{\left\{ 3.5 + 0.8\left[\left(\frac{1,000}{77} \right) - 10 \right] \right\}} = 1.4 \text{ in}$$

$$\text{Additional area: } Q = \frac{\left\{ 3.5 - 0.2\left[\left(\frac{1,000}{95} \right) - 10 \right] \right\}^2}{\left\{ 3.5 + 0.8\left[\left(\frac{1,000}{95} \right) - 10 \right] \right\}} = 2.9 \text{ in}$$

Average June open lot runoff is:

$$= (1.4 \text{ in} \times 11.5 \text{ feedlot acres}) + (2.9 \text{ in} \times 8 \text{ additional acres})$$
$$= 39 \text{ a-in of runoff}$$

Example—Continued

Monthly runoff maps are found in chapter 10 of the NRCS Agricultural Waste Management Field Handbook.

Annual Runoff: Annual runoff from the feedlot is estimated to be:

$$\text{Annual runoff} = \text{Annual precipitation} \times \%\ \text{runoff} \times \frac{\text{area}}{100}$$

(fig. B–3) (fig. B–2)

For feedlot, annual runoff is:

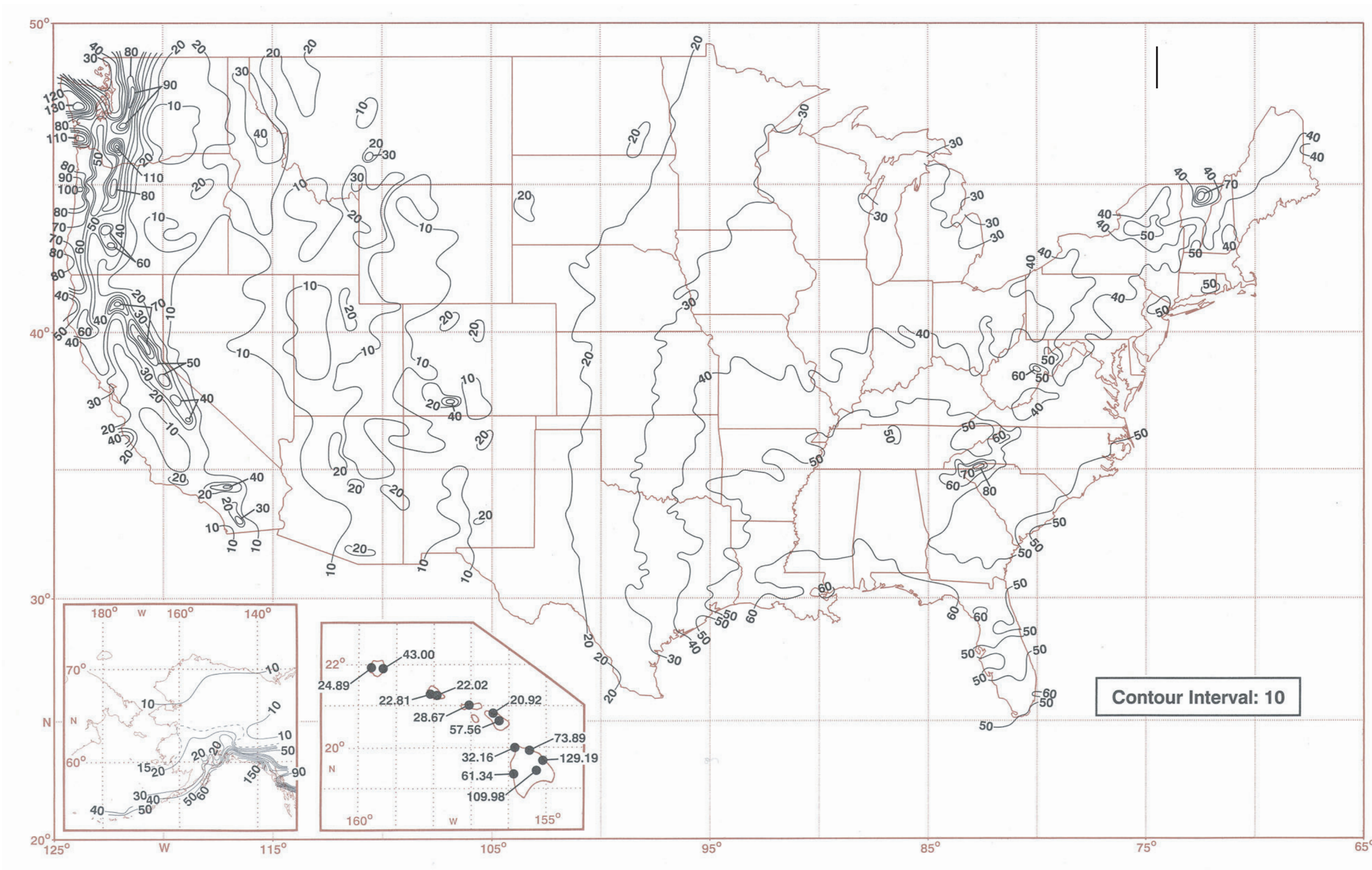
$$= 34\ \text{in} \times 23 \times \frac{11.5\ \text{a}}{100}$$
$$= 90\ \text{a-in}$$

For additional contributing area (roads, drainage ditches, feed storage and preparation areas, and compost site), it is assumed that the concrete open lot runoff value in figure B–2 is a reasonable (and likely a conservative) approximation of runoff:

$$= 34\ \text{in} \times 55 \times \frac{8\ \text{a}}{100}$$
$$= 150\ \text{a-in}$$

Total annual runoff should not exceed 240 acre-inches (sum of feedlot and contributing area estimates).

Figure B–3 Mean annual precipitation (inches) for 1961 to 1990 (National Climate and Data Center, *http://www.ncdc.noaa.gov/img/documentlibrary/clim81supp3/precipnormal_lowres.jpg)*



Appendix C Example Sizing of Settling Basin

Problem

Design a settling basin for a 2,000 head dirt feedlot located in central Iowa. The outflow of the basin will be to a VTA. The feedlot is 11.5 acres in area an additional 8 acres of roads, drainage ditches, feed storage and preparation areas, and compost site drains into the settling basin. The basin will be cleaned once a year in late summer. The site restricts basin depth to 4 feet. There will be a sloped screen and a perforated riser pipe with an orifice plate at the basin outlet. Basin must have a detention time of at least 1 hour. Basin capacity of equivalent runoff from a 25-year, 24-hour storm will also be assumed necessary because liquid release will be spread over a 72-hour period for this storm event. Sizing procedures are described in section 5.

Solution

1. Rainfall volume for a 25-year, 24-hour storm in central Iowa (fig. B–1) is 5.5 inches. Rainfall volume for a 10-year, 1-hour storm in central Iowa (fig. B–1) is 2.4 inches.

2. Peak flow rate off lot

$$= 19.5 \text{ a} \times 43{,}560 \text{ ft}^2/\text{a} \times \frac{2.4 \text{ in/h}}{43{,}200}$$
$$= 47 \text{ ft}^3/\text{s}$$

3. Use settling rate of 4 feet per hour.

4. Basin surface area

$$= \frac{(47 \times 3{,}600 \text{ s/h})}{4}$$
$$= 42{,}300 \text{ ft}^2$$

5. Liquid storage depth $= 4 \text{ ft/h} \times 1 \text{ h}$
   $= 4$ ft. maximum depth
   Select actual storage depth of 2.75 feet liquid depth and 0.25 feet freeboard depth for solids storage.

6. Liquid volume

$$= 2.75 \text{ ft} \times 42{,}300 \text{ ft}^2$$
$$= 116{,}000 \text{ ft}^3$$

   (Provides about a 40-min detention time)

   Liquid volume = 93 acre-inch or 338,000 cubic foot (based from 25-yr, 24-hr storm as calculated in app. B example). Select larger of two volumes or 338,000 cubic foot for settling basin storage volume.

   Recalculate basin surface area holding depth constant:

   Basin surface area

$$= \frac{338{,}000 \text{ ft}^3}{2.75 \text{ ft liquid depth}}$$
$$= 123{,}000 \text{ ft}^2$$

7. Solids storage volume

$$= 0.5 \text{ a-in/a} \times 11.5 \text{ a} \times 1.0 \text{ yr} \times \frac{43{,}560 \text{ ft}^2\text{/a}}{12 \text{ in/ft}}$$
$$= 21{,}000 \text{ ft}^3$$

8. Solids storage depth

$$= \frac{21{,}000 \text{ ft}^3}{123{,}000 \text{ ft}^2}$$
$$= 0.2 \text{ ft}$$

(Slightly less solids storage will be required than 0.25 ft allowed in step 5…no design change will be made at this time.)

9. Overall basin depth

$$= 2.75 + 0.25$$
$$= 3 \text{ ft}$$

10. Screen area

$$= \frac{(2.2 \times 60 \text{ s/min})}{(0.6 \times 2.5 \text{ ft/min})}$$
$$= 88 \text{ ft}^2$$

Screen length

$$= \frac{88 \text{ ft}^2}{3 \text{ ft}}$$
$$= 32 \text{ ft}$$

11. Minimum basin length

$$= 3 \text{ ft} \times \frac{12}{1} \text{ ramp ratio} + 32$$
$$= 68 \text{ ft}$$

(based on screen length and ramp…actual basin length will be much longer)

12. Assume basin average width of 59 feet (50 ft wide bottom and 3 to 1 slope sidewalls for 3 ft depth basin).

Basin length

$$= \frac{123{,}000 \text{ ft}^2}{59 \text{ ft}}$$
$$= 2{,}100 \text{ ft}$$

13. a. Average flow rate from basin

Outlet flow rate

$$= \frac{338{,}000 \text{ ft}^2}{(72 \text{ hr} \times 3{,}600 \text{ s/h})}$$
$$= 1.3 \text{ ft}^3\text{/s for a 72 hour release rate into VTA}$$

b. Assume that two riser pipes will be used (0.65 ft^3/s per pipe). Orifice diameter from table 5–2 for a 0.65 cubic foot per second flow and a 2.75 foot head is between 3.75 (0.62 ft^3/s), and 4 inches (0.71 ft^3/s). Select the 3.75-inch orifice with a flow rate of 0.62 cubic foot per second.

c. Open area for riser pipe is estimated from table 5–3 to be 6 square inch per foot for a flow rate of 0.62 cubic foot per second.

d. Select 7.5 inches per foot allowing for 25 percent greater open area per foot of riser than that shown in table 5–3 for orifice flow rate. This is done to ensure orifice diameter controls discharge.

14. Assuming separate mainlines for each riser, a 1 percent mainline pipe slope, and a flow rate of 0.62 cubic foot per second for each line, an 8 inches mainline pipe is required according to figure 5–6.

15. The minimum riser pipe size selected should be the largest of the following three possibilities:

(1) The diameter of the mainline or offset line if used, (8 in) determined in step 14,

(2) 2 inches larger than the selected orifice diameter (3.75 + 2 = 5.75 in), or

(3) The diameter from table 5–4 for the design flow rate of 0.62 cubic foot per second (3.6 in).

Select a riser diameter of 8 inches. If each 8-inch riser were equipped with two slots of 1 foot by 4 inches per linear foot of riser, the 7.5 square inch per linear foot requirement would be satisfied. Thus, two 8-inch riser pipes with 3.75-inch orifice plates would be recommended. Each riser would have 8-inch mainline conveying water to the VTA.

Appendix D Tile Design Example

Design a VIB for a 2,000 head 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 that drains into the settling basin. The areas of the settling basin and VIBs are 2.8 and 6 acres, respectively. The VIB will be located in a soil with an infiltration rate of 0.6 to 2 inches per hour. It is desirable that the basin drain in 72 hours for a 25-year, 24-hour storm.

From example calculation in section 7 on VIB sizing:

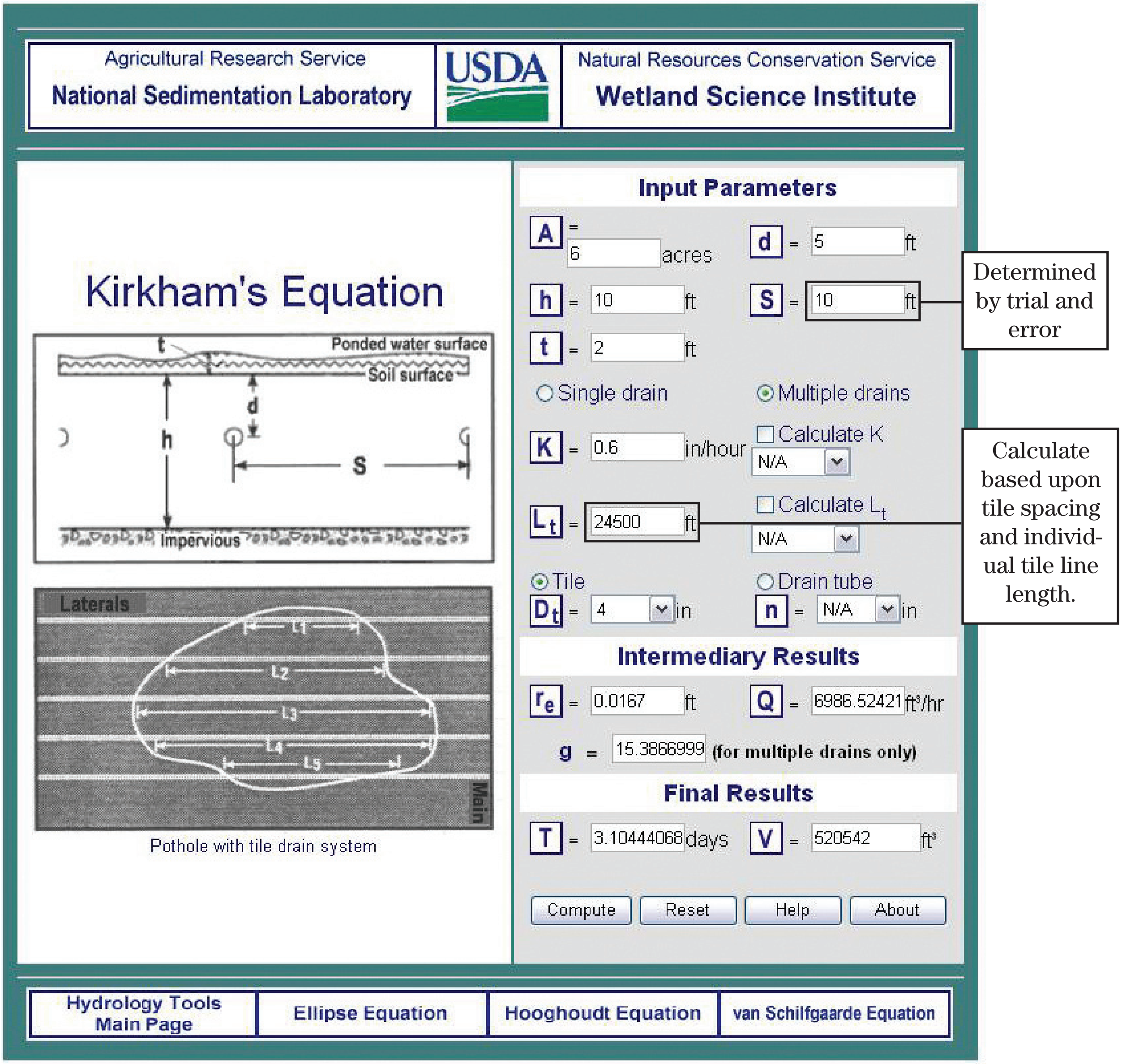
– Total runoff from area contributing to the VIB for the 25-year, 24-hour event is 109 acre-inches (excluding rainfall on the VIB) and 142 acre-inches (including rainfall on 5.9-acre VIB)

– Area of VIB = 5.9 acres

Tile design variables	*Example problem values*
A = area of the infiltration basin	6.0 acres with dimensions of 510 square foot
d = depth of tile drains	5 feet
h = depth to impermeable layer	10 feet
S = tile spacing	Determined by trial and error
t = depth of ponding	2 feet
K = permeability of the soil in the VIB select lower value of range of soil permeabilities listed in county soil survey	County soil survey suggests 0.6 to 2.0 inch per hour. Select 0.6 inch per hour
L_t = total length of tile under the infiltration basin	Tiles installed to within 10 feet of edge of VIB or 490 feet per tile line L_t = 490 feet per tile line x [(VIB width / tile spacing) – 1] L_T = 490 x [(510 / S) – 1]
Tile lateral diameter	4 inches

Use Kirkham's equation for ponded conditions to determine required tile spacing. Use software tool found at *http://msa.ars.usda.gov/ms/oxford/nsl/java/Kirkham_java.html* to solve by trial and error for S (the tile spacing) as illustrated in figure D–1. Tile spacing to achieve required drainage is 10 feet, assuming a drain time of 3.1 days or 74 hours is acceptable. 24,500 feet of tile line will be required. The 10-foot tile spacing may be unreasonably close in some situations. This design will be re-evaluated to achieve more reasonable tile spacing.

Figure D–1 Example of tile drainage spacing design using USDA design tool based upon Kirkham's method (Kirkham 1957). The Web site for this design tool is *http://msa.ars.usda.gov/ms/oxford/nsl/java/Kirkham_java.html*



Redesign of tile spacing

Assume a maximum ponding depth of 12 inches instead of 24 inches. Use equation 5 in section 6 to compute area of VIB based upon a practical depth:

$$A_{VIB} = \frac{\left[R + \left(A_{SB} \times P\right)\right]}{\left[\left(D_P - F\right) - P\right]}$$

$$A_{VIB} = \frac{\left[93 + \left(2.8 \times 5.5\right)\right]}{\left[12 - 5.5\right]}$$

$$A_{VIB} = 16.7 \text{ a}$$

Substitute results of equation 5 into equation 2 of section 7 to calculate VIB volume:

$$V_{VIB} = R + \left(A_{SB} + A_{VIB}\right) \times P$$

$$V_{VIB} = 93 + \left(2.8 + 16.7\right) \times 5.5$$

$$V_{VIB} = 200 \text{ a-in}$$

Accounting for precipitation on the VIB and a maximum ponding depth of 12 inches, the size is approximately 16.7 acres. Design the tile system on 16.7 acres (600 ft wide by 1,210 ft long) to drain the VIB in 72 hours.

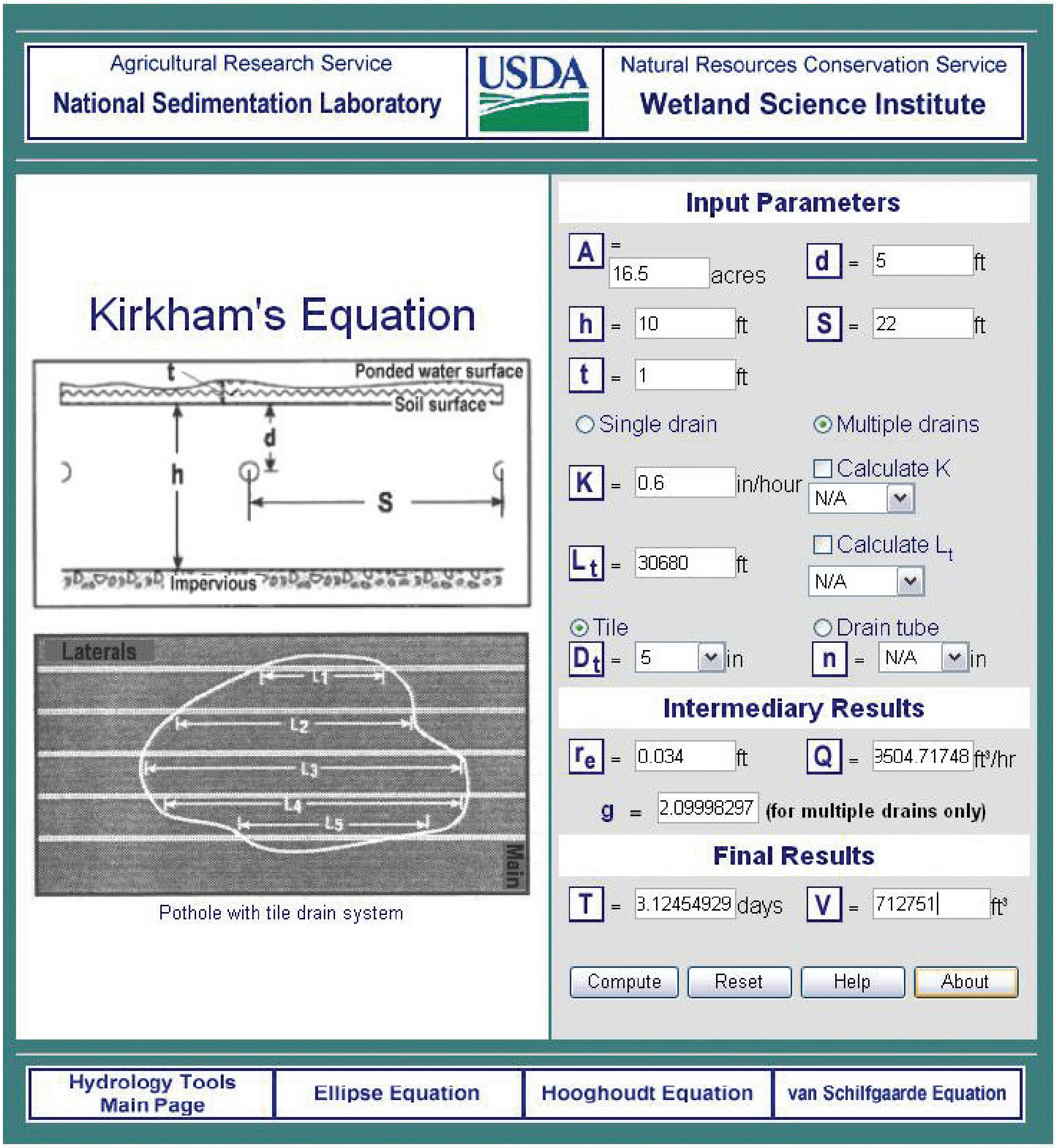
Tile design variables for redesigned VIB	*Example problem values*
A = area of the infiltration basin	16.7 acres with dimensions of 600 by 1,210 feet
d = depth of tile drains	5 feet
h = depth to impermeable layer	10 feet
S = tile spacing	Determined by trial and error
t = depth of ponding	2 feet
K = Permeability of the soil in the VIB. Select lower value of range of soil Permeabilities listed in county soil survey	County soil survey suggests 0.6 to 2.0 inch per hour. Select 0.6 inch per hour
L_t = total length of tile under the infiltration basin	Tiles installed to within 10 feet of edge of VIB or 1,190 feet per tile line. L_t = 1,190 ft/tile line x [(VIB width / tile spacing) – 1] $L_T = 1{,}190 \times \left[\left(\frac{600}{S}\right) - 1\right]$
Tile lateral diameter	5 inches

Use Kirkham's equation for ponded conditions to again determine required tile spacing (software tool found at *http://msa.ars.usda.gov/ms/oxford/nsl/java/kirkham_java.jtml;* see fig. D–2).

The redesigned system allowed for a larger spacing of tile line (20 vs. 10 ft) and has the advantage of a berm height (18 vs. 30 in). The larger tile spacing requires a significantly larger VIB (16.5 vs. 6.0 a), longer berms to be built (3,620 vs. 2,040 ft) and significantly greater length of tile (30,940 ft of 5-in tile vs. 24,500 ft of 4-in tile).

The remaining option for reducing VIB area and increasing tile spacing is to accept a longer VIB drain time. The ability of the selected vegetation is an important consideration as to whether this change is acceptable.

Figure D–2 Tile spacing to achieve required drainage is 22 feet with VIB drain time of 3.1 days or 75 hours for a 16.7-acre VIB. 30,940 feet of tile line will be required.



Sizing of VIB laterals

Compute the required tile size:

1) Assume slope of the pipe = 0.20 percent (0.002 ft/ft) (assume plastic pipe not subjected to fine sand or silt)

2) Calculate overall drainage rate = 9,505 ft³/h / (600 ft x 1,200 ft) = 0.0132 ft/h (12 in 72 h)

3) Calculate discharge from each lateral = 0.0132 ft/h x (1,180 ft x 22 ft) = 343 ft³/h = 0.095 ft³/s

4) Calculate tile diameter using equations 6 and 7 of section 7 as follows:

$$AR^{\frac{2}{3}} = \frac{Q}{\frac{1.49s^{\frac{1}{2}}}{n}} \qquad (1)$$

where:
A = cross-sectional area of drain tile
R = hydraulic radius of drain tile if flowing full (0.25 x tile diameter (D))
Q = discharge, ft³/s
s = grade of tile (0.002)
n = Manning's roughness = 0.015

By substitution into equation 1:

$$\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{\frac{2}{3}} = \frac{0.095}{\frac{1.49\times(0.002)^{\frac{1}{2}}}{0.015}}$$

$$D = 0.37 \text{ ft} = 4.4 \text{ in}$$

Thus, tile with a 5 inch diameter is adequate size for the laterals

(5) Compute velocity if pipe (5-in diameter) were flowing full

$$V = \frac{1.49\times R^{\frac{2}{3}}\times s^{\frac{1}{2}}}{n}$$

$$= \frac{1.49\times(0.104)^{\frac{2}{3}}\times(0.002)^{\frac{1}{2}}}{0.015}$$

= 0.98 ft/s (below maximum velocity of 1.5 ft/s to prevent erosion)

Sizing the VIB tile main

(1) Assume two mains sections, one draining each side of VIB

(2) Assume slope of pipe = 0.05% (0.0005 ft/ft)

(3) Non-perforated pipe so shouldn't have to worry about exceeding maximum velocity

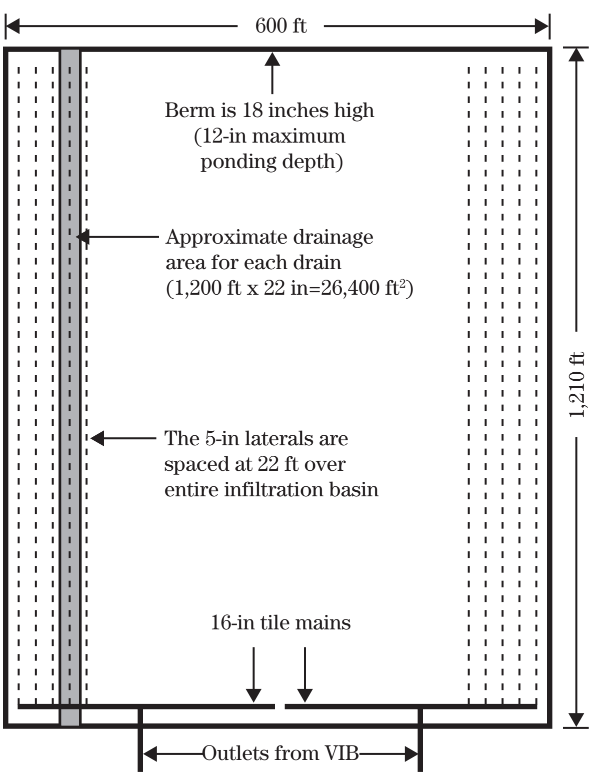
(4) Discharge from each main section

$$= 0.0132 \text{ ft/h} \times 0.5 \times (600 \times 1{,}200)$$
$$= 4{,}750 \text{ ft}^3/\text{h} = 1.32 \text{ ft}^3/\text{s}$$

$$\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{\frac{2}{3}} = \frac{1.32}{\dfrac{1.49 \times (0.0005)^{\frac{1}{2}}}{0.015}}$$
$$D = 1.27 \text{ ft} = 15.2 \text{ in}$$

Size of the main should be at least 16 inches.

Design summary



Appendix E Tolerance Factors

Table E–1 is a listing of a several tolerance factors for forages and legumes to various soil and moisture conditions as assembled by a team from the University of Montana and USDA NRCS. For information on additional crop tolerance factors not listed in this table log onto:

http://www.animalrangeextension.montana.edu/Aticles/Forage/Main-species.htm

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Table E–1 Tolerance factors

Species	pH tolerance	Salt tolerance	Moisture range	Tolerance to water table	Tolerance to early spring flooding	Drought tolerance
Forages						
Big bluegrass	2,3		12–22	4		2
Kentucky bluegrass	2,3		14–22	2		2
Smooth bromegrass	2,3	2	12+	3	35–56	2
Meadow bromegrass	2,3	2	14+	3		2
Reed canarygrass	1,2,3	2	15+	1	35–56	2
Tall fescue	1,2,3,4	1	16+	2		2
Creeping foxtail	2,3,4	2	18+	1		3
Meadow foxtail	2,3		18+	1	21–42	3
Green needlegrass	3		18–22	4		1
Orchardgrass	2,3	2	15+	3		2
Timothy	2,3		15+	2	21–56	3
Beardless wheatgrass	3		12–18	3		1
Bluebunch wheatgrass	3		10–18	4		1
Crested wheatgrass, fairway	3	1	10–18	4		1
Crested wheatgrass, standard	3	1	11–18	4		1
Intermediate wheatgrass	2,3	1	13–22	3	21–28	2
Pubescent wheatgrass	2,3	1	12–20	3		2
Siberian wheatgrass	3		10–18	4		1
Slender wheatgrass	2,3,4	1	12–20	3	35–56	1
Tall wheatgrass	3,4	1	14+	2	35–56	1
Thickspike wheatgrass	3	2	10–18	3		1
Western wheatgrass	3,4	1	12+	2		1
Russian wildrye	3,4	1	10–18	3	21–35	1
Altai wildrye	3,4	1	12–18	3	2	1
Legumes						
Alfalfa	2,3	2	12+	3	7–14	2
Red clover	1,2,3	3	16+	3		3
Alsike clover	1,2,3	3	16+	2	7–14	3
Ladino or white clover	1,2,3	3	16+	2		3
Dutch clover	1,2,3	3	14+	2		2
Sainfoin	3		12–20	4		2
Sweetclover, yellow or white	2,3	2	10+	3	7–14	1
Birdsfoot trefoil	1,2,3	2	14+	2		2
Cicer milkvetch	2,3	2	14+	2		2

pH tolerance

Soil pH levels:
1 = < 5.5 pH: Tolerant to strong acid conditions.
2 = 5.6 – 6.5 pH: Tolerant to weak acid conditions.
3 = 6.6 – 8.4 pH: Tolerant to neutral to moderately alkaline conditions.
4 = >8.5 pH: Tolerant to strongly alkaline conditions.

Salt tolerance

Salt tolerance is the relative capacity of a forage to produce satisfactory yield or cover on a salty site. Saline soils are usually a mixture of some of the chloride, sulfate or bicarbonate salts of calcium, magnesium, and sodium. The total concentration of ions in the soil-water solution influences plant response more than the specific salt composition. For most purposes, soil salinity levels can be determined using the electrical conductivity (EC) of the soil solution.

1 = Good salt tolerance
2 = Fair salt tolerance
3 = Poor salt tolerance

Salt tolerance in forage species is complex, and information on many species is lacking. Once established, most forages can tolerate fairly high levels of salinity. Caution is urged to carefully select species based on utilization needs for conservation practices, many species are available; however, for grazing or hay, salinity can affect production, palatability, and concentration of nutrients and minerals. Further, soils that are high in exchangeable sodium (sodic soils) present special problems in addition to those attributed to total salinity. High levels of exchangeable sodium break down organic matter and cause soil particles to disperse, resulting in small pores. Poor aeration, water movement, and root growth are associated with these changes in soil structure (black alkali soils). Leaching of sodium and application of soil amendments can improve soil structure.

Moisture range to which species is well adapted

Plant response to moisture is subject to many variables: elevation, exposure, total heat units, season when greatest amount of moisture is received, and runoff losses to name a few. Moisture, as used here, includes all sources: annual precipitation, natural flooding, and irrigation. Some species may do well in rows under lower moisture than shown since this makes the available moisture more effective.

In defining a moisture range for a species, the lower limit is the minimum at which the species gives satisfactory production in solid stand. The upper limit is the amount beyond which the species will not utilize additional moisture. If no upper limit is given, it means it does well under maximum precipitation experienced in forage producing areas in Montana or under irrigated conditions. Ratings are expressed as inches of moisture.

Tolerance to water table

1 = Species will grow on sites with soil-water at or above field capacity, will grow when the water is ponded on the surface for several weeks at a time, and will grow under marshy conditions.

2 = Species will grow on sites with the soil-water at or above field capacity for most of growing season. It does not grow well when water is ponded on the surface for more than a few days at a time.

3 = Species will grow on sites with the soil-water at or above field capacity for several weeks in early spring. It will not grow well on soils where the water is ponded on the surface during the growing season.

4 = Species will grow on well-drained sites without a water table.

Tolerance to early spring flooding

Ratings are given in days for several species (McKenzie, R.E., Vol. 31, 1951, Sci. Agric. pp. 358-367). Based on observations, estimates of flooding tolerance of mature plants have been made for other species. To distinguish between these and the research data these estimates are shown as follows:

Exc. = (excellent) more than 49 days
Good = 14 to 49 days
Poor = less than 14 days

Very little information is available on tolerance to summer flooding. It is known that plants are far less tolerant to flooding with warm water and even less to still, warm water.

Drought tolerance

This rates the ability of a species or strain to survive prolonged periods of dry weather. It rates survival during periodic severe drought but not relative yield in an arid climate. Ratings assume the species is well adapted to the soil site, is being utilized each year, and is under good management.

1 = High
2 = Medium
3 = Low

Appendix F Records for VTA Systems

Form 1: Livestock Manure and Effluent Discharge Notification

Caution: Individual permitting authorities will define which releases of runofff from a VTA will qualify as a discharge and require reporting within 24 hours. This question should be raised for clarification with permitting authority. The information requested in this form should also be verified with the individual permitting authority or preferred alternative record used by the permitting authority substituted for this record.

Name: ____
Permitted Operation Name

Owner/Manager: ____

Address: ____
P.O. Box/Street Address

____
City, State, and Zip Code

Legal Description of Operation

________, of ________, _____________N, ___________ ☐ E or ☐ W, ____________________ County
1/4 1/4 Section Township Range

Do you have an **NPDES** permit? ________ Yes ________ No **If** yes, Permit No. ________________

Do you have a **State** Permit? ________ Yes ________ No **If** yes, Permit No. ________________

Complete the following:

1. List reason(s) for discharge (i.e., power failure, large storm or chronic wet period, leak or break in the water supply system, component failure of the waste control facility; and/or releases during land application due to equipment failure, accidents or irrigation equipment failure):

   ____

   ____

2. The discharge flowed into ____
   (ditch, drainage way, stream name)

3. Did the discharge flow directly into surface water (stream, river, drainage ditch, lake, wetland) or did the discharge flow over cropland prior to discharging to surface water? ______________________

4. The approximate width and depth of the surface water (which the discharge entered):
   ____________________ (width in feet) and ____________________ (depth in feet)

5. The discharge started on (date and time): Please indicate if this was the actual time or if this was when the discharge was discovered.

   ____

   ____

6. The discharge ended on (date and time): Please indicate if this was the actual or the estimated time

   ____

   ____

(continued on next page)

Form 1: Livestock Manure and Effluent Discharge Notification (continued)

7. Average flow of the discharge was: ____(gallons/minute)

8. Estimated total volume of discharge (ft^3): ______________________________________(L x W x D)

9. List any damage to the waste control facility: ____

____

____

10. Describe factors and conditions that were used to minimize the adverse effects to the environment from the discharge:

____

____

____

Additional Information

1. You may submit rainfall, land application, and system storage records for up to a 12-month period prior to the discharge event to demonstrate the need for the discharge.

2. Samples of discharge are required for all NPDES permitted animal feeding operations. The following characteristics should be analyzed. Sample locations, at a minimum, must include point of discharge, upstream, downstream and the mix zone (where the discharge mises with surface water). Provide a map with collection sites marked.

   a) Five-day Biochemical Oxygen Demand (BOD^5)
   b) total ammonium-nitrogen
   c) nitrate-nitrite nitrogen
   d) pH (field measurement)
   e) temperature of the effluent and receiving stream (field measurement)
   f) total phosphorus
   g) total suspended solids
   h) Escherichia coli or fecal coliform

3. Was sample kept cool with ice or frozen during time between sample was taken and delivery to lab?
   ______ Yes ______ No

I HEREBY CERTIFY THAT THE INFORMATION SUBMITTED HEREIN IS TRUE AND CORRECT TO THE BEST OF MY KNOWLEDGE AND BELIEF.

X____

Signature of authorized representative Date

Form 2: Record of Precipitation, Land Application, and Liquid Levels

Purpose: A record of precipitation, land application events, and liquid levels is required for all permitted storage facilities for containing storm related runoff from open lot production systems.

Month and Year: _________________ **Settling Basin ID:** _________________ **VTA Site ID:** _________________

Day	Precipitation	Vegetative Treatment Area					
		Hour pumping or release started	Hour pumping or release stopped	Flow rate (gpm)	Total volume released or pumped	Check if discharge from VTA[1]	Settling basin or pond liquid level[2]
1	in.			gpm	gal.		ft.
2	in.			gpm	gal.		ft.
3	in.			gpm	gal.		ft.
4	in.			gpm	gal.		ft.
5	in.			gpm	gal.		ft.
6	in.			gpm	gal.		ft.
7	in.			gpm	gal.		ft.
8	in.			gpm	gal.		ft.
9	in.			gpm	gal.		ft.
10	in.			gpm	gal.		ft.
11	in.			gpm	gal.		ft.
12	in.			gpm	gal.		ft.
13	in.			gpm	gal.		ft.
14	in.			gpm	gal.		ft.
15	in.			gpm	gal.		ft.
16	in.			gpm	gal.		ft.
17	in.			gpm	gal.		ft.
18	in.			gpm	gal.		ft.
19	in.			gpm	gal.		ft.
20	in.			gpm	gal.		ft.
21	in.			gpm	gal.		ft.
22	in.			gpm	gal.		ft.
23	in.			gpm	gal.		ft.
24	in.			gpm	gal.		ft.
25	in.			gpm	gal.		ft.
26	in.			gpm	gal.		ft.
27	in.			gpm	gal.		ft.
28	in.			gpm	gal.		ft.
29	in.			gpm	gal.		ft.
30	in.			gpm	gal.		ft.
31	in.			gpm	gal.		ft.

1. This column should be checked if pump out or VTA discharge is directed to surface waters, wetlands, ditch or drainage connecting to surface waters. Regulatory authority should be notified by phone within 24 hours.
2. Liquid level is measured from: _____low point at top of berm, dam, or spillway; _____bottom of storage; _____must pump level mark on liquid level indicator.

Measure to the nearest one foot increment.

Form 3: Vegetated Treatment System Inspection Checklist

Checks in shaded boxes suggest potential problem or risk.

Farm:______________________________________ Facility ID: ______________________________________ Year: _____________________

Date								
Inspected by (initials)								

Solids settling component observations

	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Comments
Signs of berm/dam damage due to:																	
Burrowing animals?																	
Presence of trees or large weeds?																	
Erosion, gullies or poorly established sod?																	
Is solids accumulation excessive?																	
For settling basins, is maximum solids storage clearing marked and visible?																	
Are gravity drained outlets free of obstructions?																	
Security: Are gravity drain valves or pump power supplies locked/secure from tampering?																	

Vegetated Treatment Area (VTA)

	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Comments
Do VTA inlets appear to evenly distribute flow?:																	
Are VTA inlets free of obstructions and debris?																	
Are there signs of erosion/damage to field border?																	
Signs of channel or non-uniform flow?																	
Presence of wheel ruts or gullies?																	
Presence of eroded areas?																	
Infield spreader erosion/maintenance needs?																	
Signs of ponding within VTA?																	
Signs of high areas which runoff does not reach?																	
Does forage need to be harvested?																	
Are there signs of fertility deficiencies?																	
Are there signs of undesirable plant species?																	
Is there a good stand of forage in first 50 ft?																	
Is there a good stand of forage in rest of)?																	

Form 3: Vegetated Treatment System Inspection Checklist (continued)

Checks in shaded boxes suggest potential problem or risk.

Date																
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**

Vegetative Infiltration Basin (VIB)

																	Comments
Signs of berm/dam damage due to:																	
Burrowing animals?																	
Presence of trees or large weeds?																	
Erosion, gullies, or poorly established sod?																	
Is water flowing from all drainage tile runs?																	
Is there a good stand of forage in first 1/3 of VIB?																	
Is there a good stand of forage in last 2/3 of VIB?																	
Does water drain from VIB within three days?																	
Does water spread evenly over VIB?																	

Clean Water Diversion

Signs of berm/dam damage due to:																	
Burrowing animals?																	
Presence of trees or large weeds?																	
Erosion, gullies, or poorly established sod?																	
Are perimeter drains plugged or blocked?																	
Is roof water entering storage?																	
Is field runoff entering storage?																	
Are diversions/waterways maintained?																	

Visual Appearance and Safety

Is site neat and recently mowed?																	
Are mortality or afterbirth observed?																	
Are medical consumables observed?																	
Is area fenced and properly marked?																	

Form 4: VTA System Maintenance Record

Date	Component or equipment	Maintenance performed	Worker initials

Form 5: VTA Documentation of Nutrient Management

Review Ground Water Protection and Soil Sampling discussion in Chapter 8

Farm Owner: ______________________ **VTA ID:** ______________ **Crop:** ______________

Sample date	Nitrogen management monitoring options[1]						Shallow soil test results							
	Option 1: Soil nitrate level (ppm) and sample depth (inches)		Option 2: Forage nitrate level (ppm)	Option 3: Crop nitrogen removal			Soil organic matter		Soil residual P		Soil EC (mmhos/cm)		Soil pH	
	First 50 ft	Rest of VTA		Tons harvested	Percent protein	lbs. N[2] removal	First 50’	Rest of VTA	First 50’	Rest of VTA	First 50’	Rest of VTA	First 50’	Rest of VTA

[1] Only one of these three indicators of nitrogen management is recommended unless risk to ground water is high.
[2] lbs N removed = tons harvested x % protein x 20/6.25.