Section 9 Literature Review

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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)

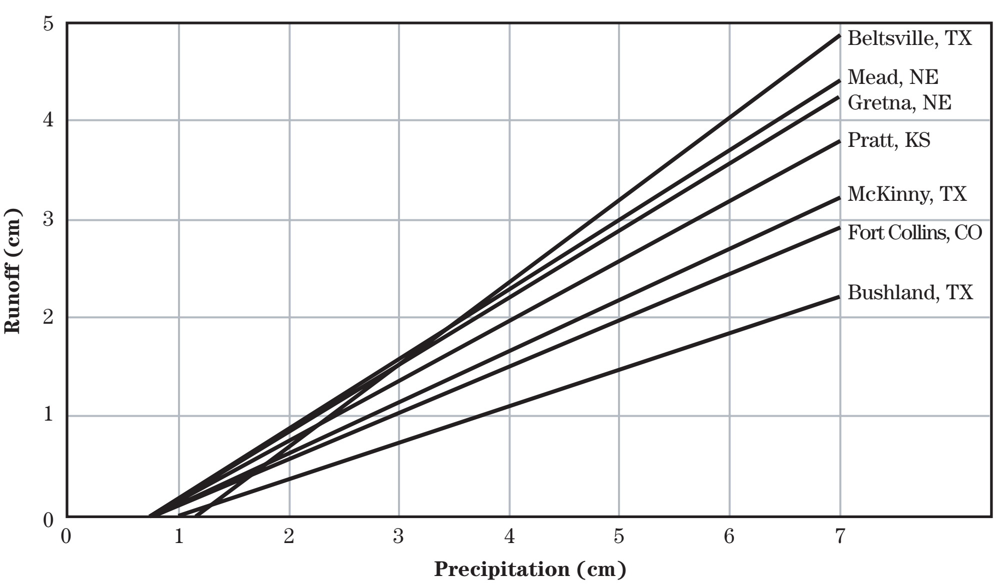
Source	Total solids (ppm)	Electrical conductivity (mmho/cm)	Chemical oxygen demand (ppm)	Total nitrogen (ppm)	Total phosphorus (ppm)	Sodium (ppm)	Potassium (ppm)
Feedlot runoff[1]							
Average	11,200	6,500	9,200	580	120	440	1,020
Range	3,000–17,500	3,200–8,600	2,200–17,800	80–1,080	50–300	230–590	340–1,320
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

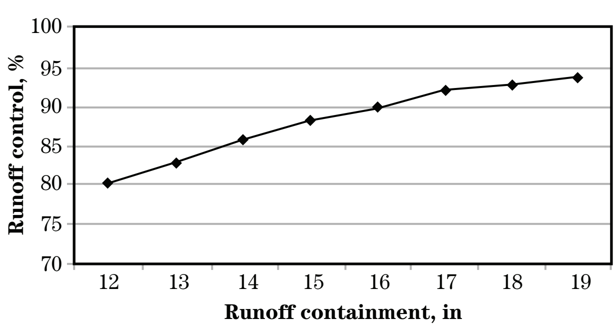
The predicted performance of the baseline system illustrated regular discharge occurrences for all scenarios evaluated. Northeast and East Central Iowa conditions produced the most frequent discharges and the lowest volume of runoff control. Land application systems that were not able to land apply runoff 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)

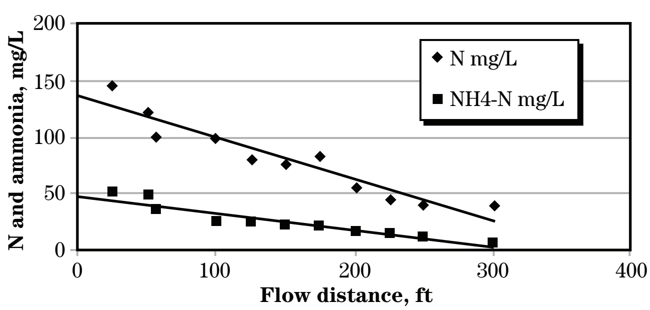


Figure 9–4 Nutrient removal by VTA based upon VTA to feedlot drainage area (DA) ratio for references listed in tables 9–8 and 9–9

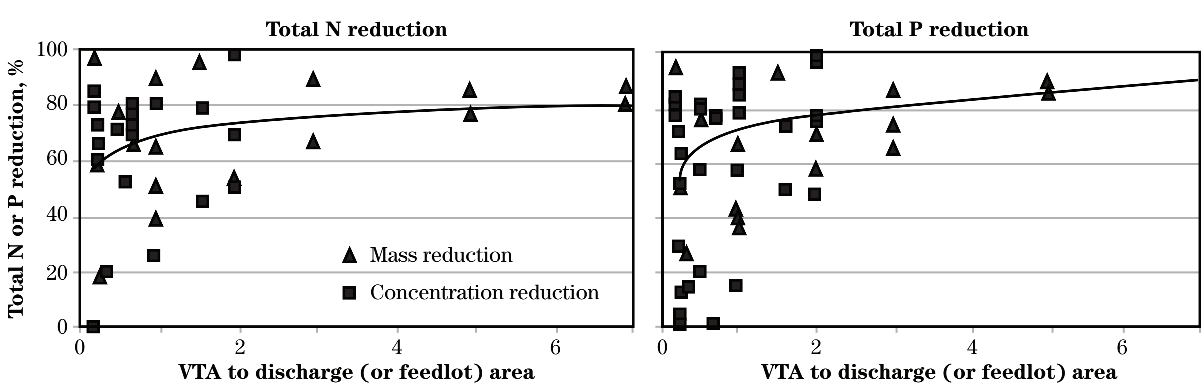


Table 9–8 Summary of VTA performance when placed on commercial or research livestock facilities

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
				Org N			NO_3-N before:							
61–81			69–87	69–85		69–92	1 ppm		62–91	73–93				c
							After 1 and 2:							
55–83			59–86	59–87		56–89	76 and 64 ppm		63–89	67–90				c
				Org N										
82			85	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) 225 head feedlot	Yes Yes	79 58	0.2 0.2	1.2 0.5	Grass Grass	silt loam 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 Mass reductions at: 30 m 150 m	silt loam
Paterson et al. 1980	Milking center waste and barnyard runoff from 70 cow dairy studied for a 5-yr period	5 yr	Natural rainfall Snow melt Perched water table	Yes	36		3.4	Tall fescue	Silt loam
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	m
	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 feed-lot 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 trans-port 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 organ-isms • 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/m² 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.

References

Anschutz, J.A., J.K. Koelliker, J.J. Zovne, T.A. Bean, and M.J. Peterson. 1979. Sizing components on open feedlot runoff control systems. Trans. of ASAE. 22:803–808.

Barker, J.C. and B.A. Young. 1984. Evaluation of a vegetative filter for dairy wastewater treatment in southern Appalachia. North Carolina State University research report. Published by US Department of Commerce, National Technical Information Service. 69 pp.

Brach, J.C. 2003. Feedlot runoff control, the Minnesota approach. ASAE Paper Number 032310. 2003 ASAE Annual International Meeting. 6 pp.

Chaubey, I., D.R. Edwards, T.C. Daniel, P.A. Moore and D.J. Nichols. 1994. Effectiveness of vegetative filter strips in retaining surface applied swine manure constituents. Trans. ASAE. 37(3): pp. 845–850.

Chaubey, I., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. and D.J. Nichols. 1995. Effectiveness Of vegetative filter strips in controlling losses of surface-applied poultry litter constituents. Trans. ASAE. 38(6): pp. 1687–1692.

Clark, R.N., C.B. Gilbertson, and H.R. Duke. 1975. Quantity and quality of beef feed yard runoff in the Great Plains. Managing Livestock Wastes, The Proceedings of the 3rd International Symposium on Livestock Wastes. ASAE. St. Joseph, MI. pp. 429–431.

Coyne, M.S., R.A. Gilfillen, A. Villalba, Z. Zhang, R. Rhodes, L. Dunn, and R.L. Blevins. 1998. Fecal bacterial trapping by grass filter strips during simulated rain. Journal of Soil and Water Conservation. 53(2): pp. 140–145.

Culbertson, T.L. and S.L. Hutchinson. 2004. Bioretention cell. Resource: Engineering & Technology for a Sustainable World. March 2004. ASAE. St. Joseph, MI. pp. 9–10.

Dickey, E.C. and D.H. Vanderholm. 1981a. Performance and design of vegetative filters for feedlot runoff treatment. Livestock Waste: A Renewable Resource. Proc. of the 4th International Symposium on Livestock Wastes, 1980. ASAE. St. Joseph, MI. 49085. pp 257–260.

Dickey, E.C. and D.H. Vanderholm. 1981b. Vegetative filter treatment of livestock feedlot runoff. J. Environ. Qual. 10(3): pp. 279–284.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, V. O. Shanholtz. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. Journal of the Water Pollution Control Federation. 60(7): pp. 1231–1238.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, V.O. Shanholtz and W.L. Magette. 1986. Use of vegetative filter strips to minimize sediment and phosphorus losses from feedlots: Phase I. Experimental Plot Studies. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University. Bulletin 151.

Edwards, W.M., L.B. Owens and R.K. White. 1983. Managing runoff from a small, paved beef feedlot. J. Environ. Qual. 12(2): pp. 281–286.

Edwards, W.M., L.B. Owens, R.K. White and Fausey, N.R. 1986. Managing feedlot runoff with a settling basin plus tiled infiltration bed. Transactions of ASAE. 29(1): pp. 243–247.

Erickson, G. and W. Kissinger. 2004. Unpublished runoff data from five years of nutrient balance studies on University of Nebraska beef feed yard. Personal communications, June 1, 2004.

Fajardo, J.J., J.W. Bauder and S.D. Cash. 2001. Managing nitrate and bacteria in runoff from livestock confinement areas with vegetative filter strips. Journal of Soil and Water Conservation. 56(3): pp. 185–191.

Fausey, N.R., W.M. Edwards, L.B. Owens and R.K. White. 1988. Subsurface drained infiltration beds for feedlot runoff management. Transactions of ASAE. 31(1): pp. 98–101.

Federal Register. 2003. 40 CR Parts 9, 122, 123, and 412, National Pollution Discharge Elimination System Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations; Final Rule. February 12, 2003. 68(29): pp. 7176–7274.

Fields, W. 1971. Hydrologic and water quality characteristics of beef feedlot runoff. M.S. Thesis. Kansas State University. Manhattan, KS.

Fischer, J.R., D.M. Sievers and C.D. Fulhage. 1975. Settling characteristics of swine manure as related to digester loading. In Managing Livestock Wastes. Proceedings of the 3rd International Symposium on Livestock Waste, American Society of Agricultural Engineers, St. Joseph, MI. pp. 456–462.

Gilbertson, C.B., T.M. McCalla, J.R. Ellis, O.E. Cross, and W.R. Woods. 1970. The effect of animal density and surface slope on unpaved beef feedlots. Nebraska Agr. Exp. Sta. Pub. No. SB508.

Gilbertson, C.B., T.M. McCalla, J.R. Ellis, and W.R. Woods. 1971. Methods of removing settleable solids from outdoor beef cattle feedlot runoff. Transactions of ASAE. 14(5): pp. 899–905.

Gilbertson, C.B., J.A. Nienaber, T.M. McCalla, J.R. Ellis, and W.R. Woods. 1972. Beef cattle feedlot runoff, solids transport and settling characteristics. Transactions of the ASAE 15(6): pp. 1132–1134.

Gilbertson, C.B. and J.A. Nienaber. 1973. Beef cattle feedlot runoff – physical properties. Transactions of ASAE. 16(5): pp. 997–1001.

Gilbertson, C.B. and J.A. Nienaber. 1973. Feedlot runoff control system design and installation – A case study [1]/ Proceedings, Livestock Waste Management System Design Conference for Consulting and SCS Engr. University of Nebraska. pp. IV 1 – IV 16.

Gilbertson, C.B., J.A Nienaber , J.L. Gartung, J.R. Ellis and W.E. Splinter. 1979. Runoff control comparisons for commercial beef cattle feedlots. Trans of the ASAE Paper No. 842–847. ASAE, St. Joseph, MI 49085.

Gilbertson, C.B., Ellis, J.A Nienaber, T.M. McCalla and T.J. Klopfenstein. 1975. Physical and chemical properties of outdoor beef cattle feedlot runoff. Agricultural Experiment Station, University of Nebraska. 16 pp.

Gillbertson, C.B., J.C. Nye, R.N. Clark, N.P. Swanson. 1981. Controlling runoff from livestock feedlots: a state of the art. U.S. Department of Agriculture, Agricultural Research Service. Agricultural Information Bulletin 441. 19 pages.

Goel, P.K., R.P. Rudra, B. Gharabaghi, S. Das, N. Gupta. 2004. Pollutants removal by vegetative filter strips planted with different grasses. ASAE paper no 042177. Presented at 2004 International ASAE Meeting, Ottawa, CA. August 4, 2004. 14 pp.

Hawkins, G.L., D.T. Hill, E.W. Rochester, and C.W. Wood. 1998. Evaluation of vegetative filter strips for swine lagoon wastewater. Trans. ASAE. 41(3): pp. 639–643.

Harner, J.P. and P.K. Kalita. 1999. Vegetative filters for improving environmental quality. Cattlemen's Days 1999 conference proceedings. Kansas Agricultural Experiment Station. Kansas State University. pp 44–47.

Hubbard, R.K., R.R. Lawrence, J.G. Davis, and G.L. Newton. 1994. Removing nitrogen from swine waste using riparian zones. 1994 International ASAE Summer Meeting. ASAE Paper number 94–4070. 18 pp.

Hubbard, R.K., J.M. Ruter, G.L. Newton, and J.G. Davis. 1999. Nutrient uptake and growth response of six wetland/riparian plan species receiving swine lagoon effluent. Transactions of ASAE. 42(5): pp. 1331–1341.

Ikenberry, C.D. and K.R. Mankin. 2000. Review of vegetative filter strip performance for animal waste treatment. Presented at the 2000 ASAE Mid-Central Meeting, Paper No. MC00–128. American Society of Agricultural Engineers, St. Joseph, MI 49085.

Iowa Department of Natural Resources. 2004. Siting criteria: non-basin technology for waste treatment systems for open feedlots. Shared by Gene Tinkler, IDNR, by personal communications, July 2004. 9 pp.

Keaton, M.R., P.K. Kalita, J.P. Harner, S.K. Starrett. 1998. Evaluation of vegetative filter strips for nutrient removal from feedlot runoff. American Society of Agricultural Engineers. 1998 ASAE Annual International Meeting. Paper No. 98–2014. 20 pp.

Koelliker, J.K., H.L. Manges and R.I. Lipper. 1975. Modeling the performance of feedlot-runoff control facilities. Trans of the ASAE 18 (6) pp. 1118–1121.

Komor, S.C. and D.S. Hansen. 2003. Attenuation of runoff and chemical loads in grass filter strips at two cattle feedlots, Minnesota, 1995–98. U.S. Geological Survey. Denver, CO. Water-Resources Investigations Report 03–4036. 15 pp.

Lim, T.T., D.R. Edwards, S.R. Workman and B.T. Larson. 1997. Vegetated filter strip length effects on quality of runoff from grazed pastures. Paper No. 97–2060. American Society of Agricultural Engineers, St. Joseph, MI 49085.

Lim, T.T., D.R. Edwards, S.R. Workman, a B.T. Larson and L. Dunn. 1998. Vegetated filter strip removal of cattle manure constituents in runoff. Trans. ASAE 41(5): pp. 1375–1381.

Linderman, C.L. and L.N. Mielke. 1975. Irrigation with feedlot runoff. Nebraska short course irrigation proceedings. University of Nebraska. June 20–21, 1975. pp. 26–36.

Lorimor, J.C., S.W. Melvin, and K. Adam. 1995. Settling basin performance from two outdoor feedlots. Presented at ASAE Mid Central Conference, St. Joseph, MO.

Lorimor, J.C., L. Wulf, and P. Jaranilla. 2003. An infiltration-wetland system for treating open feedlot runoff. Proceedings of the 9th International Symposium. ASAE. pp. 405–410.

Lott, S.C., R.J. Loch, and P.J. Watts. 1994. Settling characteristics of feedlot cattle feces and manure. Transactions of the ASAE 37(1): pp. 281–285.

Mankin, K.R. and C.G. Okoren. 2003. Field evaluation of bacteria removal in a VHS. Paper No. 032150. Presented at 2003 ASAE Annual International Meeting, Las Vegas, NV. 9 pp.

Minnesota Pollution Control Agency. 2003. Vegetated infiltration areas and filter strips to treat feedlot runoff: interim guidelines. *www.pca.state.mn.us/hot/feedlots*. 12 pp.

Moffit, D., B. Wilson, P. Willey. 2003. Evaluating the design and management of waste storage ponds receiving lot runoff. 2003 ASAE Annual International Meeting. Paper no. 034129. 12 pp.

Monkus, V. 1964. Estimation of runoff from storm rainfall. Chapter 10. National Engineering Handbook. USDA NRCS Publication NEH Part 630–10 (*ftp://ftp.wcc.nrcs.usda.gov/downloads/ hydrology_hydraulics/neh630/630ch10.pdf*). 24 pp.

Montana NRCS. 2003. Analysis procedures for ag-waste collection basin/VFS. Montana Supplement to Chapter 10 of the Agricultural Waste Management Field Handbook.

Moore, J.A., R.O. Hegg, D.C. Scholz, and Egon Strauman. 1973. Settling solids in animal waste slurries. 1973 ASAE Annual International Meeting. ASAE pp. 73–438.

Murphy, J.P. and J.P. Harner. 1999. Runoff compliance for Kansas cattle feedlots. Cattlemen's Days 1999 conference proceedings. Kansas Agricultural Experiment Station. Kansas State University. pp. 40–43.

Murphy, P. and J.P. Harner. 2001. Open lot runoff management options. Livestock Poultry Environmental Stewardship curriculum, Lesson 22. *http://www.LPES.org*. 30 pp.

Murphy, T.J. and W.M. Bogovich. 2001. Vegetated filter areas for agricultural wastewater treatment. 2001 ASAE Annual International Meeting. ASAE paper number 012296. 12 pp.

MWPS. 1985. Livestock waste facilities Handbook. Midwest Plan Service Publication MWPS–18. Iowa State University, Ames, IA.

Nienaber, J.A., C.B. Gilbertson, T.M. McCalla and F.M. Kestner. 1974. Disposal of effluent from a beef cattle feedlot runoff control holding pond. Transactions of ASAE. 17(2): pp. 375–378.

Norman, D.A. and Edwards, W.M. 1978. Design criteria for grass filter areas. ASAE paper number 78–2573. Presented at 1978 American Society of Agricultural Engineers Winter Meeting. 7 pp.

Nye, J.C. 1982. Runoff control fro livestock feedlots. Research results in manure digestion, runoff, refeeding, odors. North Central Regional Research Publication No. 284. Midwest Plan Service. pp. 10–17.

Overcash, M.R., S.C. Bingham and P.W. Westerman. 1981. Predicting runoff pollutant reduction in buffer zones adjacent to land treatment sites. Trans. ASAE 24(2): pp. 430–435.

Paterson, J.J., J.H. Jones, F.J. Olsen and G.C. McCoy. 1980. Dairy liquid waste distribution in an overland flow vegetative-soil filter system. Transactions of ASAE. 23(4): pp. 973–978.

Pope, R.O. and D.E. Stoltenberg. 1991. A review of literature related to vegetative filter strips. Agronomy Department publication. Iowa State University, Ames, IA. 15 pp.

Prantner, S.R., R.S. Kanwar, J.C. Lorimor and C.H. Pederson. 2001. Soil infiltration and wetland microcosm treatment of liquid swine manure. Applied Engineering in Agriculture. 17(4): pp. 483–488.

Sanderson, M.A., R.M. Jones, M.J. McFarland, J. Stroup, R.L. Reed and J.P., Muir. 2001. Nutrient movement and removal in a switchgrass biomass-filter strip system treated with dairy manure. J. Environ. Qual. 30(1): pp. 210–216.

Schellinger, G.R. and J.C. Clausen. 1992. Vegetative filter treatment of dairy barnyard runoff in cold regions. J. Environ. Qual. 21: pp. 40–45.

Schmitt, T.J., M.G. Dosskey and K.D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. J. Environ. Qual. 28(5): pp. 1479–1489.

Schwer, C.B. and J.C. Clausen. 1989. Vegetative filter treatment of dairy milkhouse wastewater. J. Environ. Qual. 18: pp. 446–451.

Srivastava, P., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. and T.A. Costello. 1996. Performance of vegetative filter strips with varying pollutant source and filter strip lengths. Transactions of the ASAE 39(6): pp. 2231–2239.

Swanson, N.P. and L.N. Mielke. 1973. Solids trap for beef cattle feedlot runoff. Transactions of ASAE. 16(4): pp. 743–745.

Swanson, N.P., L.N. Mielke, J.C. Lorimor, T.M. McCalla and J.R. Ellis. 1971. Transport of pollutants from sloping cattle feedlots as affected by rainfall intensity, duration, and recurrence. Proceedings of the International Symposium on Livestock Wastes. ASAE., St. Joseph, Mich. pp 51–55.

Sweeten, J.M. 1991. Cattle feedlot waste management practices for water and air pollution control. Texas Agricultural Extension Service. Texas A&M University. College Station, TX. 24 pp.

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

Vanderholm, D.H. and E.C. Dickey. 1980 Design of vegetative filters for feedlot runoff treatment in humid areas. Transactions of ASAE. 23(3): pp. 661–684.

Williamson, T.S. 1999. Effectiveness of vegetative filter strips in reducing fecal coliform from surface runoff. Unpublished Masters Thesis. Biological & Agricultural Engineering. Kansas State University, Manhattan, KS.

Willrich, T.L. and J.O. Boda. 1976. Overland flow treatment of swine lagoon effluent. ASAE Paper No. 76–4515. St. Joseph, MI 49085.

Wilson, B,W. Boyd and D. Moffitt. 2003. AWM: A computer program for planning/design of manure and wastewater storage/treatment facilities. 2003 ASAE Annual Meeting. Paper no. 034160. 9 pp.

Woodbury, B.L., J.A. Nienaber and R.A. Eigenberg. 2003a. Sustainability of a passive feedlot runoff control system using a vegetative filter strip for nutrient control. Presented at the 2003 ASAE Annual International Meeting, Las Vegas, NV. Paper No. 032269.

Woodbury, B.L., J.A. Nienaber and R.A. Eigenberg. 2002. Operational evaluation of a passive beef cattle feedlot runoff control and treatment system. Applied Engineering in Agriculture, Volume 18 (5) pp. 541–545.

Woodbury, B.L., J.A. Nienaber and R.A. Eigenberg. 2003b. Nitrogen management of a feedlot runoff control system with vegetative filter strip. Proceedings of the 9th International Symposium. pp. 372–376.

Wulf, L.W., J.C. Lorimor and S.W. Melvin. 2003. Modifications to feedlot runoff containment systems in Iowa. Animal, Agricultural and Food Processing Wastes IX. Proceedings of the Ninth International Symposium. ASAE. St. Joseph, MI. pp. 387–396.

Wulf, L.W., J.C. Lorimor and S.W. Melvin. 2004. Modifications to feedlot runoff containment systems in Iowa. Paper submitted to ASAE Applied Engineering Journal.

Yang, P. and J. Lorimor. 2000. Physical and chemical analysis of beef cattle feedlot runoff before and after soil infiltration and wetland treatment. Presented at the Eighth International Symposium on Ag and Food Processing Wastes. Oct. 9–11, 2000. ASAE. St. Joseph, MI. pp. 203–209.

Younos, T.M., A. Mendez, E.R. Collins, and B.B. Ross. 1998. Effects of a dairy loafing lot-buffer strip on stream waster quality. Journal of American Water Resources Association. 34(5): pp. 1061–1069.

Young, R.A., T. Huntrods and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. J. Environ. Qual. 9(3) pp. 483–487.

Zhang, Q., C.G. Okoren and K.R. Mankin. 2001. Modeling fecal pathogen transport in vegetative filter strips. Presented at 2001 ASAE Annual International Meeting. Paper no. 012194. 16 pp.