ALTERNATIVE TREATMENTS TO MINIMIZE WATER POLLUTION FROM OPEN ANIMAL FEEDLOTS

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EXECUTIVE SUMMARY
Current rules for CAFOs will achieve approximately 95% control of open feedlot runoff in the most of the U.S. (Anshutz et al., 1979). While complete containment has been the rule for 30 years, livestock producers are interested in utilizing alternative treatment systems, rather than complete containment and land application, in order to minimize capital expense and management requirements. Several systems have been researched since the late 1960s including solids settling, vegetative filter strips, soil infiltration areas, and constructed wetlands. This paper reviews the research literature for each of these alternative treatment technologies. While variability is an inherent part of all biological systems, this review shows that piggybacking two or more technologies selected on a site specific basis, will provide equivalent pollution reduction to complete containment. Proper construction and management is necessary to achieve the "functional equivalency" desired.

INTRODUCTION

Nonpoint source pollution from agriculture continues to be recognized as a significant contributor to surface water impairment throughout the United States. Livestock waste has historically been stockpiled as a solid or stored as liquid, and applied to cropland as a source of crop nutrients. Handling and transports costs of feedlot runoff often outweigh the benefits associated with the agronomic returns the runoff may provide. This report looks at various best management, or alternative management, practices that livestock producers, beef feedlots in particular, can potentially use with their operations to achieve the same pollution prevention end result that is achieved by current EPA (NPDES) requirements.

According to current NPDES permit rules, CAFOS are required to contain all wastes, including liquid runoff from feedlots and other waste contributing areas, resulting from precipitation up to and including the largest 24 hour rainfall that occurs on the average of once every 25 years (25-year, 24-hour storm). This rule has been in effect for nearly 30 years. Early studies done by Koelliker et al., (1975) examined rainfall timing, amount, air temperature, and geographic location in Kansas. They looked at land-applying the runoff liquid when the theoretical soil moisture (took into account temperature and evapotranspiration) was deemed appropriate. They found that "control by 25-year facilities is expected to be 97.0 percent compared to 95.7 percent for 10-year facilities." Later modeling by Anshutz et al. (1979) extended the work to other areas of the West, Midwest, and Southwest. They stated "the EPA must expect some uncontrolled discharges for other than 25-yr events. Our work shows that to increase control from 95 to 100 percent, a runoff-retention pond 2.8 times as large is required."

Requiring total containment, or zero-discharge of livestock waste, may cause economic stress for a significant number of feedlots as shown in table 5-9 of EPA's current Notice of Data

Availability for the proposed new CAFO regulations. A combination of treatment alternatives such as constructed wetlands, vegetative filter strips and soil infiltration areas may provide "functionally equivalent control" of pollution from feedlot runoff as the currently-required impoundment and land application for CAFO's.

BOVINE FEEDLOT RUNOFF AND SWINE LAGOON EFFLUENT

Several of the papers reviewed for this report addressed wetland or Vegetative Filter Strip (VFS) treatment of swine lagoon wastewater. In order to quantify the effectiveness of wetlands, vegetative filter strips, and infiltration areas as possible alternative treatments for beef feedlot (open feedlot) runoff, it is necessary to address the similarities of swine lagoon effluent and beef feedlot runoff. Because swine lagoon effluent and open beef feedlot runoff are similar, the results from swine lagoon effluent studies can be used as a predictor for beef feedlot runoff treatment results. Table 1 lists waste characteristics for liquid swine lagoon effluent and beef feedlot effluent.

Table 1. Solids and chemical characteristics of swine lagoon effluent and open feedlot runoff

	Typical Concentrations mg/l				
	Total Solids	COD	Total N	NH_4-N	Total P
Swine Lagoon Effluent	3000	1658	560	360	100
Beef Feedlot runoff	15,000*	6100	515*	400	500

*Gilbertson et al., 1980

Based on the similarities shown in Table 1, especially for N and P, we will therefore extrapolate results from studies using swine lagoon effluent to predict removal efficiencies of wetlands, vegetative filter strips and infiltration areas for beef feedlot runoff.

SETTLING BASINS

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 type II 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% of the total solids.

A study of two feedlots in Iowa was conducted in the early 1990's (Lorimor et al., 1995). One lot was an open concrete swine lot. The other was an earthen beef feedlot. Settling basins below the lots were monitored for two years. Solids in the swine runoff were reduced 29% from 3.1% to 2.2% wet basis. Solids concentration within the basin increased to an average of 12.7% as solids settled out and the liquid passed through the basin. On a mass basis the settling basin below the swine lot retained an average of 46% of the solids, 31% of the total Kjeldahl nitrogen (TKN), and 31% of total phosphorus (P) over the two years of monitoring.

Research has shown that settling below bovine facilities is more effective than below swine facilities. Settling below the earthen beef feedlot in this study removed a mean of 64% of the solids from the raw runoff. It removed 84% of the TKN, 80% of the P and 34% of potassium (K). Runoff concentrations from the lot were similar to those reported by Sweeten (1990).

The first treatment of any open feedlot runoff treatment system, whether it is total containment or another 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% of the N and P from the runoff from swine lots and approximately 80% of each from bovine lot runoff.

VEGETATIVE FILTER STRIPS

Vegetative filter strips (VFS) are increasingly being viewed as practical, low-cost management options for improving the quality of surface runoff from pollutant sources as well as providing erosion protection.

Ikenberry and Mankin (2000) presented a good review of VFS effectiveness at reducing the pollution potential from feedlot runoff. They defined a VFS 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 filtration, adsorption, settling and infiltration. Vegetative filter strip efficiency can be determined by looking at the reduction of pollutant concentrations from waste entering and leaving the VFS. Pollutants of concern in livestock runoff include: solids, nitrogen, phosphorus and bacterial contamination BOD/COD and microbial constituents.

Vegetative filter strips provide an opportunity for runoff and pollutants to infiltrate into the soil profile; allow deposition of total suspended solids. They enhance filtration of suspended sediment by vegetation; provide adsorption on soil and plant surfaces; and enhance adsorption of soluble pollutants by plants (Fajardo et al. 2001).

VFS flow can be classified as either channelized or overland flow (Dickey & Vanderholm, 1979). Channelized-flow systems are systems in which flow through the VFS is concentrated in channels. One can more clearly define this as gullied or preferential flow systems. This type of system should be avoided. If gullied or preferential flow develops, non-uniform loading of VFS occurs leading to eventual failure of the system due to soil erosion and reduced utilization of the VFS area. *Overland flow systems are the preferred type of VFS*. Overland flow systems allow a uniform loading of waste (across the width of the VFS) at a relatively shallow depth (<1.5 inches). Uniform depth across the entire width of the VFS 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 & Vanderholm (1981) showed progressively better removal up to 100 meters (300 ft) of overland flow VFS for a 100 head dairy and 500 head beef lot as shown in Figure 1.

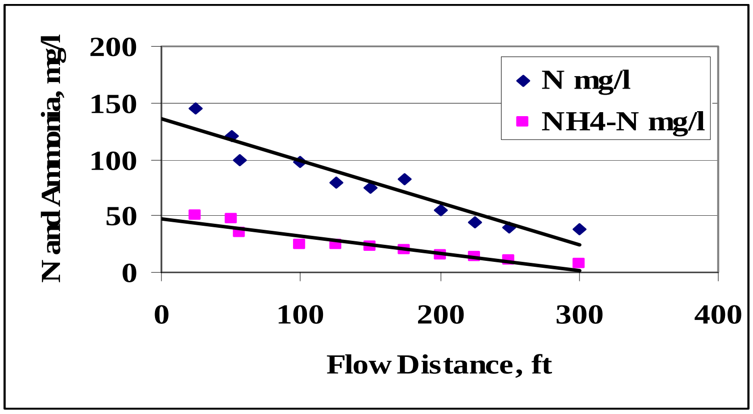

Figure 1. Effect of VFS length on TKN and ammonia N reduction.

They recommended a minimum VFS width of 20 ft and a length adequate to completely infiltrate the feedlot runoff and rainfall from a 1-yr, 2-hr storm. They calculated minimum flow lengths to provide 2 hour contact times. Based on their model, minimum lengths varied from 300 feet for a 0.5% slope up to 860 feet for a 4% slope. Their work showed that "the channelized flow system required a flow length over 5 times longer than the overland flow systems to achieve a similar concentration reduction", as shown in Table 2 below.

Table 2. Contaminant removal of settling basin effluent by VFS.

	Flow Distance		Percent Concentration Reduction				
	m	ft	Total Solids	NH_3-N	TKN	P	COD
Overland Flow							
100 head dairy	91	300	73.1	86.2	80.1	78.2	85.4
450 head beef	61	200	63.1	71.5	71.1		81.2
Channelized Flow							
500 head beef	533	1750	79.7	83.4	83.1		86.0
480 head swine	148	450	78.7	85.2	88.9		92.1

Dickey and Vanderholm 1981.

Dillaha (1988) studied concentrated flow effects on removal efficiencies and found that lower removal efficiencies occurred in VFSs with concentrated flows than in VFSs with shallow, uniform flow.

Solids Removal

Extensive research has been conducted on solids removal by VFS. According to Ikenberry and Mankin, (2000) solids concentrations have been shown to be reduced by up to 98%, with most reductions in the 70-90% range. 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, VFS remove most solids within the first few feet of the filter strip. Chaubey et al., (1994) showed improved ammonia and P removal effectiveness from swine lagoon effluent with increased VFS length up to 9 meters (30 ft). This quick reduction can be attributed to a significant reduction in flow velocity due to vegetation retarding the flow.

Fecal Coliform Removal

More research on fecal coliform (FC) removal by VFS is needed. Reported values vary greatly and few studies have been conducted on large scale VFS. Fajardo (2001) report (FC) removal rates between 64% and 87% when using small scale simulated runoff events with stockpiled manure. Lim (1997) found that all fecal coliforms were removed in the first 6.1m of a VFS used to treat runoff from a simulated pasture. Average FC removal in the studies reported here was 76.6%.

Nitrogen Removal

The most common gauges of nitrogen content in surface runoff include total nitrogen (TN), total Keldahl 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 VFS, have been shown to exceed 85%. Nitrate (NO_3) removal has typically been much lower, although Fajardo et al.(2001) reported 97 and 99% reductions in simulated VFS 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 VFS. Overall properly designed and managed VFSs are very effective, averaging 71.5% nitrogen removal.

Phosphorous Removal

Because the majority of the phosphorous is adsorbed to solids particles, total phosphorous removal is directly related to solids removal efficiencies. Phosphorous removal rates have ranged from 12-97%, averaging 68.7%.

VFS Design

Ikenberry and Mankin (2000) suggest that not enough research exists to support wide spread use of the many proposed VFS design methods which are typically based on hydraulic loading. This review indicates the following:

- Solid settling should precede VFS to reduce solids buildup which will cover plants and “kill” the VFS.
- VFS should be designed in such a manner as to not permit channels or gullies to form.
- VFS should also have a flat cross section with a slight slope (<4%).
- Greater length generally means better removal, although minimum length is difficult to determine.
- Vanderholm and Dickey’s data indicated that approximately 0.5 foot of VFS overland flow per head would provide 85% reduction of N. Channelized flow requires 5 times as much VFS length.
- Based on data from 10 separate studies conducted over the last 25 years, Figures 2, and 3 show that 80% reductions of TKN, and P are achievable as a function of the ratio of VFS to the feedlot drainage area (VFS:DA)

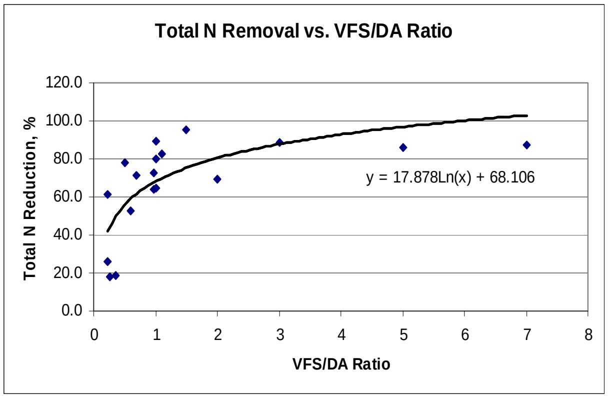

Figure 2. Total N removal by VFS

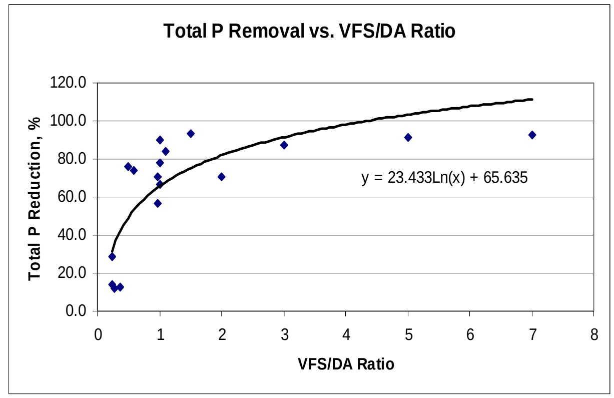

Figure 3. Total P removal by VFS

VFS Maintenance

VFS maintenance must not be overlooked. Effective VFSs require a good stand of dense vegetation, uniform flow conditions, minimal soil disturbances (animal and vehicle traffic should be minimized), and proper harvesting of vegetation (Ikenberry and Mankin, 2000).

VFS Summary

Properly designed and maintained VFS provide excellent removal of feedlot runoff contaminants as shown in Table 3.

Table 3. Summary of VFS contaminant removal

	Percent Removal					
	Total Solids	COD	Total N	NH_4-N	Total P	Fecal Coliform
Average	64.5	74.8	71.5	69.4	68.7	76.6
Maximum	87.0	92.1	95.3	99.2	97.0	100.0
Minimum	23.6	15.0	18.0	18.6	12.0	31.0

A good stand of vegetation will lead to uniform filtration of waste. Minimizing traffic will reduce soil compaction, which slows infiltration. Good vegetative cover helps prevent soil erosion and helps minimize the formation of gullies. Harvesting should be done periodically to not only remove nutrient accumulation, but to help in maintain a healthy stand.

CONSTRUCTED WETLANDS

Constructed wetlands are another possible low-cost alternative to the land application of feedlot waste. They may make it possible to reduce capital costs and manpower requirements associated with the land application of feedlot waste (Payne et al. 1992).

Constructed wetlands provide many services and perform many functions for our natural environment. Constructed wetlands provide fish and wildlife habitat, drinking water supply, ground water recharge, flood control, protection from erosion, improvement of water quality, and nutrient recycling (Ancell et al. 1998). However Hammer (1994) states that the most important of these wetland functions is water quality improvement.

Constructed wetlands are one possible option for treating livestock wastes and removing nutrients when used in combination with some form of pretreatment (Ancell et al. 1998).

Wetlands can not be used as a stand alone procedure for treating feedlot runoff because of high ammonia concentrations typically found in the runoff which are toxic to wetland plants. If properly designed and maintained, wetlands can serve as a polishing system for feedlot runoff.

The two primary types of constructed wetlands that are used today are free water surface (FWS) and submerged flow (SF). With free water surface wetlands, influent passes over and through wetland plant material. Submerged flow wetlands act as an infiltration area for wastewater. The influent passes through the soil eliminating surface water flow out of the wetland. Submerged flow wetlands are typically deeper that free water surface lagoons and made up of various sizes of gravel, crushed rock and soil (Reed et al., 1995). They are typically used for small systems such as private septic systems. Free water systems are more appropriate for open feedlot runoff due to the larger flow volumes required.

Constructed wetlands improve water quality through numerous physical and biological events. Wetland vegetation slows wastewater flow. Plants that are typically used in constructed wetlands include: rushes (*Scirpus* spp.), cattails (*Typha* spp.), curly dock, duckweed (*Lemna* spp.), knotgrass (*Paspalum distichum*), smartweed (*Polygonum* spp.), spiked bulrush (*Eleocharis* spp.), reeds (*Phragmites* spp.), sedge (*Carex* spp.), and sulfuria (Ancell et al. 1998 and Reed et al. 1995). Some form of preliminary treatment is needed to keep the organic loading within design limits. (Reed et al., 1988).

Design

Proper design of constructed wetlands (CW) may result in the (CW area) exceeding the size of the feedlot. Generally the higher the loading rate, the less effective the pollutant reduction. Loading rates are typically based on the amount of nitrogen per unit area per day that the wetland can treat. TKN loading rates normally vary from 3 to 10 kg/ha-day (2.7-8.9 lb/ac-day), but Zirschky (1986) reported up to 79% N removal at loading rates up to 44 kg/ha-day (40 lb/ac-day). Nitrogen removal typically results for a diurnal nitrification-denitrification cycle that converts N from organic N and NH_3/NH_4 to N_2 gas. Table 4 summarizes a study by Stone et al. (2000) that shows the effect of loading rates on removals of N and P.

Table 4. Contaminant removal by a constructed wetland at varying loading rates

Constituents	Loading Rate, kg/ha-day	Percent removal, %
TKN	13	92
TKN	50	70
NH_3/NH_4-N	4	93
NH_3/NH_4-N	44	74
Total P	1	88
Total P	11	30

Care must be taken to ensure that wetland influent ammonia does not exceed 100-200 mg/L to avoid plant toxicity. Greater concentrations can be toxic to many wetland plants (Reed, 1995; Skarda, 1994**;** Bankson, 1994). Combining the nitrogen loading rate, dilution water, and wetland volume yields the detention time. Reed et al. (1995) reported that a linear correlation exists between loading rate and BOD removal up to a loading rate of 100 kg/ha-day (89 lb/ac-day). Generally the longer the detention time, the greater the pollutant reduction. Eight studies reviewed here (including some with heavy loadings for research purposes) averaged removals as follows:

Solids	30-99%, averaging 74.7%	n = 5
Nitrogen	23-92%, averaging 62.7	n = 14
NH_4-N	26-97%, averaging 72.1	n = 14
Phosphorus	28-88%, averaging 70.2	n = 6
BOD	26-96%, averaging 93.0	n = 5

Wang and Mankin (2000) in a review of wetland literature reported removals varied from 60-99% for BOD, 43-97% for N, and 28-99% for P.

Bacteriological removals are sometimes reported, and show that wetlands are very effective at reducing indicator organism counts. Typical results show 80%+ removals (Skarda et al., 1994). Humenik (2001) reported on a literature review conducted by EPA on constructed wetland effectiveness for treating animal waste that examined a large number of wetlands. Table 5 shows average contaminant reductions for the wetland studies reviewed for that project were lower than the two above studies.

Table 5. Contaminant reduction summary of 68 constructed wetlands.

Wastewater Constituent	Average concentration, mg/L		Average Reduction
	Inflow	Outflow	%
5-day BOD	263	93	65
TSS	585	273	53
NH_3-N, NH_4-N	122	64	48
TN	254	148	42
TP	24	14	42

Humenik (2001)

Although the different studies show different results, it appears that wetlands should be expected to provide 50% or more reduction of N, P, and solids, and 60% or greater reductions of BOD when properly loaded.

Infiltration Areas

Soil infiltration is another type of alternative treatment that can be used below a feedlot to significantly improve water quality. It is consequently an option for pretreatment to condition waste before it enters a vegetative filter strip or constructed wetland. Soil infiltration occurs by loading/ponding a soil medium with runoff and allowing the liquid to "soak into" the soil. As the waste infiltrates the soil, aerobic nitrification occurs, converting ammonium nitrogen to nitrates by the aerobic bacteria, *Nitrosomonas* and *Nitrobacter* (Prantner et al. 2001), and phosphorus interacts and becomes attached to the soil particles in the profile. Field drainage tile may be used to intercept the filtrate and carry it to a secondary form of treatment such as a constructed wetland or VFS.

Two recent infiltration studies at Iowa State University have shown excellent water quality improvements. Using liquid swine manure, Prantner et al. (2001) showed over 93% reductions in NH_4-N, and 89% reduction in P. Yang & Lorimor (2000) reported a field infiltration system below a 380 head concrete beef feedlot. Over two years of sampling they found an 81% reduction suspended solids, 83% reduction in TKN, an 85% reduction in NH4-N, a 78% reduction in P.

TREATMENT COMBINATIONS

By piggybacking various combinations of the above treatments, the quality of feedlot runoff can be significantly improved to the point of achieving "functional equivalency" to complete detainment and land application. Although the particular combination of treatments selected for any feedlot will be site specific, essentially all should begin with solids settling. Table 6 shows a summary of the anticipated contaminant reductions discussed above.

Table 6. Summary of contaminant reductions for various treatments.

	Solids	TKN	Amm. N	Total P	BOD
Settling	64	84	80	34	---
VFS	64.5	71.5	69.4	68.7	75
Infiltration	81	83	85	78	
Wetland	60	50	50	50	60

EXAMPLE

Consider an open beef feedlot using settling and a VFS followed by a wetland. Calculate the nitrogen reduction expected.

From table 6, settling should remove 84% of the TKN, leaving 16% remaining in the liquid. The VFS will remove an additional 71.5%, so the remaining concentration is
((100-71.5)/100) X 0.16 = 0.047, or 4.7% of the initial concentration. Finally, the wetland has potential to remove 52% of the remainder, leaving 0.48 X 0.047 = 2.3%. Overall the system has potential to remove nearly 98% of the TKN raw feedlot runoff.

The study by Prantner et al. (2001) of a combination of infiltration and wetland treatment found 99% NH_4-N reduction and 98% P reduction. Yang and Lorimor (2000) found an 88% TKN reduction over 2 years of data of already-settled runoff, and 82% P reduction.

The literature supports the proposition that properly designed and managed treatment and release systems can provide equal protection of the nations waters as total containment and land-application.

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