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VEGETATIVE TREATMENT SYSTEMS FOR MANAGEMENT OF OPEN LOT RUNOFF: REVIEW OF LITERATURE

R. K. Koelsch, J. C. Lorimor, K. R. Mankin

ABSTRACT. *Runoff from open lot livestock systems (beef and dairy) defined as Concentrated Animal Feeding Operations (CAFO) 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-yr, 24-h 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 article reviews the research literature on vegetative treatment systems (VTS) for managing open lot runoff summarizing available science on system performance, design, and management.

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

(1) Substantial research (approximately 40 identified field trials and plot studies) provides a basis for understanding the performance of VTS. These performance results suggest that a vegetative system consisting of a settling basin and VTA or Vegetative Infiltration Basin (VIB) has the potential to achieve functional equivalency to conventional technologies.

(2) 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.

(3) The pollutant reduction resulting from a VTS is based upon two primary mechanisms: 1) sedimentation, typically occurring within the first few meters of a VTS, and 2) infiltration of runoff into the soil profile. Systems relying primarily on sedimentation only are unlikely to perform equal to or better than baseline technologies. System design based upon sedimentation and infiltration is necessary to achieve a required performance level for CAFO application.

(4) Critical design factors specific to attaining high levels of pollutant reduction within a VTS include pre-treatment, sheet flow, discharge control, siting, and sizing. Critical management factors include maintenance of a dense vegetation stand and sheet flow of runoff across VTA as well as minimization of nutrient accumulation.

Keywords. *Vegetative Treatment Systems, Vegetative Infiltration Basin, Feedlot, Runoff.*

Runoff from open lot livestock production systems continues to be a contributor to surface and groundwater impairment. Vegetative Treatment Systems (VTS) applied to open lot systems represent an alternative technology that may potentially achieve significant pollutant reduction. [The terms VTS and VTA will both be used. Vegetative Treatment Area (VTA) applies to a cropped area with perennial grass or forage specifically designed to manage runoff from an open lot livestock facility. VTS will refer to the combination of treatment components including a VTA or Vegetative Infiltration Basin (VIB) and other possible treatment components (e.g. solids settling).]

The United States Environmental Protection Agency (USEPA), National Pollutant Discharge Elimination System (NPDES) establishes a technology-based standard that defines the acceptable performance for runoff control on permitted facilities. 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 Concentrated Animal Feeding Operations (CAFO).

The 2003 final federal rule for the NPDES Permit Regulation and Effluent Limitation Guidelines (ELG) and Standards for CAFOs (Federal Register, 2003) sets the 25-yr, 24-h storm technology standard for baseline systems (runoff holding facilities dewatered by irrigation systems). The federal rule also opens the door for alternative technologies (such as a VTS) if they can be documented to achieve equal or better pollutant control performance as the baseline technology. A “site-specific comparison” provision within these regulations places the burden of proof on the individual producer for comparing the baseline and alternative technology for individual farms.

The objective of this article is to summarize the knowledge base for VTS. This literature review provided a foundation for the development of a USDA Natural Resource Conservation Service guidance document on VTS siting, design, and management. At the time this review was

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prepared, a draft of this guidance document was available at http://www.heartlandwq.iastate.edu/manure.

PERFORMANCE MODELS FOR VTS

An Iowa State University VTS software modeling tool has been designed to predict the performance of a site-specific VTS to meet the Voluntary Alternative Performance Standards (see Introduction) of the new EPA CAFO rules (Wulf et al., 2003). The VTS model performs site-specific modeling using daily weather inputs to estimate the performance of site-specific feedlots and VTS designs. The model uses weather data for 25-yr period to compare performance of the alternative VTS (median outflow for 25-yr period times pollutant concentration) with baseline containment system performance for the same site. It follows procedures outlined by the Voluntary Alternative Performance Standards provisions of the CAFO regulations (Federal Register, 2003). At the time this literature review was prepared, a peer review process for the model was completed and the Iowa Department of Natural Resources has accepted model results as acceptable documentation for an NPDES permit application.

Another systematic model was develop by a collaboration of several Minnesota agencies to identify appropriate applications of VTSs to feedlot runoff (Brach, 2003; Minnesota Pollution Control Agency, 2003). They 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.

IN-FIELD VTS PERFORMANCE

Literature review of performance data from 16 research citations reporting 40 sets of performance data under field conditions are listed in table 1. An additional 16 research citations reporting 58 sets of performance data under simulated conditions are included in table 2. Results are for both VTAs and Vegetative Infiltration Basins (VIB). The preponderance of the performance data is for a VTA. VTA efficiency was estimated from 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.

VTAs provide an opportunity for reduction of pollutants in runoff through two primary mechanisms: 1) sedimentation, typically occurring within the first few meters of a VTA, and 2) 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 (e.g., restricting movement of most protozoa and bacteria), immobilization (e.g., soil cations immobilizing ammonium), aerobic processes (e.g., conversion of organic compounds to water and carbon dioxide), and anaerobic process (e.g., conversion of nitrates to nitrogen gas). The VTA also allows the uptake of nutrients by plants (Fajardo et al., 2001).

TYPE OF VTA

Ikenberry and Mankin (2000) defined a VTA as a band of planted or indigenous vegetation situated down-slope 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 plant-based treatment systems:

- Grass filters can be designed with a 1% to 4% slope and 61 m (200 ft) of filtering length per 1% slope. Total area should be designed to match crop nitrogen uptake with estimated N in runoff. Sheet 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 suggest that seasonal open lots used for winter livestock housing and empty during the summer may be a preferred application for constructed wetlands.
- Infiltration basins are a containment type of system with a 30- to 60-cm (12- to 24-in.) berm placed around the vegetated area. They can be designed as discharging or non-discharging systems. A vegetative area necessary to infiltrate design runoff within 30 to 72 h must be considered in the sizing of an infiltration basin.
- 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.

FLOW WITHIN VTA

VTAs can be classified as either channelized or sheet 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, sheet flow.

Channelized surface flow in VTAs results in non-uniform nutrient and hydraulic loading of VTA thereby reducing system performance and increasing soil erosion. Sheet flow systems allow a uniform loading of runoff (across the width of the VTA) at a relatively shallow depth (<4 cm). Uniform flow results in a slower velocity, which allows sediment and nutrients to be trapped by the vegetation and adsorbed by the soil. Dickey and Vanderholm (1981b) showed progressively better removal of TKN and ammonium (NH_4^+) with VTA length for a 100-head dairy and 500-head beef lot (fig. 1). Lim et al. (1997) and Chaubey et al. (1995) demonstrated that a first-order exponential relationship better described the interaction between VTA length and pollutant transport.

Table 1. Summary of VTA performance (no pre-treatment performance included in values) on commercial or research livestock facilities. This table was originally developed by Ikenberry and Mankin (2000) and updated with additional references. Reductions are either in concentration or mass for individual studies as indicated by the last column.

Study Description			VTA Information							Percent Reduction													
Reference	Summary	Study Period	Pollutant Source	Settling Basin	Length (m)	AR (1)	Slope (%)	Vegetation	Soil	TS	TSS	BOD$_5$	COD	Total N	TKN	NH$_4$-N (2)	NO$_3$-N (3)	Total P	Ortho-P	FC	FS	E. Coli	(4)
Adam et al., 1986	Settling basin and vegetative filter operated below 75 head feedlot in Quebec cold climate.	70 mm on 9/27/86	75 hd beef feedlot	Y	108	2.3	0.75%	Kentucky blue grass	Sandy loam	99.5			99.9		99.9	99.9		<0.01 kg	<0.01 kg				m
			For 21 additional snow and rainfall feedlot runoff events between September 1985 and April 1986, 100% treatment efficiency occurred with no VTS runoff observed.																				
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 9 m intervals were designed to create a cascading type system. System was monitored over two years	5/82 – 5/84	Milking Center wastewater only	Yes	91 Width =23	--	10	Orchard grass and foxtail at upper end. Hairy crabgrass in drier areas.	VTA only	90	--	--	96	97	97	99	82	98	--	--	--	--	c
									VTA+ Basin	95	--	--	98	99	99	98	81	98	--	--	--	--	c
									VTA only	99	--	--	100	100	100	100	99	100	--	--	--	--	m
									VTA+ Basin	100	--	--	100	100	100	100	99	100	--	--	--	--	m
			Milking center waste water and paved dairy lot runoff	Yes	91 Width =23	--	10	Orchard grass and foxtail at upper end. Hairy crabgrass in drier areas.	VTA only	45	--	--	56	46	46	55	-68	68	--	--	--	--	c
									VTA+ Basin	65	--	--	65	60	60	40	-17	68	--	--	--	--	c
									VTA only	97	--	--	98	97	97	98	92	98	--	--	--	--	m
									VTA+ Basin	98	--	--	98	98	98	97	94	98	--	--	--	--	m
Dickey & Vanderholm, 1981a	4 different VTA systems after settling basins at actual feedlots	17 months	Dairy farm	Yes	91	1.00	0.5	reed canary, brome grass, and orchard grass	--	73.1	--	--	85.4	--	80.1	86.2	--	78.2	--	--	--	--	c
	*Influent concentrations estimated from a similar site		450 head beef feedlot	Yes	61	0.70	2	fescue alfalfa mix	sandy	63.1	--	--	81.2	--	71.1	71.5	--	--	--	--	--	--	c
	*Channelized flow VTA (serpentine terrace channel)		500 head beef feedlot	Yes	533	--	0.25	--	--	79.7	--	--	86	--	83.1	83.4	--	--	--	--	--	--	c
	*Vegetated terrace channel and grassed waterway		480 head swine finisher	Yes	148	--	0.25	garrison creeping foxtail	--	78.7	--	--	92.1	--	88.9	85.2	--	--	--	--	--	--	c
Fausey et al., 1988	Infiltration basin used with 56 head of beef cattle on concrete lot	3 year study	56 head beef feedlot	Yes	27.5 Width =6m	0.7	1	Reed canary grass	Silt loam					Org N									
								1) Drain tile with slope		61-81	--	--	69-87	69-85	--	69-92	(5)	62-91	73-93	--	--	--	c
								2) Drain tile across slope		55-83	--	--	59-86	59-87	--	56-89	(5)	63-89	67-90	--	--	--	c
Edwards et al., 1986	Infiltration basin used with 56 head of beef cattle on concrete lot	3 year study	56 head beef feedlot	Yes	27.5 Width =6m	0.7	1	Reed canary grass	Silt loam					Org N									
								1) VTA and Settling		82	--	--	85	80		50	-643	--	80	--	--	--	c
								Basin		80	--	--	83	78		50	-940	--	74	--	--	--	m
								2) VTA only		66	--	--	69	70		73	-733	--	77	--	--	--	c
										61	--	--	65	66		72	-1150	--	70	--	--	--	m
Harner and Kalita, 1999 Keaton, 1998	300-head feedlot runoff is directed to settling basin and VTA,	2 years	300-head beef feedlot	Yes	427	0.97	0.3-4	Brome	silty clay	--	65	--	--	26	--	44	2	14	18	--	--	--	c
									loam	--	76	--	--	50	--	63	34	42	45	--	--	--	m
	300-head beef feedlot discharge to settling basin and VTA	2 years	350-head beef feedlot	Yes	239	0.23	0.5-2	Brome	sandy	--	78	--	--	73	--	74	95	71	64	--	--	--	c
									loam	--	83	--	--	59	--	74	87	52	44	--	--	--	m
Komor and Hansen, 2003	Settling basin and VTA were placed below two cattle feedlots and monitored for seven storm events	1995-96	200 head capacity lot (35 cattle during test)	Yes	79	0.2	1.2	Grass	Silt loam	1.5 cm rainfall on 5/14/96					85	61	--	82	25	62	--	--	m
			225 head feedlot	Yes	58	0.2	0.5	Grass	loam	9.1, 3.6, and 0.6 cm rainfalls on7/27/96, 6/2/96, & 6/27/98					35- 75	35- 80	--	Susp. P 25- 75	15- 75	20- 80	--	--	m

Table 1 (continued). Summary of VTA performance when placed on commercial or research livestock facilities.

Study Description				VTA Information						Percent Reduction													
Reference	Summary	Study Period	Pollutant Source	Settling Basin	Length (m)	AR (1)	Slope (%)	Vegetation	Soil	TS	TSS	BOD_5	COD	Total N	TKN	NH_4-N (2)	NO_3-N (3)	Total P	Ortho-P	FC	FS	E. Coli	(4)
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 five years	380 head concrete beef cattle facility	Yes	108	0.18	0	IB: Reed canary grass. CW: Common cattails	Loam														
									IB:	65	--	--	--	80	--	81	-87	77	--	--	--	--	c
									IB+CW:	71	--	--	--	85	--	83	-43	83	--	--	--	--	c
									IB+CW:	93	--	--	--	97	--	98	86	95	--	--	--	--	m
										Most mass flow reduction occurred in infiltration basin.													
Mankin and Okoren, 2003	300 head heifer feedlot with runoff directed to settling basin (1st stage) and VTA (2nd stage).	5/01-5/02	300 head dairy heifer feedlot	Yes	150	--	2	Fescue	Silt Loam														
									Mass Reductions at:			TDS											
									30 m	--	93	74	--	77	--	--	--	84	--	84	--	91	m
									150 m	--	95	68	--	81	--	--	--	79	--	85	--	90	m
Paterson et al., 1980	Milking center waste and barnyard runoff from 70 cow dairy studied for five year period	5 years	Natural rainfall	Yes	36	--	3.4	Tall fescue	silt loam	--	71	42	--	--	--	38	incr.	7	--	--	--	--	c
			Snow melt							--	84	77	--	--	--	78	-40	32	--	--	--	--	c
			Perched water table							--		99	--	--	--	97	incr.	98	--	--	--	--	c
Schellinger & Clausen, 1992	Runoff from paved dairy lot to detention pond then VTA subject to natural rainfall	18 months	Dairy barnyard	Yes	22.9	0.27	2	fescue, bluegrass, and ryegrass mix	--	--	33	--	--	--	18	15	--	12	6	--	--	--	m
Williamson, 1999	Describes and compares design and performance of 4 VTA in Kansas for feedlot	5 months 5/98	350 head beef feedlot	Yes	239	0.23	1.2	brome grass	sandy loam	--	--	--	--	61.5	--	--	--	28.6	--	78.9	--	79.3	c
	*Same study, different VTA location and design	11/98 for all sites	300 head beef feedlot	Yes	427	0.97	0.75	brome grass	silty clay loam	--	--	--	--	63.7	--	--	--	56.8	--	76.5	--	78.2	c
	*Same study, different VTA location		300 head beef feedlot	Yes	213	0.36	2	fescue	silt loam	--	--	--	--	19	--	--	--	13	--	36	83	--	c
	*Same study, different VTA location		200 head beef feedlot	Yes	137	0.59	0.6	brome grass	loam	--	--	--	--	52.8	--	--	--	74.2	--	90.3	--	88.4	c
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	--	No observed discharge of water below root zone for two years or as surface water from VTA for 5 years.													m

1. AR = Area Ratio = (VTA Area) / (Feedlot Drainage Area).
2. The label NH_4–N is used to represent the sum of ammonium (NH_4) nitrogen and ammonia (NH_3) nitrogen.
3. Negative nitrate values indicate an increase in nitrate concentration.
4. m = reductions calculated on a mass basis, c = reductions calculated on a concentration basis
5. NO_3-N before VTA less than 1 ppm, NO_3-N after VTA is 76 and 64 ppm for drain tile laid with and across slope, respectively.

Table 2. Summary of VTA performance (no pre-treatment performance included in values) under simulated conditions[1]. Reductions are in concentration or mass for individual studies as indicated by the last column.

Study Description						VTA Information			Percent Reduction												
Reference	Summary	Intensity	Length (m)	AR (2)	Slope (%)	Vegetation	Soil	TS	TSS	BOD_5	COD	Total N	TKN	NH_4-N (3)	NO_3-N (4)	Total P	Ortho-P	FC	FS	E. Coli	(5)
Coyne et al., 1998	4 VTA plots placed after poultry manure amended pasture area	64 mm/hr	4.5	0.25	9	Tall fescue and Kentucky blue grass	silt loam	96	--	--	--	--	--	--	--	--	--	75	68	--	c
		64 mm/hr	9	0.66	9	fescue bluegrass mix	silt loam	98	--	--	--	--	--	--	--	--	--	91	74	--	c
Chaubey et al., 1994	Swine manure applied to VTA subject to simulated rainfall	50 mm/hr	3	1.00	3	fescue	silt loam	--	--	--	--	--	65	71	--	67	65	--	--	--	m
			6	2.00				--	--	--	--	--	69	83	--	71	71	--	--	--	m
			9	3.00				--	--	--	--	--	89	96	--	87	89	--	--	--	m
			15	5.00				--	--	--	--	--	86	99	--	91	93	--	--	--	m
			21	7				--	--	--	--	--	87	99	--	92	94	--	--	--	m
Chaubey et al., 1995	Poultry manure applied to VTA subject to simulated rainfall	50 mm/hr	3	1.00	3	fescue	silt loam	--	--	--	--	--	39	47	--	40	39	--	--	--	m
			6	2.00				--	--	--	--	--	54	70	--	58	55	--	--	--	m
			9	3.00				--	--	--	--	--	67	78	--	74	71	--	--	--	m
			15	5.00				--	--	--	--	--	76	94	--	87	85	--	--	--	m
			21	7				--	--	--	--	--	81	98	--	91	90	--	--	--	m
Dillaha et al., 1988: Dillaha et al., 1986	Simulated feedlot and rainfall	50 mm/hr	4.6	0.25	11	orchard grass	silt loam	--	87	--	--	61	64	34	-36	63	-20	--	--	--	c
			9.1	0.50	11			--	95	--	--	77	80	69	4	80	30	--	--	--	c
			4.6	0.25	16			--	76	--	--	67	69	-21	3	52	-108	--	--	--	c
			9.1	0.50	16			--	88	--	--	71	72	-35	17	57	-51	--	--	--	c
	*concentrated flow		4.6	0.25	5			--	31	--	--	0	1	1	-82	2	-3	--	--	--	c
	*concentrated flow		9.1	0.50	5			--	58	--	--	7	9	-11	-158	19	31	--	--	--	c
Edwards et al., 1983	VTA test plots after settling basin, natural rainfall, 56 head of beef cattle on concrete lot	--	30	Width =2 m	2	fescue	silt loam	87	--	81	89	83	--	--	--	84	--	--	--	--	m
Fajardo et al., 2001	Plot study comparing fallow vs. vegetated filter strip	17 mm/hr for fallow 110 mm/hr for VTA	30	--	4.3-5.1	tall fescue	fine silt	--	--	--	--	--	--	94– 99	--	--	--	No change	--	--	c
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	Width =1.2 m	3	Perennial rye	Guelph loam	--	86	--	--	91	--	--	--	88	50	61	--	66	c
			10					--	86	--	--	90	--	--	45	88	44	53	--	36	c
			5			Mixed grass species		--	87	--	--	87	--	--	25	87	44	15	--	-26	c
			10					--	91	--	--	84	--	--	16	86	48	52	--	58	c
			5			Kentucky blue grass		--	89	--	--	92	--	--	13	89	50	68	--	-130	c
			10					--	91	--	--	95	--	--	35	92	58	74	--	77	c
			5			Perennial rye		--	90	--	--	94	--	--	3	91	64	71	--	67	m
			10					--	94	--	--	95	--	--	67	95	77	77	--	64	m
			5			Mixed grass species		--	91	--	--	89	--	--	49	90	66	56	--	58	m
			10					--	95	--	--	91	--	--	52	92	75	75	--	82	m
			5			Kentucky blue grass		--	97	--	--	98	--	--	75	97	85	91	--	39	m
			10					--	99	--	--	100	--	--	96	100	97	99	--	99	m
Hawkins et al., 1998	WW pumped from swine lagoon to VTA; runoff and percolate analyzed	--	6.1	--	5	Bermuda and ryegrass mix	loamy sand	14	--	--	52	--	3	1	47	22	--	--	--	--	c
								5	--	--	81	--	60	58	54	75	--	--	--	--	m
				--	11			-557	--	--	14	--	33	33	-834	-11	--	--	--	--	c
								37	--	--	92	--	93	93	-59	92	--	--	--	--	m

Table 2 (continued). Summary of VTA performance under simulated conditions[1].

Study Description			VTA Information					Percent Reduction													
Reference	Summary	Intensity	Length (m)	AR (2)	Slope (%)	Vegetation	Soil	TS	TSS	BOD_5	COD	Total N	TKN	NH_4-N (3)	NO_3-N (4)	Total P	Ortho-P	FC	FS	E. Coli	(5)
Lim et al., 1997	Simulated pasture and rainfall	10 cm/hr	6.1	0.50	3	fescue	silt loam	23.6	70	--	--	--	78	18.6	-498.2	76.1	74.5	100	--	--	m
			12.2	1.00				40.8	89.5	--	--	--	89.5	52.8	-140.1	90.1	87.8	100	--	--	m
			18.3	1.50				69.8	97.6	--	--	--	95.3	68	-96.7	93.6	93	100	--	--	m
Prantner et al., 2001	Lab scale study of raw swine manure applied to soil infiltration areas	--	--	--	--	No vegetation	Clarion loam soil	1998 Undiluted swine manure					94	--	Inc.	85	--	--	--	--	c
								3 parts manure + 1 part water					87	--	from 1	78	--	--	--	--	c
								1999 Undiluted swine manure					96	--	to 77	98	--	--	--	--	c
								3 parts manure + 1 part water					94	--	mg/l	97	--	--	--	--	c
Sanderson et al., 2001	Manure application to grassland with VTA down gradient.	--	16.4	1.0	1	Switch grass	Fine sandy loam	--	--	--	25-44	--	--	--	--	--	47-76	--	--	--	m
Schwer & Clausen, 1989	VTA test plot, natural rainfall, milk house waste water pumped to VTA	--	26	--	2	fescue, ryegrass, bluegrass mix	sandy loam	--	92	--	--	--	83	46	--	86	82	--	--	--	c
								--	97	--	--	--	93	70	--	92	90	--	--	--	c
	*Same VTA, subsurface flow analysis	Hi Rate: 20 to 27 cm/week	--	--	--		Loam (surface) and clay loam (sub-surface)	Turbidity				--									
						Fescue		31	--	31	15	--	--	26	--	14	--	13	--	--	c
		Low Rate: 6 to 16 cm/week				Low Rate			--	--	67	--	--	62	--	62	--	--	--	--	m
						High Rate			--	--	50		--	43	--	46	--	--	--	--	m
Srivastava et al., 1996	Nine control VTA plots placed after manure amended pasture		3.1-18.3	3/1	3	Fescue	Silt loam	--	--	--	30	--	67	75	--	66	--	--	--	--	m
				1/1				--	--	--	11	--	44	39	--	36	--	--	--	--	m
				1./3				--	--	--	13	--	21	27	--	26	--	--	--	--	m
											(6)										
Young et al., 1980	Rainfall simulator applied 25-year, 24-hour storm to VTA plots containing corn, orchard grass, sorghum-Sudan grass mix over 2 year test period.	6.35 cm/hr for 71 minutes					Runoff volume reduction:	Sediment												Total Coli-forms	
			27	2	4	Corn	98%	93	--	--	--	--	98	98	95	98	100	--	--		c
			27	2	4	Orchard grass	81%	66	--	--	--	--	69	65	9	76	77	55	72	53	c
			27	2	4	Sorghum-Sudan grass mix	61%	82	--	--	--	--	50	47	-81	48	42	83	68	81	c
			21	1.6	4	Corn	66%	81	--	--	--	--	79	78	-441	74	41	--	--	71	c
			21	1.6	4	Oats	41%	75	--	--	--	--	45	33	-1130	50	-3	--	--	70	c
Willrich & Boda, 1976	VTA test plots, natural rainfall, swine lagoon effluent pumped to VTA	--	30.5	--	3	fescue	clay loam	--	--	31	15	--	--	26	--	--	14	31	--	--	c
			6.1	--	5	Bermuda and ryegrass mix	loamy sand	59	--	--	81	--	60	58	54	75	--	--	--	--	--
	*Same source of wastewater pumped to VTA with different slope		6.1	--	11	Bermuda and ryegrass mix	sandy loam	-557	--	--	14	--	33	33	-834	-11	--	--	--	--	--
			6.1	--	11	Bermuda and ryegrass mix	sandy loam	37	--	--	92	--	93	93	-59	92	--	--	--	--	--

1. Simulated conditions refer to studies conducted under simulated rainfall conditions and/or studies where the VTA is a bench scale or small plot scale facility.
2. AR = Area Ratio = (VTA Area) / (Feedlot Drainage Area).
3. The label NH_4–N is used to represent the sum of ammonium (NH_4) nitrogen and ammonia (NH_3) nitrogen.
4. Negative nitrate values indicate an increase in nitrate concentration.
5. m = reductions calculated on a mass basis, c = reductions calculated on a concentration basis.
6. Data represents total organic carbon as measured by Srivastava et al., 1996.

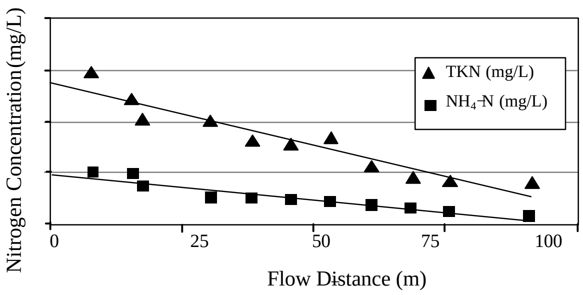

Figure 1. Effect of VTA length on TKN and ammonium-N reduction (Dickey and Vanderholm, 1981a).

SOLIDS REMOVAL

Extensive research has been conducted on solids removal by VTA. Total solids are commonly reduced by 70% to 90% (tables 1 and 2). Variations occur due to site-specific conditions such as vegetation, slope, soil type, size and geometry of VTA, 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 m. Chaubey et al. (1995) showed improved P removal effectiveness from swine lagoon effluent with increased VTA length up to 9 m (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 m. This quick reduction can be attributed to a significant reduction in flow velocity resulting in settling of solids.

NITROGEN REMOVAL

The most common gauges of nitrogen content in surface runoff include total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N) [The term ammonium nitrogen (NH_4-N) is used to represent the sum of ammonium (NH_4) nitrogen and ammonia (NH_3) nitrogen], and nitrate (NO_3) (Ikenberry and Mankin, 2000). Removal of TN, TKN, and NH_4-N by VTA, has been shown to attain or exceed 80%. Chaubey et al. (1995) noted that removal of ammonium nitrogen and TKN in VTA increased for lengths up to 15.2 and 9.2 m, respectively. Overall properly designed and managed VTAs are very effective, averaging approximately 70% nitrogen removal (Ikenberry and Mankin, 2000). Some VTA performance results have suggested 100% reduction in situations where soil infiltration of runoff prevented any effluent from leaving the vegetative area. Nitrate (NO_3) removal has typically been much lower. In some studies NO_3 increased from near-zero levels typical of most anaerobic feedlot runoff levels to concentrations commonly less than the 10-ppm drinking water standard during flow through the VTA. However, test results illustrating an increase in concentration of nitrate can be accompanied by total nitrate mass reductions due to reduction in runoff volume resulting from soil infiltration (Barker and Young; 1984).

The authors have standardized the results of multiple studies over the past 25 plus years (tables 1 and 2) to show the relationships of total N and P reduction to the ratio of VTA area to feedlot drainage area (DA). As much as an 80% reduction in total N and P was observed (fig. 2). At smaller VTA to DA ratios, reported performance levels appear to be more highly variable with multiple performance results producing less than 50% reductions in N and P. For results to consistently exceed a 50% reduction, a VTA to DA ratio of 2 or greater was necessary.

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 7% to 100% (table 1), averaging about 70%. Chaubey et al. (1995) also noted that removal of dissolved and total phosphorus in VTA increased for lengths up to 15.2 and 9.2 m, respectively. The authors have standardized the multiple studies for P removal in figure 2.

PATHOGEN REMOVAL

Research on fecal coliform (FC) removal by VTAs provides a less clear picture of performance. Reported values vary greatly and few studies have been conducted on large-scale VTAs. Fajardo et al. (2001) report FC removal rates between 64% and 87% when using small-scale simulated runoff events with stockpiled manure. Lim et al. (1997) found that all fecal coliforms were removed in the first 6.1 m of a VTA used to treat runoff from a simulated pasture. Average FC removal in the studies reported was 76.6% (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 article was prepared.

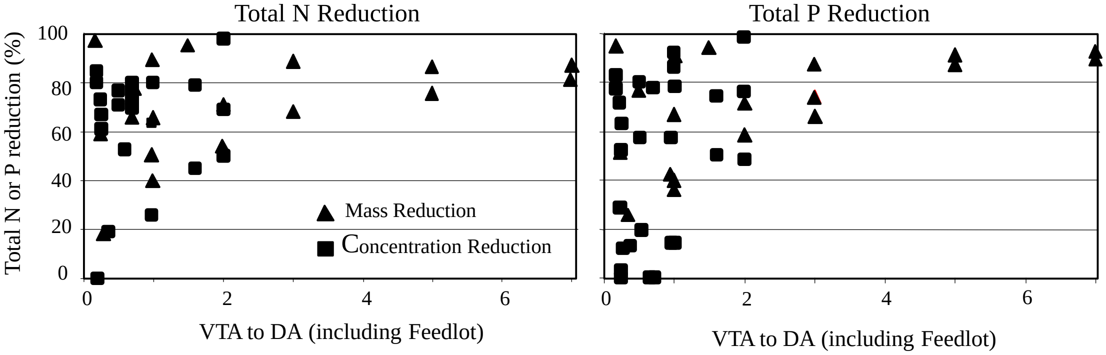

Figure 2. Nutrient removal by VTA based upon VTA to drainage area ratio for references listed in tables 1 and 2.

Vegetative Infiltration Basin (VIB)

Vegetative infiltration basins are VTS systems with additional berms that force infiltration of runoff through a soil filter and prevent surface-water discharges. As runoff infiltrates the soil, aerobic nitrification occurs, converting ammonium to nitrate by the aerobic bacteria *Nitrosomonas* and *Nitrobacter* (Prantner et al., 2001). In addition, phosphorus complexes with minerals (i.e. Ca, Mg, Fe) in the soil bound in the profile. Field drainage tile is commonly used to intercept the filtrate and carry it to an additional treatment system, such as a constructed wetland or VTA (Lorimor et al., 2003; Fausey et al., 1988). A VIB has a smaller surface area (1/6 to 1/12 of most standard VTA designs) and no direct surface-water discharge. Infiltration basins also slow the flow rate exiting the infiltration basin during the storm event and delay much of the discharge until after the event, which enhances the potential for successful treatment in later treatment components, such as a VTA (Lorimor et al., 2003). Preferential flow through the soil filter may be a potential concern over time. Reduction in infiltration due to potential sealing has not been observed after more than five years of operation (Lorimor et al., 2003).

Using a lab-scale VIB to treat liquid swine manure, Prantner et al. (2001) showed over 93% reduction in NH_4-N and 89% reduction in P. Lorimor et al. (2003) and Yang and Lorimor (2000) reported operation of a bermed infiltration area that allowed discharges only through subsurface drain tiles placed 1.8 m (6 ft) below the surface of this basin. After five years of experience, soil P levels did not show signs of buildup (Lorimor et al., 2003). Yang and Lorimor (2000) reported average reductions of 81% for suspended solids, 83% for TKN, 85% for NH_4-N, and 78% for P. Nitrate levels increased by 87%. Edwards et al. (1986) and Fausey et al. (1988) reported operation of an infiltration basin below a small open-lot cattle facility with similar decreases in organic and ammonium nitrogen and significant increases in nitrate N. These studies suggest a need for nitrate utilization or treatment downstream of an infiltration system (Lorimor et al., 2003;. Edwards et al., 1986).

Infiltration basins based upon soil filters are limited to sites conducive to tile drainage where a restrictive soil layer exists below the surface to minimize contaminant (especially nitrate) 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) or a wood chip bed (Murphy and George, 1997), may have application to livestock runoff.

Overall VTS Performance

By coupling various combinations of treatment technologies, including VTA and/or VIB, 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 removal. Table 3 shows a summary of the anticipated contaminant reductions discussed previously plus common performance levels for constructed wetlands. A combination of a settling basin with a VTA or a VIB has the potential for achieving functional performance equivalency to runoff holding ponds designed to manage a 25-yr, 24-h storm plus normal precipitation runoff based upon results reported by Anschutz et al. (1979), Koellicker et al. (1975), and Wulf et al. (2003).

Table 3. Summary of typical contaminant concentration reductions for various treatment components associated with a dairy or beef open lot facility.[a]

	Total Solids (%)	TKN (%)	Ammonium N (%)	Total P (%)	BOD[b] (%)
Settling basin[b]	60	80	80	80	−−
VTA	60	70	70	70	75
VIB	80	80	85	80	−−

[a] Reductions for two or more components can be estimated by multiplying remaining contaminants (1 − reduction) for each component. A settling basin and VIB will reduce concentration by 92% or $\{1-[(1-0.6)\times(1-0.8)]\}\times 100$. Caution: These values are the author’s best estimates of typical performance for well designed and managed treatment systems. Individual conditions may result in lower performance.

[b] Biochemical Oxygen Demand.

[c] USDA NRCS (2005). Chapters 4 and 9 review performance of settling basins.

VTA Design

The literature provided illustrations of a number of critical design considerations for VTAs (table 4). Based upon this literature, there are several design considerations that are generally accepted for VTAs:

Pre-Treatment

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 developing where runoff first enters the VTA.

Sheet Flow

Sheet flow of liquid is essential for optimum VTA performance. Design of VTA 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 require additional structures and ongoing maintenance to redistribute flow.

Discharge Control

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

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. These included 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).

SIZING CRITERIA

Multiple approaches have been suggested for VTA sizing:

- Dickey and Vanderholm (1981a) recommended a minimum VTA width of 61 m (200 ft) and a length adequate to completely infiltrate the feedlot runoff and rainfall from a 1-yr, 2-h storm. They calculated minimum flow lengths to provide 2-h contact times. Based on their model, minimum lengths varied from 91 m (300 ft) for a 0.5% slope up to 262 m (860 ft) for a 4% slope.
- Nienaber et al. (1974) suggested a disposal area of one-half hectare per hectare of feed lot is needed. Data in figure 2 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.
- A design procedure was developed by NRCS in Pennsylvania suggesting that the VTA be designed for the peak discharge resulting from a 2-yr, 24-h storm event at a maximum flow depth of 1.3 cm with a minimum flow through time of 15 minutes (Murphy and Bogovich, 2001). A design procedure based upon a sheet flow equation was proposed:

  $$T = 0.29\ (n\ L)^{0.8} / (P_2{}^{0.5} \times s^{0.4}) \qquad (1)$$

  where T represents travel time (h), n represents Manning's roughness coefficient (0.24 for dense grass), L equals flow length (m), P_2 equals 2-yr, 24-h storm (cm), and s equals land slope (m/m). Schellinger and Clausen (1992) used this USDA SCS design standard for Vermont applications and observed poor performance results. Additional design criteria have been assembled by other USDA 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 by this resource.
- Overcash et al. (1981) proposed a design equation based on influent and effluent concentrations.

  $$C_X = C_B + (C_O - C_B) \times e^{\{[1/(1-D)] \times \ln[1/(1+K)]\}} \qquad (2)$$

  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 4):

- A good stand of dense vegetation is needed. Dickey and Vanderholm (1981a) 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.
- Sheet flow conditions are essential to VTA performance. Minimizing animal traffic and limiting vehicle traffic to dry conditions are critical to sheet flow maintenance.
- Minimization of nutrient accumulation in VTA is important. Regular harvesting with crop removal to encourage a balance of nutrients is necessary. Mechanical harvesting and animal grazing have been used for harvesting vegetation. Grazing results in low nutrient removal rates and potential nutrient accumulation concerns.
- Higher nutrient deposition is anticipated in the first few meters of the VTA suggesting a potential for nitrate leaching and increased soil P. Regular soil testing for residual soil nitrates and phosphorus may be necessary at the upper end of the VTA.

CONCLUSIONS

Based upon this review of the literature, 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. These performance results suggest that a vegetative system consisting of a settling basin and VTA or VIB has the potential to achieve functional equivalency to conventional technologies.
- 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: 1) sedimentation, typically occurring within the first few meters of a VTS, and 2) infiltration of runoff into the soil profile. Systems relying primarily on sedimentation only are unlikely to perform equal to or better than baseline technologies. System design based upon sedimentation and infiltration is necessary to achieve a required performance level for CAFO application.
- Critical design factors specific to attaining high levels of pollutant reduction within a VTS include pre-treatment, sheet flow, discharge control, siting, and sizing. Critical management factors include maintenance of a dense vegetation stand and sheet flow of runoff across VTA as well as minimization of nutrient accumulation.

Table 4. Summary of design and management recommendations for VTA for past research and field demonstration projects.

Reference	Type of System	Design Recommendations	Management Recommendations
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.	Initial seeding of fescue, ye and reed canary grass was used due to tolerance to wet conditions. Four distribution points at upper end of VTA proved inadequate to create sheet flow. Later expansion to seven distribution points reduced problems of channel flow.	At conclusion of study, orchard grass 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 to 12 in. high.
Dickey and Vanderholm (1981a); 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)	Solids settling in advance of a VTA minimize vegetation damage and maintain VTA effectiveness. Overland or sheet flow within VTA. Minimum recommend contact time for runoff with a VTA is 2 h. Overland VTA does 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: 1 Flow distances at least 10 times greater that sheet flow design; 2 One additional hour of contact time beyond the 2 h minimum for each 465 m^2 (5,000 ft^2) of open lot greater than 929 m^2 (10,000 ft^2); 3 Large areas for open lots of more than 0.4 ha (1 acre);	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 have value in pollutant removal from winter precipitation and snowmelt runoff.
Dillaha et al. (1988); Dillaha et al. (1986)		Effectiveness of VTA is dependent upon design and management measures that create shallow sheet flow and prevent concentrated flow. VTA site selection should target flat areas and avoid hilly terrain.	See first bullet under design recommendations.
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.		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.
Ikenberry and Mankin (2000)	Review of literature		Key management considerations recommended: 1 Soil testing to determine fertilization requirement at time of planting of vegetation; 2 Reseeding and fertilization to maintain dense stand; 3 Repairing of gullies soon after their development, 4 Regular moving and harvesting of plant material to remove nutrients and maintain dense vegetation stand; 5 Restriction of field traffic and grazing during wet periods to avoid development of ruts leading to channel flow and damage to vegetation.
Lorimor et al. (2003)	Runoff from concrete open lot beef facility is directed to settling basin, totally bermed infiltration basin, and constructed wetland	Infiltration basin was bermed to provide total containment fo 25-yr, 24-h storm. Infiltration basin was size to provide a land area that was 1/6 th 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.	

Table 4 (continued). Summary of design and management recommendations for VTA for past research and field demonstration projects.

Reference	Type of System	Design Recommendations	Management Recommendations
Murphy and Bogovich (2001)	Summarizes NRCS design recommendations for application of VTA to open lot dairies in Pennsylvania for handling runoff and milking center effluent.	Determines hydarulic 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.	Checking of pre-treatment facilities on a routine basis, after major rainfall events, and before winter.
Nienaber et al. (1974)	Settling basin, holding pond, sprinkler irrigation on grassed treatment area. Fresh water application compared with beef feedlot runoff.	$\text{VTA size} = \dfrac{\text{Annual Feedlot Runoff (acre}-\text{in.)}}{\text{Max. annual crop water tolerance} - \text{Annual precipitation (in.)}}$	Applied effluent to a grassed disposal area planted with a mixture of nine cool and warm season grasses. Brome grass and intermediate wheat grass 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.
Norman and Edwards (1978)	Ohio NRCS recommendations for sizing of buffer strip dimensions for cattle feedlots.	Travel time should be proportional to BOD concentration.	
Paterson et al. (1980)	Milking center waste and barnyard runoff from - dairy was directed through settling basin (1st stage), holding tank with lift pump, and VTA (2nd stage).	Distribution lines longer than 30 m created challenges with sheet flow. Filter area designed for flow of 4.5 L/m^2 VTA/day was a safe load for high rainfall and snowmelt events. Discharge from VTA was common.	Daily application of waste resulted in tall fescue being replaced by barnyard grass in early season and crab grass 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.
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.	VTA should be located at least 3 m (10 ft) above groundwater 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 days per year, 1 ha of VTA is suggested per 1000 head	Quality of vegetation impacts nutrient removal of vegetation. Establishment procedures and harvesting frequency is important to establishing lush forage growth.
Murphy and Harner (2001)		VTA systems should be sized by matching normal nutrient runoff and crop nutrient utilization.	
Scheilinger and Clausen (1992)	Runoff from dairy barn yard is directed through a detention pond and then to a VTA	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.
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).	A mean hydraulic retention time of 5 to 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 brome grass was considered adequate. Herbicides were used for broadleaf weed control on the VTA and settling basin berm.

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