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Using Total Solids Concentration to Estimate Nutrient Content of Feedlot Runoff Effluent from Solid Settling Basins, Vegetative Infiltration Basins, and Vegetative Treatment Areas

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Abstract

Increased environmental awareness has promoted the need for improved feedlot runoff control. The use of vegetative treatment systems (VTSs) to control and treat feedlot runoff may enhance environmental security and protect water quality. Knowledge of effluent nutrient concentrations throughout the vegetative treatment system is required to evaluate system performance and impact on water quality. Previously collected VTS monitoring data has provided the opportunity to investigate relationships between effluent quality parameters. The objective of this study was to evaluate, through correlation and regression, the relationships between total solids, nutrients, and effluent quality indicator concentrations of feedlot runoff at various stages of treatment in a VTS, including solid settling basin, vegetative infiltration basin, and vegetative treatment area effluent. Results of a correlation and primary factor analysis showed that most of the effluent concentrations were strongly correlated to each other, with a single factor capable of describing more than 60% of the total variability of the monitored parameters. Regression equations were developed to relate nutrient content and effluent quality indicator concentrations to total solids concentrations. Results were satisfactory for NH3-N, BOD5, COD, Cl-, TP, and TKN, indicating that total solids concentrations provided significant insight into VTS performance relative to nutrient concentration and effluent quality indicators. A comparison between predicted, based on total solids content, and monitored annual mass release of the parameters was conducted. No statistical difference was found for NH3-N, BOD5, COD, Cl-, TP, and TKN; indicating that effluent volume release along with total solids concentrations could be used to provide an estimate of nutrient mass in solid settling basin, vegetative infiltration basin, and vegetative treatment area effluent.

Keywords

Feedlot runoff, Vegetative treatment systems, Solid settling basin, Vegetative treatment areas, Vegetative infiltration basins, Nutrient content, Correlation, Regression, Total solids

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Comments

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USING TOTAL SOLIDS CONCENTRATION TO ESTIMATE NUTRIENT CONTENT OF FEEDLOT RUNOFF EFFLUENT FROM SOLID SETTLING BASINS, VEGETATIVE INFILTRATION BASINS, AND VEGETATIVE TREATMENT AREAS

D. S. Andersen, R. T. Burns, L. B. Moody, M. J. Helmers

ABSTRACT. *Increased environmental awareness has promoted the need for improved feedlot runoff control. The use of vegetative treatment systems (VTSs) to control and treat feedlot runoff may enhance environmental security and protect water quality. Knowledge of effluent nutrient concentrations throughout the vegetative treatment system is required to evaluate system performance and impact on water quality. Previously collected VTS monitoring data has provided the opportunity to investigate relationships between effluent quality parameters. The objective of this study was to evaluate, through correlation and regression, the relationships between total solids, nutrients, and effluent quality indicator concentrations of feedlot runoff at various stages of treatment in a VTS, including solid settling basin, vegetative infiltration basin, and vegetative treatment area effluent. Results of a correlation and primary factor analysis showed that most of the effluent concentrations were strongly correlated to each other, with a single factor capable of describing more than 60% of the total variability of the monitored parameters. Regression equations were developed to relate nutrient content and effluent quality indicator concentrations to total solids concentrations. Results were satisfactory for NH_3-N, BOD_5, COD, Cl^-, TP, and TKN, indicating that total solids concentrations provided significant insight into VTS performance relative to nutrient concentration and effluent quality indicators. A comparison between predicted, based on total solids content, and monitored annual mass release of the parameters was conducted. No statistical difference was found for NH_3-N, BOD_5, COD, Cl^-, TP, and TKN; indicating that effluent volume release along with total solids concentrations could be used to provide an estimate of nutrient mass in solid settling basin, vegetative infiltration basin, and vegetative treatment area effluent.*

Keywords. *Feedlot runoff, Vegetative treatment systems, Solid settling basin, Vegetative treatment areas, Vegetative infiltration basins, Nutrient content, Correlation, Regression, Total solids.*

Runoff from open-lot animal feeding operations (AFOs) has been recognized as a potential pollutant source to receiving waters because it contains nitrogen, phosphorus, organic matter, solids, and pathogens. The U.S. Environmental Protection Agency (EPA) developed a set of effluent limitation guidelines (ELGs) that described the design and operating criteria for feedlot runoff control systems on concentrated animal feeding operations (CAFOs) (Anschutz et al., 1979). These effluent limitation guidelines historically required collection, storage, and land application of feedlot runoff; however, recent modifications allowed the use of alternative treatment systems when the performance of the alternative systems, based on the mass of nutrients released, was equivalent to or exceeded that of an appropriately sized and managed containment system (EPA, 2006). One method of making this comparison was to use simulation models, along with site-specific climate and wastewater characterization data, to determine the pollutant discharge level that the alternative treatment and the containment basin systems would achieve (EPA, 2006).

Vegetative treatment systems (VTSs) are one possible alternative runoff control technology that has been proposed. A VTS is a combination of treatment components, at least one of which utilizes vegetation, to manage runoff from open lots (Koelsch et al., 2006). Vegetative treatment areas (VTAs) and vegetative infiltration basins (VIBs) are two possible treatment components for VTSs. A vegetative treatment area is a band of planted or indigenous vegetation situated down-slope of cropland or animal production facility that provides localized erosion protection and contaminant reduction (Koelsch et al., 2006). As vegetative treatment technology has matured, different types of treatment systems have been developed; for example, Bond et al. (2011) discuss costs associated with constructing sloped, level, pumped, and sprinkler vegetative treatment areas along with vegetative infiltration basins. Briefly, a sloped VTA is an area level in one dimension, to facilitate sheet flow, with a slight slope along the other, planted and managed to maintain a dense

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stand of perennial vegetation (Moody et al., 2006). Operation of a sloped VTA consists of applying solid settling basin effluent uniformly across the top of the vegetated treatment area and allowing the effluent to sheet-flow down the slope, whereas a level VTA uses a flood effect to distribute the effluent over the VTA surface. A pumped VTA has the increased flexibility of allowing the treatment area to be located upslope of the cropland or animal production facility, but still relies on flow to distribute effluent over the length of the vegetative treatment area surface. A sprinkler VTA has the same location flexibility as a pumped VTA, but has the additional advantage of uniform effluent application over the treatment area surface. Ikenberry and Mankin (2000) identified several possible methods in which effluent was treated by VTAs, including settling solids, infiltrating the runoff, and filtering of the effluent as it flowed through the vegetation. Additionally, interactions between soil and soil fauna and the flowing effluent could provide mechanisms of nutrient retention. A VIB is a flat area, surrounded by berms, planted to permanent vegetation. A VIB uses a flood effect to distribute effluent over the surface. These areas have drainage tiles located 1 to 1.2 m (3.4 to 4 ft) below the soil surface to encourage infiltration of effluent. The tile lines collect effluent that percolates through the soil profile. The effluent then receives additional treatment, often through the use of a VTA. Nutrient and pathogen removal in the VIB relies on effluent filtration as it percolates through the soil, plant uptake and removal through harvest, microbial degradation of the nutrients and pathogens by soil fauna, and sorption of contaminants to soil particles.

Young et al. (1980) and Dickey and Vanderholm (1981) provided two of the earlier studies of vegetative treatment of feedlot runoff. In their study, Young et al. (1980) found that concentrations of total phosphorus, ortho-phosphorus, total Kjeldahl nitrogen, and ammonium nitrogen all decreased linearly down the length of the vegetative treatment area and found that percent reductions in total solids transported were similar to those for total phosphorus. Similarly, Dickey and Vanderholm (1981) found that concentrations of total Kjeldahl nitrogen, ammonia nitrogen, and chemical oxygen demand all showed similar reduction patterns as total solids down the length a vegetative treatment area. Dillaha et al. (1988) suggested that vegetative filtration changes flow hydraulics enhancing the opportunity for sedimentation of solids. More recent applications of vegetative treatment systems have been reported by Woodbury et al. (2003) and Faulkner et al. (2011a, 2011b). Woodbury et al. (2003) used a solid settling basin – sloped vegetative treatment area system to control and treat runoff from a beef feedlot in Nebraska. Over a three-year monitoring period no release from the vegetative treatment area were reported. Faulkner et al. (2011a) reported on the use of a vegetative treatment area system for controlling silage bunker runoff. The Faulkner et al. (2011b) site was underlain by a shallow fragipan that restricted drainage and limited impacts on deep groundwater, but also contributed to surface flow releases.

These studies, along with the review of (Koelsch et al., 2006), have shown that vegetative treatment systems can be successful in a variety of situations. This has led to increased interest in their use on animal feeding operations for control of various wastewaters. As part of the permitting process on CAFO-sized operations the EPA requires modeling the performance of the proposed control system and suggests the use of site-specific wastewater characterization data. Recent research (Andersen et al., 2009) has shown that effluent concentrations from runoff control systems components can vary substantially from site to site, thus the use of book values to predict nutrient concentrations could be highly inaccurate. Likewise, Edwards et al. (1986) reported high year-to-year variation in effluent concentrations with annual averages varying by approximately a factor of two for effluent from the feedlot, settling basin, and infiltration basin for total solids, chemical oxygen demand, nitrate, ammonia, organic nitrogen, total phosphorus, and soluble phosphorus. Moreover, numerous authors (Swanson et al., 1971; Swanson and Mielke, 1973; Andersen et al., 2009) have shown that event-to-event variability in feedlot runoff and solid settling basin effluent concentrations can be quite large. This isn't unexpected as event-to-event variability in storm pattern, size, and feedlot surface characteristics can be substantial, which can lead to large variations in runoff hydrology. Overal, this suggests that the use of book-values may not be sufficient for modeling control system performance.

Moreover, CAFOs utilizing alternative treatment systems are required to monitor system performance to ensure that the system is meeting minimum performance standards. Chemical analysis in the laboratory could provide high accuracy, but is expensive in terms of both the time and resources required to collect effluent samples and to carry out the laboratory analysis. Moreover, the results from the chemical analysis are often provided several weeks after sample collection; this limits applicability for making real-time decisions and other practical applications, particularly, since manure composition can change with time. This has lead to interest in developing rapid methods for estimating nutrient concentrations of animal manures based on physicochemical properties. Previous studies (Moral et al., 2005; Chen et al., 2008; Marino et al., 2008) have attempted to relate manure slurry nutrient content to easily measured parameters including pH, total solids content, and electrical conductivity using linear regression and artificial neural network modeling. These studies have met with varying degrees of success, often finding that such relations are species and sometimes region dependent. For instance, Chen et al. (2008) investigated the use of multiple linear regression, polynomial regression, and artificial neural networks to model the nutrient concentrations of dairy manures finding that the artificial neural network model was most successful in estimating nutrient concentrations on dairies in China. Moral et al. (2005) evaluated the potential of linear relationships among nutrient contents and other easily measured parameters on pig slurries in Southeast Spain, finding that electrical conductivity was a strong predictor of ammoniacal nitrogen and potassium concentrations. Marino et al. (2008) suggested that dry matter content and electrical conductivity were good predictors of variables of agronomic interest for liquid dairy manures. In another study, Kim and Gilley (2008) applied artificial neural network modeling to estimate erosion and nutrient concentrations in runoff from manure land application areas. In this study manure was surface applied once and then a rainfall simulator was used to create runoff 4, 32, 62, 123, and 354 days following manure application.

Gilley et al. (2009) found that concentrations of particulate phosphorus, ammonium-nitrogen, nitrate-nitrogen, and electrical conductivity were significantly correlated to feedlot soil characteristics. Moreover, Gilley et al. (2008) suggested that it may be possible to predict runoff nutrient concentrations based on measurements of feedlot soil electrical conductivity. If, as Gilley et al. (2009) suggest, nutrient concentrations in feedlot runoff effluent were significantly related to feedlot soil characteristics, and as shown by Moral et al. (2005), Chen et al. (2008), and Marino et al. (2008) that nutrient content of manures is often related to solids content, then we hypothesize that there would be a strong correlation between the total solids concentration and nutrient content in feedlot runoff and total solids could potentially be used as an estimator of other water quality parameters.

This estimation method could serve several purposes; first, it has the potential to be used to better evaluate the impact feedlot runoff could be having on water quality. This information could be useful for prioritizing sites in need of enhanced or improved runoff control systems. For instance, Baker (2005) developed a model to assess the impact a feedlot would have on surface waters. Relating nutrient concentrations to total solids could provide improvements to models of this type by providing a simple mechanism by which nutrient concentrations could be modeled. Second, at many locations feedlot runoff is land applied as a nutrient source for crops. The estimation method could be used to provide an estimate of the appropriate application rate required to meet crop nutrient demand. The effluent could be tested for solids just prior to the application event and the nutrient estimate used to determine the application rate, Third, CAFOs utilizing vegetative treatment systems are required to perform substantial monitoring to validate the performance of their runoff control system; moreover, this data can be useful in making system management decisions and in determining appropriate system modifications. This monitoring can be expensive as every VTS release event needs to be sampled for numerous nutrient and effluent quality indicators. An estimation method has the potential to reduce these costs by allowing an estimate of nutrient mass release to be calculated based on fewer, more-easily monitored parameters. Additionally, the sample handling and preservation strategies required for certain parameters, such as total solids, are much less stringent than those required for nutrients and could thus reduce the effort required in sampling. Thus the opportunity to utilize an indicator parameter offers the opportunity to make more timely management decisions and to reduce time required in preparing samples for shipment for analysis. The estimation method could also be utilized to approximate nutrient content of the feedlot effluent throughout treatment, providing a better indication of how the runoff control system is performing and offering the operator with opportunity to improve system management. Finally, relating nutrient retention to sediment capture offers the potential to perform detailed modeling on the solids in the runoff and then using this as a proxy to understand nutrient reductions. This methodology has the potential to allow development of algorithms that would provide a more detailed description of how treatment is occurring within the runoff control system, leading to optimized system designs.

The objective of this study was to evaluate the use of total solids concentrations to predict nutrient and effluent quality indicator concentrations of feedlot runoff from solid settling basins and vegetative treatment components. This was conducted by performing correlation and regression analysis for effluent concentrations samples collected on six Iowa sites over a four-year period. Prediction equation verification was performed by evaluating the developed regression equations ability to predict nutrient concentrations on a validation data set and by comparing annual mass releases from each VTS component to the estimated nutrient mass release based on effluent total solids concentration.

Materials and Methods

The performance of six vegetative treatment systems was monitored. These treatment systems were located on CAFO beef feedlots throughout the state of Iowa. At many of the locations more than one VTS was installed. At each site, one VTS was monitored by Iowa State University (ISU). Table 1 shows the VTS configuration, the number of head of cattle, and the areas of the feedlot (and additional drainage area if present), VIB (where applicable), and VTA for the ISU-monitored systems. Full descriptions of these sites are available in Andersen et al. (2009).

Two different VTS configurations were monitored. These were a solid settling basin (SSB) followed by a VTA (SSB-VTA), and an SSB followed by a VIB in series with a VTA (SSB-VIB-VTA). In the SSB-VTA systems, runoff was collected from the beef feedlot and temporarily stored in a solid settling basin. Effluent from the solid settling basin was then released to the VTA. The VTA utilized gravity flow to spread the effluent down the length of the VTA. In the SSB-VIB-VTA systems, a solid settling basin captured the feedlot runoff. Solid settling basin effluent was released onto the VIB, and tile lines located 1 m below the VIB surface collected effluent draining through the VIB soil profile. This effluent was pumped onto a VTA for further treatment.

Table 1. Description of VTSs monitored by ISU including number of head, VTS configuration, and size of the feedlot, settling basin (SSB), vegetative infiltration basin (VIB), and vegetative treatment area (VTA).

Site	No. of Head	System Configuration	Feedlot Area (ha)	SSB Volume (m^3)	VIB Area (ha)	VTA Area (ha)
CN IA 1	1,000	1 SSB - 1 VTA	3.09	4,300	NA	1.52
CN IA 2	650	1 SSB - 1 VIB - 1 VTA	1.07	560	0.32	0.20
NW IA 1	1,400	1 SSB - 1 VTA	2.91	3,700	NA	1.68
NW IA 2	4,000	1 SSB - 1 VIB - 1 VTA	2.96	1,120	1.01	0.60
SW IA 1	2,300	1 SSB - 1 VTA	7.49	11,550	NA	4.05
SW IA 2	1,200	1 SSB - 1 VTA	3.72	6,300	NA	3.44

Monitoring Methods

Descriptions of the monitoring methodologies can be found in Moody et al. (2006) and Andersen et al. (2009). Briefly, Isco samplers (6712 portable samplers, Teledyne Isco, Lincoln, Nebr.) were equipped with either a pressure transducer (720 submerged probe module, Teledyne Isco, Lincoln, Nebr.) or an area-velocity meter (750 area velocity module, Teledyne Isco, Lincoln, Nebr.) and programmed with site and VTS component specific programs that collected multiple samples from each runoff event based on cumulative flow volumes. One sample, believed to be closest to the peak of the hydrograph, was selected for analysis per flow event. The sample was determined by noting sample collection times and the volume of flow programmed to occur between samples and determining an approximate hydrograph. After collection, the samples were placed on ice and shipped to a certified laboratory for analysis following chain-of-custody protocol during sample shipment. Effluent samples were analyzed for ammoniacal-nitrogen (NH_3-N), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), chloride (Cl^-), pH, total phosphorus (TP), total dissolved solids (TDS), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (OP), and Fecal Coliform (FC) concentrations. Total solids (TS) content was calculated as the sum of TDS and TSS.

Data Analysis

For this study, all concentration data, except pH, were log transformed prior to statistical analysis to correct for normality (normality was tested using the Shapiro-Wilk test). Pearson correlation and regression analysis were conducted to determine correlation among sampled parameters and to find equations to predict nutrient/contaminant concentrations. Correlation analysis was performed on the entire data set using the PROC CORR command in SAS 9.2. A separate correlation analysis was performed for each VTS component, i.e., the SSB, VIB, and VTA. A primary factor analysis was conducted in SAS 9.2 using the PROC FACTOR command. A factor analysis is a statistical method used to describe variability among observed variable in terms of a potentially lower number of unobserved variables, called factors. In this analysis it was used to determine how many variables were required to describe the variability of the dataset.

A regression analysis was then conducted. The data set for each VTS component was randomly divided into a calibration and validation data sets (half of dataset used in calibration and half used in validation). The data from all sites was pooled together for each treatment component before dividing the data sets. A linear regression analysis, on the log values of the concentration data, was performed in Microsoft Excel on the calibration data set to generate relationships between the variable of interest and the total solids concentration. The regression equations were then applied to the validation data. Modeling statistics and graphical comparisons were used to determine the ability of the developed regression equations to predict effluent concentrations. Modeling statistics used were the Nash-Sutcliffe efficiency (NSE), percent bias (BIAS), and the ratio of the root mean square error to the standard deviation of the monitored results (RSR). The NSE provided a measure of how well the predicted values followed the trends of the monitored data, BIAS measured the average tendency of the predicted data as compared to the monitored data, and RSR provided an index to evaluate the magnitude of the residual variations (Moriasi et al., 2007).

In addition to the above analysis, the prediction intervals were determined for each of the regression equations developed. The prediction interval provides a confidence interval on future observed responses, thus they provide an indication of how well the prediction equation works and the certainty with which the prediction can be made. That is, they provide the net accuracy of the regression equation, as they state 90% confidence interval around the mean of the selected value.

Results and Discussion

Correlation Analysis

Correlation tests the extent to which two variables are linearly related. Pearson correlation coefficients among the tested parameters for the SSB, VIB, and VTA effluent were determined. Results were similar for all three components and are shown in tables 2, 3, and 4 for the SSB, VIB, and VTA, respectively. We defined a strong correlation as

Table 2. Pearson correlation coefficients for effluent from the solid settling basin.[a][b]

	NH_3	BOD_5	COD	Cl	pH	TP	TKN	TSS	NO_3	OP	TDS	TS
BOD_5	**0.80**	---	---	---	---	---	---	---	---	---	---	---
COD	**0.81**	**0.90**	---	---	---	---	---	---	---	---	---	---
Cl	**0.58**	**0.54**	**0.63**	---	---	---	---	---	---	---	---	---
pH	**-0.54**	**-0.58**	**-0.59**	**-0.34**	---	---	---	---	---	---	---	---
TP	**0.79**	**0.77**	**0.84**	**0.54**	**-0.56**	---	---	---	---	---	---	---
TKN	**0.86**	**0.86**	**0.92**	**0.64**	**-0.54**	**0.82**	---	---	---	---	---	---
TSS	**0.62**	**0.72**	**0.79**	**0.52**	**-0.45**	**0.70**	**0.77**	---	---	---	---	---
NO_3	0.08	0.07	**0.15**	**0.21**	-0.08	**0.15**	**0.15**	**0.15**	---	---	---	---
OP	**0.62**	**0.57**	**0.58**	**0.37**	**-0.52**	**0.78**	**0.57**	**0.37**	**0.18**	---	---	---
TDS	**0.79**	**0.79**	**0.86**	**0.76**	**-0.52**	**0.77**	**0.86**	**0.74**	**0.21**	**0.53**	---	---
TS	**0.75**	**0.79**	**0.89**	**0.72**	**-0.52**	**0.80**	**0.87**	---	**0.20**	**0.50**	---	---
FC	0.05	**0.21**	**0.22**	**0.17**	**-0.21**	0.08	**0.17**	**0.32**	**0.11**	-0.07	**0.22**	**0.26**

[a] A correlation coefficient is significant at the 95% confidence level if |correlation| > 0.11. Data represent 434 samples.
[b] Values in bold are statistically significant.

Table 3. Pearson correlation coefficients for effluent from the vegetative infiltration basin.[a][b]

	NH_3	BOD_5	COD	Cl	pH	TP	TKN	TSS	NO_3	OP	TDS	TS
BOD_5	**0.84**	---	---	---	---	---	---	---	---	---	---	---
COD	**0.86**	**0.95**	---	---	---	---	---	---	---	---	---	---
Cl	**0.68**	**0.60**	**0.60**	---	---	---	---	---	---	---	---	---
pH	0.12	0.05	0.06	**0.15**	---	---	---	---	---	---	---	---
TP	**0.80**	**0.90**	**0.92**	**0.57**	0.07	---	---	---	---	---	---	---
TKN	**0.88**	**0.92**	**0.95**	**0.63**	0.08	**0.91**	---	---	---	---	---	---
TSS	**0.39**	**0.61**	**0.60**	**0.26**	**-0.20**	**0.67**	**0.57**	---	---	---	---	---
NO_3	**-0.14**	0.08	0.07	-0.07	-0.04	**0.15**	0.08	**0.32**	---	---	---	---
OP	**0.67**	**0.80**	**0.80**	**0.48**	**0.16**	**0.85**	**0.76**	**0.58**	**0.31**	---	---	---
TDS	**0.83**	**0.83**	**0.83**	**0.66**	**0.16**	**0.76**	**0.83**	**0.43**	-0.01	**0.65**	---	---
TS	**0.66**	**0.79**	**0.78**	**0.50**	-0.07	**0.81**	**0.78**	---	**0.17**	**0.67**	---	---
FC	**0.39**	**0.64**	**0.63**	**0.25**	-0.03	**0.59**	**0.61**	**0.43**	**0.28**	**0.54**	**0.49**	**0.51**

[a] A correlation coefficient is significant at the 95% confidence level if |correlation| > 0.13. Data represent 237 samples.
[b] Values in bold are statistically significant.

having a value of 0.7 or more, as this would indicate that 50% of the variability of the parameters was shared. Based on this interpretation, many of the parameters were strongly correlated to each other, with only pH, nitrate, and fecal coliforms showing no strong correlations to the other parameters. Due to the correlation among the variables, a factor analysis was performed to assess how much of the variability was due to common factors, i.e., the communality of the dataset. The factor analysis of the settling basin effluent indicated that a single factor could explain 62% of the total variability for the effluent quality parameters. No additional factor could explain more than 9% of the dataset's variability. This indicated that only a single variable was justified in the regression equations. Factor analysis was also conducted for the VIB and VTA effluent. Results indicated that a single factor could again explain 61% and 68% of the total variability, with no other factors explaining more than 13% and 10% of the total variability, respectively. Based on the primary factor analysis, four parameters (total solids, total dissolved solids, total Kjeldahl nitrogen, and chemical oxygen demand) were strongly correlated to the primary factor. Total solids concentration was selected for use in the regression analysis as it is an easily measured parameter and it has the possibility to provide insight into transport of both particulate and dissolved parameters in that it is composed of both a dissolved and particulate components. That it may have the potential to track treatment through both sedimentation, interaction with soil particles, and dilution from outside water sources (rainfall, run-on, etc.) as solids is affected by all three treatment processes.

Regression Equation Calibration

Linear regression was performed on the log of the concentration data to relate parameter concentration to total solids concentration for the SSB, VIB, and VTA effluent. Developed regression equations are shown in table 5. The amount of the variability described by the regression equation is also provided (R^2). Several parameters (pH, NO_3-N, ortho-phosphorus, and fecal coliform) could not be described by the regression equations as indicated by the low (less than 0.50) R^2 values. In addition, the 90% prediction interval is also provided for each equation. The prediction interval provides a confidence interval on future observed responses.

Regression Equation Validation

The regression equations' ability to predict constituent concentration based on the total solids concentrations in the SSB, VIB, and VTA effluent was then tested. This testing used the validation data set. Figure 1 shows the ability of the regression equations, based on TS concentrations, to predict parameter concentrations for NH_3-N, TKN, TP, and COD.

Table 4. Pearson correlation coefficients for effluent from the vegetative treatment area.[a][b]

	NH_3	BOD_5	COD	Cl	pH	TP	TKN	TSS	NO_3	OP	TDS	TS
BOD_5	**0.90**	---	---	---	---	---	---	---	---	---	---	---
COD	**0.92**	**0.96**	---	---	---	---	---	---	---	---	---	---
Cl	**0.64**	**0.64**	**0.71**	---	---	---	---	---	---	---	---	---
pH	**-0.48**	**-0.50**	**-0.47**	-0.03	---	---	---	---	---	---	---	---
TP	**0.87**	**0.83**	**0.88**	**0.60**	**-0.48**	---	---	---	---	---	---	---
TKN	**0.95**	**0.93**	**0.96**	**0.71**	**-0.47**	**0.89**	---	---	---	---	---	---
TSS	**0.78**	**0.85**	**0.86**	**0.55**	**-0.48**	**0.74**	**0.83**	---	---	---	---	---
NO_3	0.07	0.08	0.05	-0.02	-0.13	0.13	0.09	0.01	---	---	---	---
OP	**0.81**	**0.73**	**0.77**	**0.54**	**-0.44**	**0.91**	**0.80**	**0.59**	**0.16**	---	---	---
TDS	**0.80**	**0.86**	**0.90**	**0.84**	**-0.27**	**0.75**	**0.86**	**0.76**	-0.01	**0.65**	---	---
TS	**0.81**	**0.87**	**0.91**	**0.80**	**-0.30**	**0.75**	---	**0.86**	-0.01	**0.63**	---	---
FC	**0.47**	**0.54**	**0.54**	**0.28**	**-0.42**	**0.51**	**0.51**	**0.55**	0.06	**0.45**	**0.45**	**0.47**

[a] A correlation coefficient is significant at the 95% confidence level if |correlation| > 0.13. Data represent 229 samples.
[b] Values in bold are statistically significant.

Table 5. Regression equations relating solid settling basin (SSB), vegetative infiltration basin (VIB), and vegetative treatment area (VTA) effluent contaminant concentrations to total solids concentrations.[a]

Dependent Variable	SSB			VIB			VTA		
	Regression Equation	R^2	90% PI[b]	Regression Equation	R^2	90% PI	Regression Equation	R^2	90% PI
NH_3-N	$=1.42*10^{-2}(TS)^{1.00}$	0.56	$=10^{logy\pm0.54}$	$=5.56*10^{-4}(TS)^{1.27}$	0.39	$=10^{logy\pm0.93}$	$=1.43*10^{-5}(TS)^{1.81}$	0.66	$=10^{logy-0.92}$
BOD_5	$=1.74*10^{-2}(TS)^{1.24}$	0.61	$=10^{logy\pm0.60}$	$=9.57*10^{-6}(TS)^{2.02}$	0.60	$=10^{logy\pm0.96}$	$=4.52*10^{-5}(TS)^{1.95}$	0.78	$=10^{logy-0.75}$
COD	$=2.77*10^{-1}(TS)^{1.10}$	0.76	$=10^{logy\pm0.37}$	$=5.13*10^{-3}(TS)^{1.48}$	0.62	$=10^{logy\pm0.67}$	$=6.27*10^{-3}(TS)^{1.53}$	0.84	$=10^{logy-0.47}$
Cl^-	$=1.24(TS)^{0.65}$	0.52	$=10^{logy\pm0.38}$	$=8.87(TS)^{0.42}$	0.30	$=10^{logy\pm0.38}$	$=2.62*10^{-1}(TS)^{0.83}$	0.62	$=10^{logy-0.46}$
pH	=9.68-0.62log(TS)	0.33	=pH±0.53	=7.40-0.11log(TS)	0.01	=pH±0.59	=8.78-0.67log(TS)	0.16	=pH±0.60
TP	$=1.58*10^{-1}(TS)^{0.69}$	0.62	$=10^{logy\pm0.33}$	$=4.08*10^{-4}(TS)^{1.29}$	0.65	$=10^{logy\pm0.55}$	$=1.05*10^{-2}(TS)^{0.97}$	0.61	$=10^{logy-0.56}$
TKN	$=3.28*10^{-2}(TS)^{1.02}$	0.72	$=10^{logy\pm0.39}$	$=5.98*10^{-4}(TS)^{1.41}$	0.61	$=10^{logy\pm0.65}$	$=3.84*10^{-4}(TS)^{1.54}$	0.76	$=10^{logy-0.61}$
NO_3-N	$=2.92*10^{-1}(TS)^{0.17}$	0.02	$=10^{logy\pm0.74}$	$=8.13*10^{-2}(TS)^{0.33}$	0.03	$=10^{logy\pm1.18}$	$=6.50*10^{-1}(TS)^{0.07}$	0.00	$=10^{logy-0.80}$
OP	$=6.08*10^{-1}(TS)^{0.48}$	0.25	$=10^{logy\pm0.51}$	$=6.25*10^{-6}(TS)^{1.59}$	0.37	$=10^{logy\pm1.20}$	$=2.37*10^{-2}(TS)^{0.80}$	0.39	$=10^{logy-0.71}$
FC	$=744(TS)^{1.05}$	0.08	$=10^{logy\pm2.19}$	$=9.52*10^{-6}(TS)^{2.82}$	0.26	$=10^{logy\pm2.81}$	$=5.93*10^{-4}(TS)^{2.52}$	0.27	$=10^{logy-2.93}$

[a] The R^2 valve of each regression equation is provided. PI is the 90% prediction interval, i.e., 90% of future measurements of the dependent variable fall inside the interval.

[b] In the 90% PI *y* represents the dependent variable.

The calibration equations were also evaluated with the use of modeling statistics. The modeling statistics used were the NSE, BIAS, and the RSR. Modeling statistics results are provided in table 6.

All regression equations were found to have a tendency to underestimate parameter concentrations as evidenced by the positive value for the BIAS statistic. The NSE provided information about the regression equations' ability to follow trends in concentration, with values greater than zero indicating that the regression equation performs better than using the average of the monitored data; for all parameters except pH, NO_3-N, and fecal coliforms the regression equations provided a better predictor than using the average value (positive NSE values). This indicates that use of these regression equations, rather than averages or table values, may provide a better estimate of parameter concentrations. The RSR value compared the standard deviation of the monitored results to the residual variability remaining after applying the regression equation; values less than one indicated that the regression equation described more variability than the mean value of the monitored data. It appeared that many of the regression equations were providing a good description of the parameter concentrations, indicating that total solids concentration had the potential to serve as a proxy for better understanding the treatment, in terms of the nutrient concentrations reduction that VTSs are achieving.

Implications

The introduction discussed five potential uses for a nutrient/contaminant concentration estimation methodology. These included using total solids concentrations to evaluate the impact feedlot runoff was having on water quality, using total solids as a proxy to determine effluent application rates for use as a fertilizer or in determining nutrient loading rates on vegetative infiltration basins and vegetative treatment areas, as part of monitoring the VTS releases as required in NPDES permits issued to animal feeding operations, making timely management systems involved in operating VTS and evaluating overall system performance, and in developing detailed process based algorithms to describe nutrient retention in vegetative treatment systems. This section of the manuscript will provide examples to illustrate these potential applications and discuss how the proposed methodology offers potential for better modeling runoff control system performance.

In practice, determining effluent application rates for use as a fertilizer, loading rates on vegetative infiltration basins and vegetative treatment areas, and monitoring VTS releases are all essentially the same. In all three cases we are most interested in estimating yearly nutrient loadings rates or contaminant releases, that is, we want to estimate the mass of contaminant either in the effluent released from the system, applied to cropland, or retained within each treatment component. To test the use of these proposed regression equations for these purposes we compared the monitored annual contaminant mass transport and the annual contaminant mass transport estimated based on total solids concentrations. These evaluations were made for NH_3-N, BOD_5, COD, Cl^-, TP, and TKN. Evaluations for NO_3-N, and OP were not performed as the R^2 values of the regression equations indicated weak relationships. The monitored total solids concentration from each release event for each VTS component was used in the regression equation to project effluent concentrations. The estimated concentrations were multiplied by the event flow volume to determine mass release. Mass releases were then summed to calculate the annual mass release. These calculated values were compared to the monitored mass release from each VTS component. A paired t-test was performed to determine if there was a statistical difference between the monitored and predicted mass release (table 7). Significant differences in mass release estimates were only seen for NO_3-N and OP. These results indicate that this methodology offers considerable insight into determining appropriate effluent application rates for use as a fertilizer, evaluating contaminant masses released from the runoff control system, and in estimating nutrient loading rates onto the vegetative treatment system components.

Likewise, evaluating the impact releases from a feedlot's runoff control system are having on water quality and developing detailed process-based algorithms to describe nutrient retention in vegetative treatment are similar tasks. In both cases, the proposed methodology regression equations would suggest that focusing on the transport of solids would provide a computationally efficient means of evaluating the systems performance relative to other nutrients. Recent work

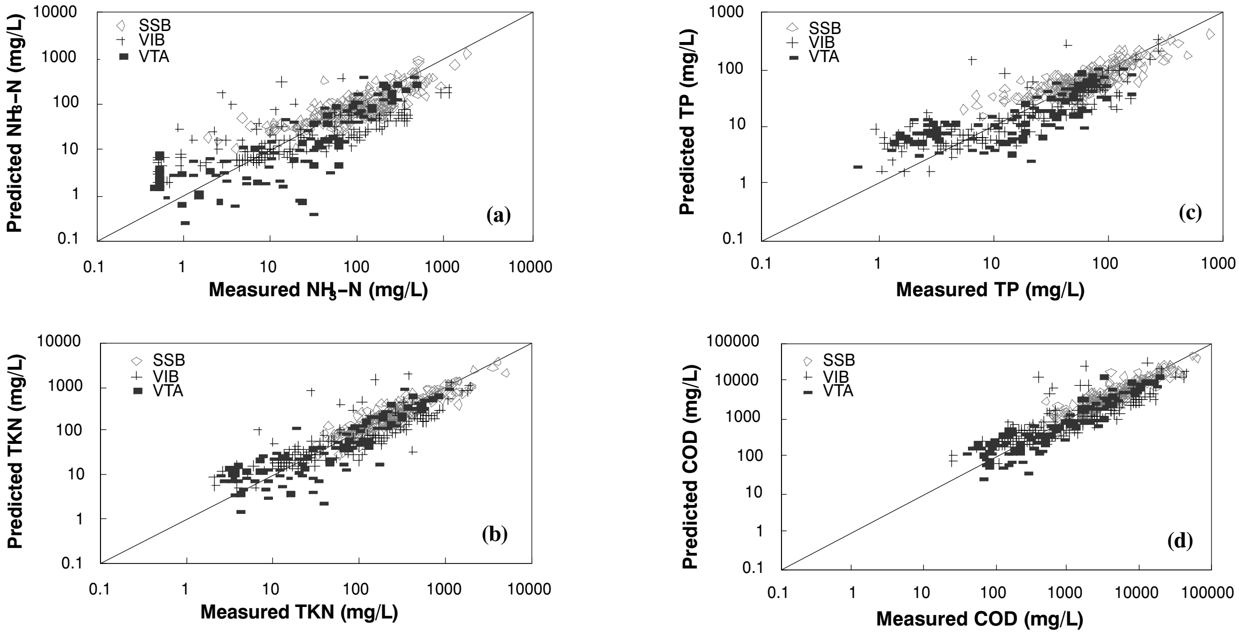

Figure 1. Plots of predicted, based on TS concentrations, versus modeled (a) ammoniacal-nitrogen (NH_3-N), (b) total Kjeldahl nitrogen (TKN), (c) total phosphorus (TP), and (d) chemical oxygen demand (COD) concentrations for solid settling basin (SSB), vegetative infiltration basin (VIB), and vegetative treatment area (VTA) effluent. The one-to-one line is also displayed in the graphs.

(Flanagan and Nearing, 2000; Gao et al., 2004) has alluded to improving methodologies for quantifying transport of soil particles and dissolved solids in agricultural settings. It's possible that the models proposed in these manuscripts could be used to estimate solids transport from the feedlot surface. Hydraulic models and flow detention techniques could then be used to estimate solid settling within the basin and estimate solids concentrations at the outlet. The proposed regression equations could then be utilized to estimate nutrient concentrations of the effluent. This methodology offers a significant advantage over utilizing book-values as it compensates for both event-to-event variability in nutrient concentrations in runoff from a single lot and has the potential to characterize the risks that feedlots of various sizes (i.e., slope lengths), slope angles, and slope profiles would pose. Similarly, further sediment deposition and filtration that occurs in vegetative treatment areas and vegetative infiltration basins could be modeled and used as a proxy to model nutrient retention.

Table 6. The Nash-Sutcliffe efficiency (NSE), percent bias (BIAS), and the ratio of the root mean square error to the standard deviation of the monitored results (RSR) for evaluating regression equation performance for ammoniacal-nitrogen, five-day biochemical oxygen demand, chemical oxygen demand, chloride, pH, total phosphorus, total Kjeldahl nitrogen, nitrate-nitrogen, orthophosphorus, and fecal coliform.

	SSB			VIB			VTA		
	NSE	RSR	BIAS	NSE	RSR	BIAS	NSE	RSR	BIAS
NH_3	0.61	0.62	26	0.15	0.92	62	0.68	0.56	20
BOD_5	0.67	0.57	28	-0.07	1.03	36	0.57	0.65	20
COD	0.75	0.50	19	0.32	0.82	37	0.74	0.51	16
Cl^-	0.38	0.78	10	0.27	0.85	10	0.61	0.62	18
pH	0.21	0.89	0	-0.02	1.01	-1	0.00	1.00	0
TP	0.67	0.58	12	0.49	0.71	22	0.55	0.67	24
TKN	0.76	0.49	17	0.26	0.86	32	0.80	0.44	10
NO_3-N	-0.07	1.03	39	-0.19	1.09	71	-0.09	1.04	58
OP	0.28	0.85	19	0.10	0.95	64	0.26	0.85	36
FC	-0.06	1.03	95	-0.02	1.01	93	-0.04	1.02	98
Ideal value	1.00	0.00	0	1.00	0.00	0	1.00	0.00	0

Table 7. P-values for a paired t-test comparing monitored mass release to predicted mass release calculated based on total solids concentration. No significant differences between monitored and predicted mass releases were found ($\alpha = 0.05$).

Component	NH_3-N	BOD_5	COD	Cl^-	Total P	TKN
SSB	0.86	0.69	0.43	0.85	0.70	1.00
VIB	0.19	0.40	0.13	0.59	0.16	0.19
VTA	0.38	0.39	0.48	0.32	0.19	0.67

Conclusions

Feedlot runoff is receiving increased attention as a potential environmental contaminant. As a result, feedlots are seeking information on runoff control practices that enhance environmental security. Vegetative treatment systems are one option that is seeing increased use; however, knowledge of effluent nutrient concentrations throughout the treatment system is required to evaluate system performance and to make real-time management decisions. The objective of this research was to evaluate the use of total solids concentrations to predict nutrient concentrations of feedlot runoff undergoing vegetative treatment. This was done by performing a correlation and regression analysis. Results of the correlation analysis indicated that most of the parameter concentrations were significantly related to each other, with all parameters exhibiting a significant correlation with at least one other monitored parameter. A primary factor analysis showed a single factor was capable of describing more than 60% of the variability of the ten monitored parameters. Regression equations were developed to relate nutrient content and effluent quality indicator concentrations to total solids concentrations. Results were satisfactory for most parameters, indicating that total solids concentrations provided significant insight into the performance, in terms of nutrient concentrations reductions, VTSs were achieving. The predicted and monitored annual mass releases were compared for NH_3-N, BOD_5, COD, Cl^-, TP, and TKN; NO_3-N and OP were not evaluated as the regression equations indicated only a weak relationship. No statistically significant differences in mass release were found. This indicates that monitoring of TS mass release may be adequate to predict these nutrient mass releases from the VTS.

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References

Andersen, D. S., R. T. Burns, L. B. Moody, I. Khanijo, M. J. Helmers, C. Pederson, and J. Lawrence. 2009. Performance of six vegetative treatment systems for controlling runoff from open beef feedlots in Iowa. ASABE Paper No. 097054. St. Joseph, Mich.: ASABE.

Anschutz, J. A., J. K. Koelliker, J. J. Zovne, T. A. Bean, and M. J. Peterson. 1979. Sizing components on open feedlot runoff control systems. *Trans. ASAE* 22(4): 803-808.

Baker, K. D. 2005. Temporal assessment of nutrient contributions to waterways from feedlots. *Applied Eng. in Agric.* 21(3): 517-528.

Bond, B. J., R. T. Burns, C. G. Henry, T. P. Trooien, S. H. Pohl, L. B. Moody, M. J. Helmers, and J. D. Lawrence. 2011. Comparison of construction costs for vegetative treatment systems in the Midwestern United States. *Applied Eng. in Agric.* 27(3): 413-423.

Chen, L. J., L. Y. Cui, L. Xing, and L. J. Han. 2008. Prediction of nutrient content in dairy manure using artificial neural network modeling. *J. Dairy Sci.* 91 (12): 4822-4829.

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

Dillaha, T. A., J. H. Sherrard, D. Lee, S. Mostaghimi, and V. O. Shanholtz. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. *J. Water Poll.* 60(7): 1231-1238.

Edwards, W. M., L. B. Owens, R. K. Whie, and N. R. Fausey. 1986. Managing runoff from a small, paved beef feedlot. *Trans. ASAE* 29(1): 243-247.

EPA. 2006. 40 CFR Parts 122 and 412: Revised national pollutant discharge elimination system: Permit regulation and effluent limitation guidelines for concentrated animal feeding operations in response to Waterkeeper decision; Proposed rule, 30 June 2006. *Federal Register* 71(126): 37744-37787.

Faulkner, J. W., W. Zhang, L. D. Geohring, and T. S. Steenhuis. 2011a. Nutrient transport within three vegetative treatment areas receiving silage bunker runoff. *J. Environ. Mgmt.* 92(3): 587-595.

Faulkner, J. W., W. Zhang, L. D. Geohring, and T. S. Steenhuis. 2011b. Tracer movement through paired vegetative treatment areas receiving silage bunker runoff. *J. Soil and Water Cons.* 66(1): 18-28.

Flanagan, D. C., and M. A. Nearing. 2000. Sediment particle sorting on hillslope profiles in the WEPP model. *Trans. ASAE* 43(3): 573-683.

Gao, B., M. T. Walter, T. S. Steenhuis, W. L. Hogarth, and J. Y. Parlange. 2004. Rainfall induced chemical transport from soil to runoff: theory and experiments. *J. Hydrol.* 295(1-4): 291-304.

Gilley, J. E., E. D. Berry, R. A. Eigenberg, D. B. Marx, and B. L. Woodbury. 2008. Spatial variations in nutrient and microbial transport from feedlot surfaces. *Trans. ASABE* 51(2): 675-684.

Gilley, J. E., E. D. Berry, R. A. Eigenberg, D. B. Marx, and B. L. Woodbury. 2009. Nutrient transport in runoff from feedlot surfaces as affected by unconsolidated surface materials. ASABE Paper No. 096310. St. Joseph, Mich.: ASABE.

Ikenberry, C. D., and K. R. Mankin. 2000. Review of vegetative filter strip performance for animal waste treatment. In *Proc. Mid-Central Conf.* ASAE Paper No. MC000128. St. Joseph, Mich.: ASAE.

Kim, M., and J. E. Gilley. 2008. Artificial neural network estimation of soil erosion and nutrient concentration in runoff from land application areas. *Computers and Electronics in Agric.* 64(2): 268-275.

Koelsch, R. K., J. C. Lorimor, and K. R. Mankin. 2006. Vegetative treatment systems for management of open lot runoff: review of literature. *Applied Eng. in Agric.* 22(1): 141-153.

Marino, P., G. De Ferrari, and L Bechini. 2008. Description of a sample of liquid dairy manures and relationships between analytical variables. *Biosystems Eng.* 100(2): 256-265.

Moral, R., M. D. Perez-Murcia, A. Perez-Espinosa, J. Moreno-Caselles, and C. Padedes. 2005. Estimation of nutrient values of pig slurries in Southeast Spain using easily determined properties. *Waste Mgmt.* 25(7): 719-725.

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R L Bingner, R. D. Harmel, and T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE* 50(3): 885-900.

Moody, L. B., C. Pederson, R. T. Burns, and I. Khanijo. 2006. Vegetative treatment systems for open feedlot runoff: Project design and monitoring methods for five commercial beef feedlots. ASABE Paper No. 064145. St. Joseph, Mich.: ASABE.

Swanson, N. P., L. N. Mielke, J. C. Lorimor, T. M. McCalla, and J. R. Ellis. 1971. Transport of pollutants from sloping cattle feedlots as affected by rainfall intensity, duration, and recurrence. In *Live. Waste Mgmt. and Pollution Abatement,Proc. Intl. Symp. on Live.Wastes,* 51-55. St. Joseph, Mich.: ASAE.

Swanson, N. P., and L. N. Mielke. 1973. Solids trap for beef cattle feedlot runoff. *Trans. ASAE* 16(4): 743-745.

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

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.