EFFECTIVENESS OF A PASSIVE FEEDLOT RUNOFF CONTROL SYSTEM USING A VEGETATIVE TREATMENT AREA FOR NITROGEN CONTROL

B. L. Woodbury, J. A. Nienaber, R. A. Eigenberg

ABSTRACT. *This study was initiated to investigate the effectiveness of a solids basin and vegetative treatment area (VTA) for nutrient control as a low-cost alternative to runoff holding ponds for cattle feedlots. The estimated total nitrogen load entering the VTA was equivalent to/or less than the total nitrogen load removed by the hay crop harvested from the VTA. No water was measured exiting the VTA, either by deep percolation or by direct release, during the four-year study period. As a result, the discharge water from the basin was effectively used for hay crop production. Electromagnetic induction maps were produced to illustrate zones within the VTA where salt and nutrient loading occurred. Soil analyses in these zones indicated that surface soil NO_3-N levels, particularly closest to the discharge tubes, had increased. Currently nitrogen is contained near the surface, and has not started to infiltrate deeper into the VTA soil. However, NO_3-N appears to be infiltrating below the solids basin where concentrations as high as 60 mg NO_3-N kg^{-1} soil were measured to a depth of 3 m. Annual removal of the solids and organic material from the solids basin may have compromised sealing of the basin. Seepage monitoring will continue in the near term.*

Keywords. *Feedlot runoff control, Vegetative treatment system, Electromagnetic Induction, Animal waste management.*

E-ffective on 15 April 2003, the Environmental Protection Agency issued a Final Rule on National Pollution Discharge Elimination System (NPDES) Permit Regulations, and Effluent Limitations Guidelines (ELG) for Concentrated Animal Feeding Operations (CAFO) (40 CFR 122). This rule was prompted by trends toward larger, more specialized and intensive production methods, which concentrated animal waste in smaller areas. This ruling requires that all CAFOs apply for a NDPES permit (40 CFR sections 122.21 and 122.25). The NPDES regulations require developing and following a nutrient management plan that would identify practices necessary to implement the ELG (EPA, 2003).

The ELG (EPA, 2003) requires that beef cattle feeding operations greater than 999 animal units contain runoff from a 25-yr, 24-h rainfall event (40 CFR section 412.26). Beef cattle feeding operations can meet these effluent limitations by application of the best practicable control technology currently available (BAT) (40 CFR section 412.31). Traditionally, this technology is an earthen runoff retention pond. However, construction costs as well as the mechanical equipment, and labor needed for their maintenance can pose monetary hardships, particularly on smaller operations. Additional provisions in the CAFO rule allow for ELG attainment by application of the best available technology economically achievable (40 CFR section 412.33). These systems can be acceptable substitutes for traditional systems, provided they meet all requirements specified in 40 CFR section 412.31.

Producers have expressed interest in control and treatment systems that eliminate need for long-term runoff storage. This interest stems from complaints about runoff storage ponds that include unpleasant odors, contaminant leakage to groundwater, difficulty to properly maintain, and environmentally unsightliness (Parker et al., 1999; Huffman and Westerman, 1995; Miller et al., 1985). For more than twenty years researchers have investigated runoff contaminants reductions through the use of vegetative treatment areas (VTA). Young et al., (1980) used a rainfall simulator to evaluate cropped vegetative buffers with a 4% slope. They found a 67% and 79% reduction in runoff and total solids, respectively. They also found an 84% and 83% reduction in nitrogen and phosphorus, respectively. Similarly, Dickey and Vanderholm, (1981) found vegetation reduced nutrients, solids, and oxygen demand by more than 80% (concentration basis) over a 17-month study. More recent research has shown manure contaminant removal of runoff through VTAs to follow a first-order reduction with respect to vegetative length (Lim et al., 1998). As a result, vegetative treatment areas demonstrate promises for remediating runoff from feedlots.

Recently, Woodbury et al. (2002, 2003) evaluated a runoff control and treatment system designed as an alternative to traditional system. This runoff control system requires minimal operator management input, provides very good solid separation, eliminates long-term runoff storage, and

Article was submitted for review in March 2004; approved for publication by the Soil & Water Division of ASAE in January 2005. Presented at the 2003 ASAE Annual Meeting as Paper No. 032269.

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

The authors are **Bryan L. Woodbury, ASAE Member Engineer,** Agricultural Engineer, **John A. Nienaber, ASAE Member Engineer,** Agricultural Engineer, and **Roger A. Eigenberg, ASAE Member,** Agricultural Engineer, USDA-ARS U.S. Meat Animal Research Center, Clay Center, Nebraska. **Corresponding author:** Bryan L. Woodbury, P.O. Box 166, Clay Center, NE 68933; phone: 402-762-4275; fax 402-762-4273; e-mail: woodbury@email.marc.usda.gov.

does not require pumping equipment for runoff distribution. Additionally, drainage water and nitrogen from the solids basin discharge were effectively used for hay production, and recycling nitrogen back into the production system. However, the long-term effectiveness of the system has not been adequately evaluated.

The overall objective of this study was to evaluate the vegetative treatment area and provide information for design modifications to improve effectiveness. Specific objectives were to: 1) determine mass balance of total nitrogen (TN) entering and exiting the VTA, 2) map solids basin discharge water distribution in the VTA using electromagnetic induction and map interpretation methods, and 3) analyze soils at various points in the solids basin and VTA for nitrogen loading and infiltration.

Materials and Methods

Details concerning the construction and instrumentation of the passive runoff control and treatment system can be found in Woodbury et al. (2002). However, a brief description is included. Eight pens (approx. 30 × 90 m each) at the Meat Animal Research Center (Clay Center, Nebr.) feedlot were selected. The open-lot earthen pens had an average 6% northward slope. These pens were stocked with 70 to 80 head/pen of finishing beef cattle (550 kg) for approximately 180-day cycles. Cattle were fed a typical feedlot ration comprised of silage and dry corn. Design components included a grass approach, a terrace with a solids basin, and a VTA (fig. 1). The VTA was sized based on runoff volumes and nutrient loads estimated by the Nutrient Fate Model for Beef Cattle Feedlots (Eigenberg et al., 1995).

A 300-m long flat-bottom solids basin and terrace was constructed to provide a 5- to 8-min hydraulic retention time for solids separation. Following separation, the liquid is decanted uniformly across the VTA for nutrient and water utilization (fig. 1). Thirteen 20-cm Ultra Rib PVC storm discharge pipes were installed through the terrace at 21-m intervals and at the same elevation to provide uniform distribution (fig. 1). The 4.5-ha bromegrass VTA was adjacent and down slope along the length of the basin, and ranged from 200 to 210 m in length at a slope of approximately 0.5% (fig. 1).

Separate sets of berms were established to co-mingle and direct runoff from two adjacent pens through one of two 0.23-m Parshall flumes (fig. 1). Samplers were installed at each flume for characterizing runoff water quality. Two additional 15 cm Parshall flumes, with samplers, were installed down-gradient from discharge tubes to sample discharge water from the basin. Measure flow values were unreliable due to difficulties of measuring upstream water levels. The NRCS curve number method was used to estimate runoff volume. A curve number of 85 was used for the pen surface and 45 for the grass approach to the solids basin. Samplers were operated annually in the field during the time period from 1 April to 31 October. Very little runoff occurred during the five month period without samplers, due to frozen conditions.

Berms were constructed at the down-gradient end and sides of the VTA to isolate it from the surrounding environment (fig. 1). A portion of the VTA was divided with a berm such that the runoff from the four pens used to sample runoff was isolated (fig. 1). At the down-gradient end of this section, a 0.15-m Parshall flume was installed and instrumented with a stage recorder to measure any runoff leaving the VTA (fig. 1). Soil water sampling ceramic cups were placed throughout the VTA at a depth of 1.8 m (fig.1).

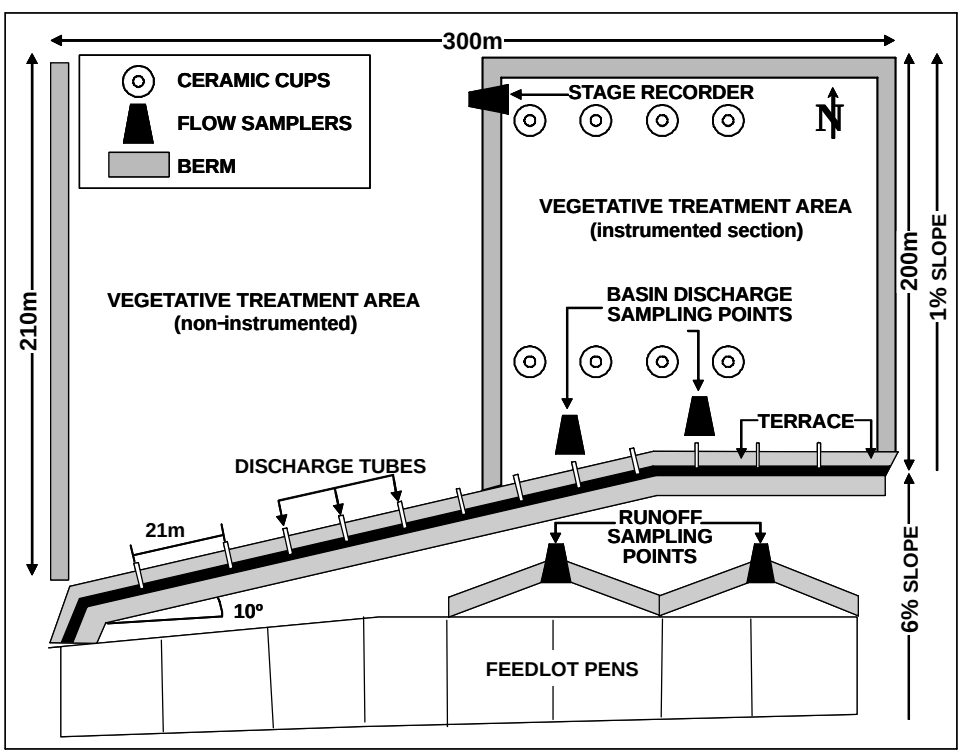

Figure 1. Plan view showing the relationship of the feedlot pens, solids basin with terrace, discharge tubes, and the vegetative treatment areas. Note the addition of the flow samplers, ceramic cups, and berms for isolation of instrumented section of the vegetative treatment area.

Bromegrass hay was harvested twice during 2000, but only one time each during 2001 through 2003. Hay was harvested using conventional windrowing and baling equipment. Multiple vegetative samples were collected from the windrows across the VTA just prior to baling. Samples were analyzed for dry matter and TN (combustion analyses, CN 2000, Leco Corp., St. Joseph, Mich.). Mass of harvested hay was recorded and used to determine mass of TN removed.

Rain events were measured during the 2000 through 2003 seasons (table 1). These events were measured by the High Plains Regional Climate Center (site number 251684), located approximately 1.6 km east-northeast of the research site. It was generally observed that precipitation events greater than 20 mm in a 24-h period generated runoff. Therefore all precipitation events during the measurement period greater than this observed threshold level were used to estimate runoff.

Estimated runoff volumes from these rain events, along with averaged solids basin discharge concentrations, were used to determine the mass of TN entering the VTA. Solids basin discharge samples were frozen until analyses could be completed. Total nitrogen was determined by combining analyses from a modified Total Kjeldahl nitrogen procedure with a cadmium reduction NO_3-N analyses. These procedures follow Methods 10072 and 10020 outlined in Hach Water Analysis Handbook (Hach Co., 1992).

Soil samples were collected in the solids basin and the VTA annually, using a hydraulically operated soil probe with a diameter of 0.03 m. Samples in the solids basin were taken to a depth of 6 m in increments of 0.3 m.

Sample locations within the basin and VTA are illustrated in figures 2 and 3, respectively. Samples were taken in the VTA to a depth of 3 m in increments of 0.3 m. Sample holes in the basin and VTA were back-filled with soil to prevent preferential flow of basin water toward groundwater. Samples were collected after solids had been removed, and the basin had been smoothed to remove wheel tracks. Soil NO_3-N analysis was performed using ion chromatography (0.01 M KCl extraction).

Electromagnetic induction maps of the VTA were made periodically during the growing seasons from 1998 through 2001. Techniques used in collecting and interpreting these maps were similar to those developed by Eigenberg and Nienaber (2003). An EM-38 (Geonics, LTD, Mississauga, ON, Canada) was moved across the VTA on a non-metallic trailer. The EM-38 was used to measure apparent bulk electrical conductivity (EC_a) of soil every two seconds. These readings were combined with GPS coordinates and stored in a data file. Data files were loaded into a 2-D graphing computer program. The same 400 × 400 grid was generated and overlaid into each data file. Apparent electrical conductivity values were interpolated at each of the intersection nodes from actual data using kriging methods. This enabled individual maps to be mathematically differenced to illustrate seasonal changes in EC_a. It was assumed that areas with increased apparent EC values were disproportionately loaded with nutrients from solids basin discharge (fig. 3). Three transects radiating from the terrace were selected. Two transects (WD and ED) were selected near two separate discharge tubes, and one transect (RDG) was selected on a ridge that received no discharge, a condition that existed prior to construction of the VTA. Five soil cores were taken along each transect (fig. 3).

Table 1. Precipitation, estimated runoff, and mass balance of total nitrogen entering and exiting the vegetative treatment area during the study period. [a]

Year	Precipitation (mm)	Estimated Runoff (m^{-3})	Hay Crop Total Mass (kg)	Total Nitrogen Entering (kg)	Hay Crop Total Nitrogen (kg)	VTA Net Total Nitrogen (kg)
2000	487	3940	34,100	360	580	−220
2001	602	3550	25,100	432	420	+12
2002	393	1800	19,360	0	435	−435
2003	450	1950	23,050	0	320	−320

[a] The basin area was approximately 900 m^2. The mean historical precipitation near the study site during the 1 April through 31 October period of 606 mm. It should be noted that the zero values in the "Total Nitrogen Entering" column indicate no basin discharge for the 2002, 2003 seasons. It should also be noted that a leaking seal on a drain tubes may have prevented basin discharge for the 2003 season. However, the precipitation events were very similar to the 2002 season and therefore it is assumed the discharge would have been negligible.

Results and Discussion

Rain events were measured during the 2000 through 2003 seasons (table 1). There were four years of runoff water collected during the study period. Runoff volumes were estimated at 3940, 3550, 1800, and 1950 m^3 from the feedlot pens during 2000 through 2003, respectively (table 1). There

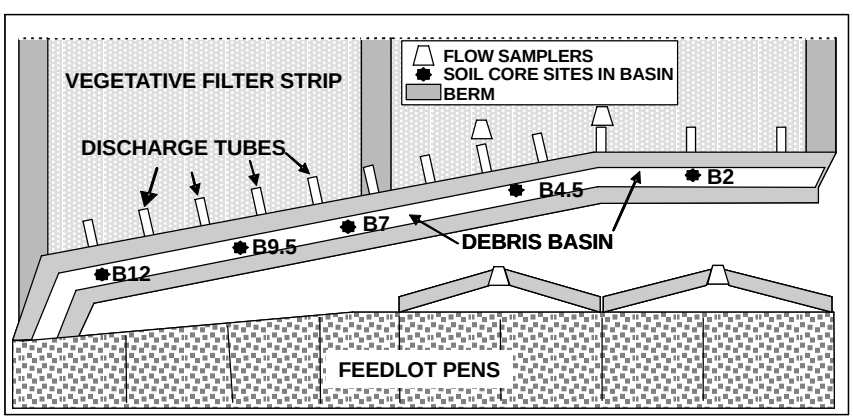

Figure 2. Plan view of the solids basin and terrace. Note the sampling location in the basin for determining nitrate infiltration below the basin.

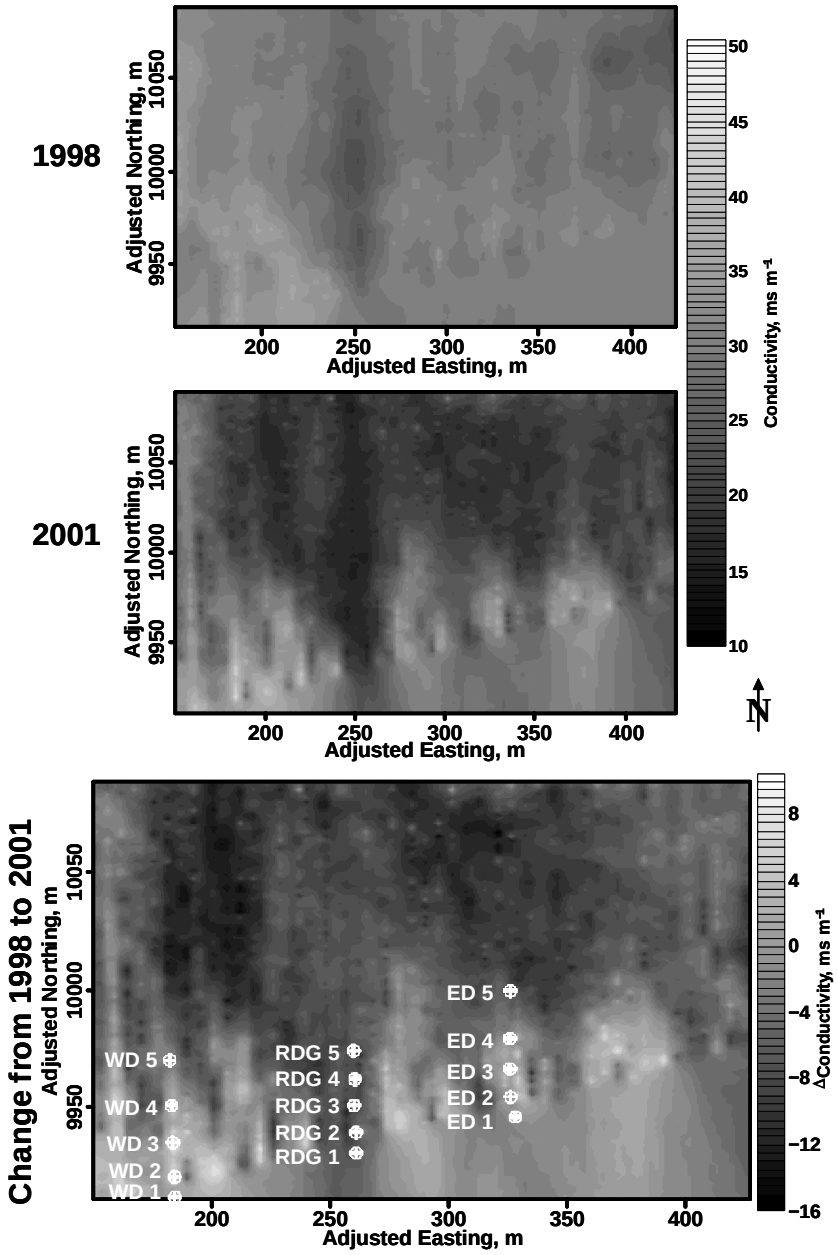

Figure 3. Electromagnetic induction maps of the vegetative treatment area. Top map was generated on 13 May 1998; middle map was generated on 14 May 2001; bottom map is a grid-differenced image illustrating changes in apparent electrical conductivity from 1998 - 2001. Note: WD 1-5, RDG 1-5, and ED 1-5 designate sampling points along west and east drain, and ridge, respectively. (Adjusted Northing = Northing - 4487000; Adjusted Easting = Easting - 570000).

were totals of 487, 602, 393, and 450 mm of precipitation from 1 April through 31 October during the 2000 through 2003 seasons, which averaged 483 mm of precipitation annually during the four years. Historical average precipitation during this period is 606 mm.

Basin discharge contained 361 and 432 kg of TN for 2000 and 2001 seasons, respectively (table 1). However, during the 2002 season, there was no measured discharge from the solids basin (table 1). There were only three precipitation events for the 2002 season with sufficient intensity and duration to generate measurable runoff. However, these events did not fill the basin to the point of discharge. Lack of discharge could be contributed to a combination of several factors. These factors include dry condition of feedlot pen surface soil, evaporation and seepage of water from the basin between precipitation events, and insufficient storm duration and/or intensity to generate runoff.

The 2003 season had a very similar precipitation pattern to the 2002 season. There were several precipitation events that were near the threshold for generating runoff but were not sufficient to generate basin discharge. An additional factor prevented the basin from filling to the drainage level; a seal covering one of the basin drain tubes ruptured near the WD transect**.** This allowed basin water level to leak slowly between precipitation events early in the season. This drainage was to the extreme southwest corner, impacting approximately 0.1 ha of the VTA. Also, this portion of the solids basin was closest to the pens and filled with sediment covering the drain, thereby minimizing the loss of basin water. The seal was repaired, but precipitation events for the

remainder of the season lacked intensity and duration to fill the basin to generate discharge to the VTA. It was assumed that the 2003 discharge to the VTA would have been negligible based on the 2002 season.

Four years of hay crop were removed from the VTA (table 1). Bromegrass hay was harvested twice during 2000, resulting in a total of 34,100 kg of dry matter removed (table 1). This dry matter contained 580 kg of TN (table 1). When compared with the estimated 360 kg TN added by the solids basin discharge, there was a net removal of 220 kg of TN from the VTA (table 1). Approximately 25,100-kg dry matter was harvested during late summer of 2001, containing 420 kg of TN (table 1). This resulted in a 12-kg net gain of TN in the VTA, when compared with the addition of TN by discharge water (table 1). During the 2002 and 2003 seasons, there were 19,360- and 23,050-kg dry matter hay removed, respectively. Since there was no measurable TN added to the VTA, net removal of TN removed was 435 and 320 kg, respectively.

Several attempts were made to extract soil water from the VTA using ceramic cups during the four years of the study (fig. 1). Soil water potential was not sufficient for extracting water, indicating minimal free drainage water was available at the 1.8-m depth. The runoff control and treatment system appears to be sufficiently sized to retain and utilize water and TN discharge from the solids basin.

Electromagnetic induction maps of the VTA were numerically differenced to illustrate areas of nutrient loading (Eigenberg and Nienaber, 2003). A distinct pattern of increased EC_a near the basin discharge tubes is illustrated by the map (fig. 3). Soil analyses of the transects indicated NO_3-N concentrations were higher in the upper 0-0.15 m horizon for all sampling sites (WD 1 − WD 5) of west drainage transect (fig. 4). Also, an increase in NO_3-N was measured for sampling site ED 1 of the east drainage transect (fig. 4). Elevated NO_3-N concentrations have been localized near the soil surface. This is illustrated by the sharp drop in concentration to levels comparable with the ridge transect

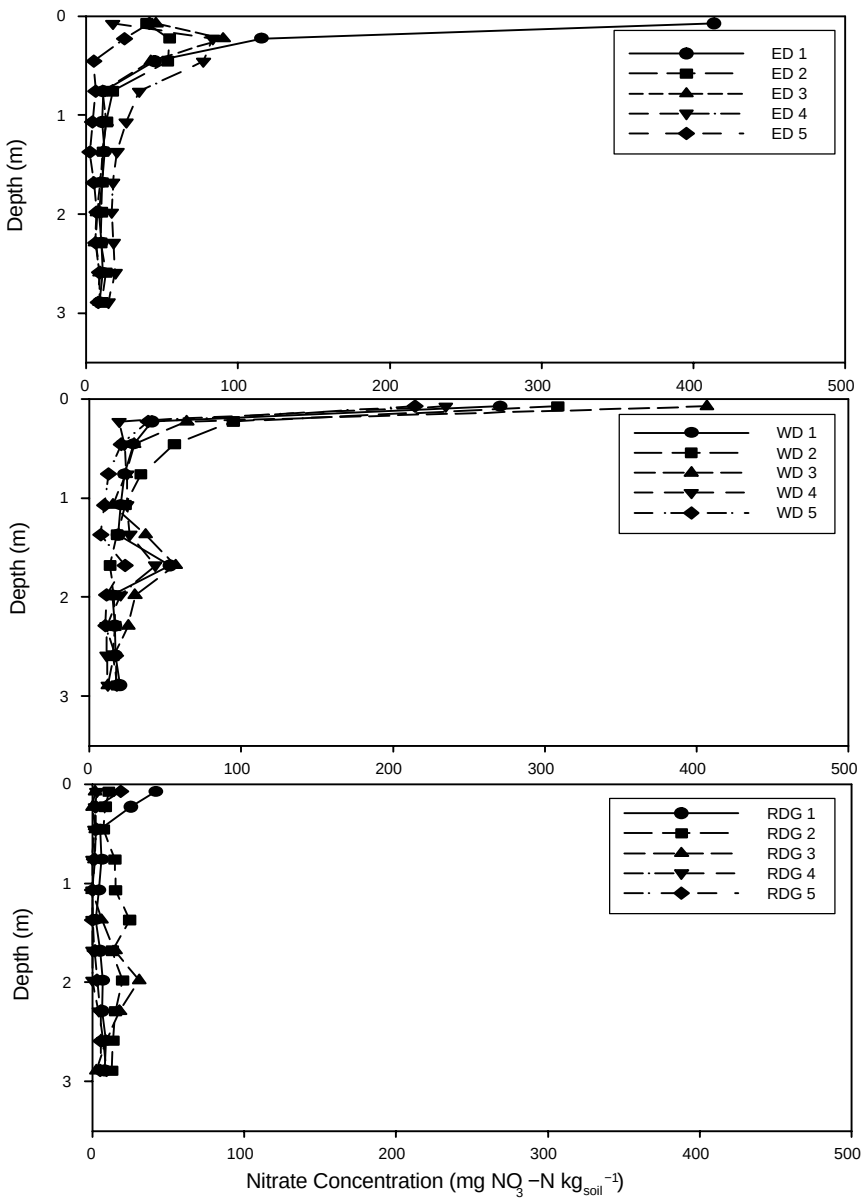

Figure 4. Nitrate-nitrogen concentrations for the east drain (ED) and west drain (WD) paths, and ridge (RDG). Note sample locations 1-5 correspond with those identified in figure 3.

below the depth of approximately 0.5 m (fig. 4). No elevated NO_3-N concentration was measured for any sampling sites (RDG 1 - RDG5) along the ridge transect (fig. 4).

Relative elevations were taken at the bottom of the inlet end of each discharge tube. These relative elevations were normalized to the elevation of discharge tube 2 (fig. 5). Coordinates of the discharge tubes were located on the EC_a manp of the VTA to evaluate the impact that inlet elevation had on discharge distribution. It should be noted that tubes with the lowest elevations corresponded with areas in the VTA that had increases in EC_a values (fig. 5). Elevation had a dramatic impact on distribution, even though the elevation difference from highest to lowest discharge tube inlet was less than 30 mm. The discharge tube with the lowest elevation could be discharging up to 4 m^3 h^{-1} before the highest elevation tube began discharging. This disproportioned discharge was exacerbated by low-intensity and short-duration storm events typified by the 2002 and 2003 seasons. Remedies for maintaining constant relative elevations among the tubes could include an adjustable inlet weir plate on each tube. This would allow for periodic adjustment to maintain uniform discharge from each tube, thereby improving distribution.

Comparing solids basin soil cores taken in 1999 with cores taken in 2002 shows NO_3^-N may be infiltrating beneath the basin (fig. 6). There is a general increase in curve area greater than 20 mg NO_3^-N/kg_{soil} from 1999 to 2002. In 1999, concentrations exceeded 20 mg NO_3^-N/kg_{soil} at only two sample locations (B9.5 and B12). In 2002, concentrations exceeded 20 mg NO_3^-N/kg_{soil} at four sample locations (B2, B7, B9.5, and B12). The greatest increase in concentration was sample location B7. In 1999, B7 NO_3^-N concentrations were less than 10-mg NO_3^-N/kg_{soil}. In 2002, B7 had concentrations greater than 50 NO_3^-N/kg_{soil} to a depth of 3 m, and did not decrease to concentrations below 20 NO_3^-N/kg_{soil} until a depth of 4 m. Traditionally, pond bottoms are effectively sealed by organic material through chemical and physical means (McCullough et al., 1999). However, annual removal of solids from the basin appears to have compromised current sealing, even though the bottom was smoothed and compacted following solids removal.

Conclusions

The passive feedlot runoff water control and treatment system demonstrated very good nitrogen control during the study period. Assuming that estimated runoff curve numbers are accurate, mass balance of the TN entering and exiting the VTA demonstrated a net removal of TN. However, to improve effectiveness and sustainability, additional considerations will have to be addressed.

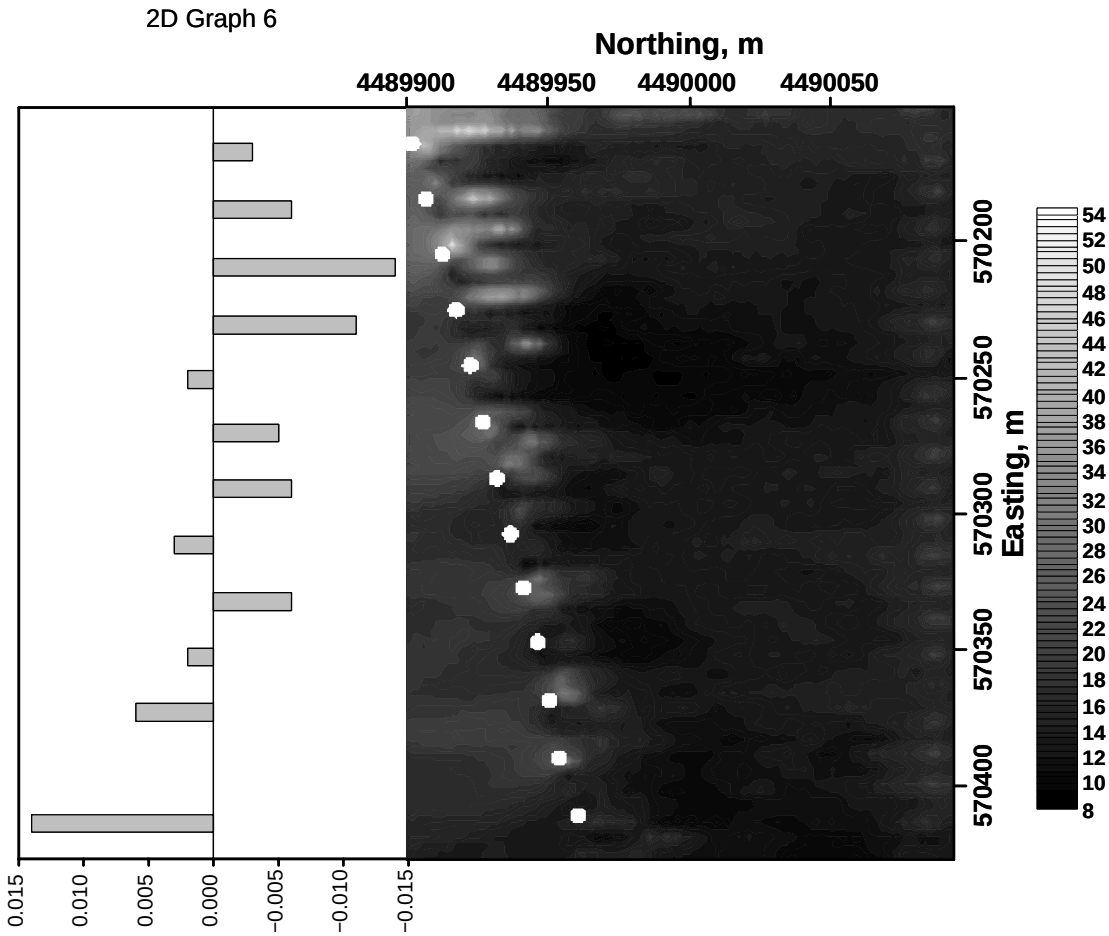

Figure 5. Electromagnetic induction map with the relative elevation of each basin discharge tube.

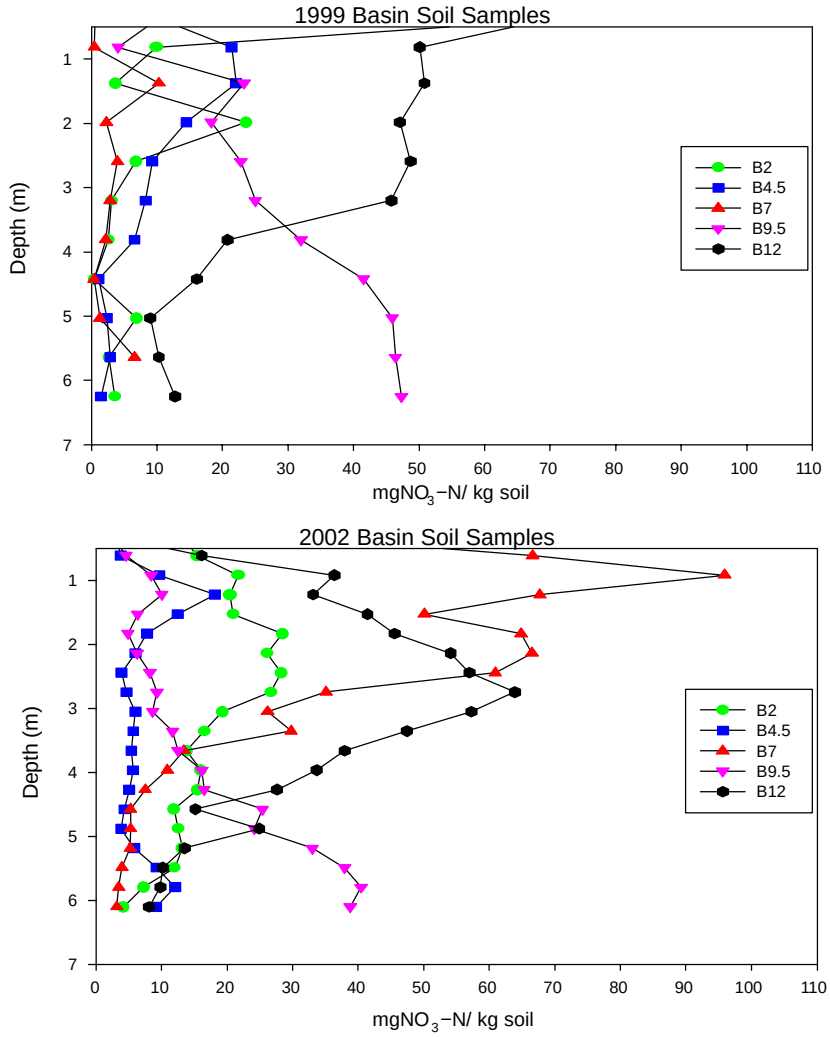

Figure 6. Nitrate-nitrogen concentrations of soil beneath solids basin for 1999 and 2002. Note the increase in curve area greater than 20 mg NO_3-N/kg soil from 1999 to 2002 illustrating the effect of basin seepage. Legend captions refer to sampling locations specified in figure 2. Note that the upper 0.5 m of the basin cores were not reported because this layer was completely disturbed during the solids removal process.

Distribution of solids basin discharge water and nitrogen across the VTA were not as uniform as expected. Nitrate-nitrogen accumulated measurably in zones within the VTA near the basin discharge tubes. Though our soil test analyses indicate this accumulation is located in the upper 0.30-m horizon, it illustrates the risk to groundwater associated with deep infiltration. Removal of this surface soil in the zones of accumulation may be necessary to improve sustainability of the system. This removal could be accomplished using the same equipment used to remove solids from the basin, and applied similarly to crop fields as a soil amendment.

Inlets of the basin discharge tubes were initially set at the same elevation on top of concrete columns placed below the expected frost depth. However, inlet elevations of the discharge tubes have changed slightly over years of operation. This change in elevation has concentrated basin drainage in isolated portions of the VTA. Additional design consideration of the discharge tubes should include an adjustable weir plate. This weir plate could be periodically set on each tube to ensure isoelevation of the basin discharge inlets. Periodically adjusting the inlets would improve the distribution across the VTA.

Soil test data indicates NO_3^-N may be migrating beneath the basin. This may be exacerbated by the annual removal of solids and the organic layer which can be effective in sealing the basin against deep infiltration. Also, plant growth on the basin approach and terrace may be contributing to NO_3^-N migration via preferential flow through root channels. Future design consideration may include a solids basin liner material or geomembrane to restrict deep infiltration.

No water was measured exiting the VTA either below the root zone or at the down-gradient end. This indicated the solids basin discharge water was effectively used by the hay crop for production. However, additional water and solute transport studies will have to be done in the zones of accumulation to ascertain environmental risk.

References

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

Eigenberg, R. A., and J. A. Nienaber. 2003. Electromagnetic induction methods applied to an abandoned manure handling site to determine nutrient buildup. *J. Environ. Qual.* 32(5): 1837-1843.

Eigenberg, R. A., R. L. Korthals, J. A. Nienaber, and G. L. Hahn. 1995. Implementation of a mass balance approach to predicting nutrient fate of manure from beef cattle feedlots. ASAE Paper No. 953555. St. Joseph, Mich: ASAE.

EPA. 2003. NPDES Permit Regulations and Effluent Limitations Guidelines for Confined Animal Feeding Operations, Factsheet #EPA 821-F-03-003. Washington, D.C.

Hach Company. 1992. *Hach Water Analysis Handbook*, 2nd Edition. Loveland, Colo.: Hach Co.

Huffman, R. L., and P. W. Westerman. 1995. Estimated seepage losses from established swine waste lagoon in the lower coastal plain of North Carolina. *Transactions of the ASAE* 38(2): 449-453.

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

McCullough, M. C., D. B. Parker, B. W. Auvermann, and C. Robinson. 1999. Investigation of seal formation on the profile. ASAE Paper No 994081. St. Joseph, Mich: ASAE.

Miller, M. H., J. B. Robinson, and R. W. Gillham. 1985. Self-sealing of earthen liquid manure storage ponds: I. A case study. *J. Environ. Qual.* 14(4): 533-538.

Parker, D. B., D. E. Eisenhauer, D. D. Schulte, and D. L. Martin. 1999. Modeling seepage from an unlined beef cattle feedlot runoff storage pond. *Transactions of the ASAE* 42(5): 1437-1445.

Woodbury, B. L., J. A. Nienaber, and R. A. Eigenberg. 2003. Performance of a passive feedlot runoff control and treatment system. *Transactions of the ASAE* 46(6): 1525-1530.

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

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): 483-487.