Groundwater Research Report
WR11R007

SILAGE STORAGE RUNOFF WATER QUALITY ASSESSMENT AND DESIGN RECOMMENDATIONS TO LIMIT ENVIRONMENTAL IMPACTS

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Funding Year:
2011

Silage Storage Runoff Water Quality Assessment and Design Recommendations to Limit Environmental Impacts

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July 1, 2011- June 30, 2013

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Project Summary

Title

Silage Storage Runoff Water Quality Assessment and Design Recommendations to Limit Environmental Impacts

Project I.D.

Investigators

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Michael Holly, Research Assistant, Biological Systems Engineering

Period of Contract

July 1, 2011- June 30, 2013

Background/Need

Silage storage is required for many livestock and poultry facilities to maintain their animals throughout the year. While feed storage is an asset which allows for year round animal production systems, they can pose negative environmental impacts due to silage leachate and runoff. Silage leachate and runoff have high levels of oxygen demand and nutrients (up to twice the strength of animal manure), as well as a low pH posing issues to surface waters when discharged. Although some research exists which shows the potency of silage leachate and runoff, little information is available to guide the design of collection, handling, and treatment facilities to minimize the impact to water quality. Detailed information to characterize the strength of the runoff through a storm is needed to develop collection systems which segregate runoff to the appropriate handling and treatment system based on the strength of the waste. In addition, more information is needed to assess filter strip performance where the waste is discharged for treatment to ensure there is no negative impact to surface and groundwater quality.

Objectives

This research aims to collect the necessary water quality data from silage storage runoff to make recommendations to reduce risk. Specific objectives include:

1. Assess the water quality from bunker silage storage systems
2. Determine the impact of system design and other management and environmental conditions on the runoff water quality (including seasonal variation)
3. Determine if first flush conditions exist for silage storage runoff (to potentially separate high and low strength waste for ease of management/treatment)
4. Make recommendations for silage storage collection systems to minimize volume collected and maximize pollutant load collection
5. Evaluate surface and subsurface water quality of a filter strip and modified filter strip which receives silage storage runoff

Methods

This research was conducted in two phases. The first phase of the research (objectives 1-4) was completed at three bunker silage storage systems in Wisconsin. Runoff from these systems was collected using automated samplers throughout one year to assess water quality for nutrients (nitrogen and phosphorus species), oxygen demand, total solids, and pH. Flow rate for each system was also recorded along with weather data including precipitation information. Feed quantity and quality was also recorded at each site to have a better understanding of the impact of silage management on water quality. Data was analyzed to determine flow weighted average runoff concentrations for pollutants measured, seasonality and feed impacts to water quality, storage design impacts, the presence or absence of first flush conditions, and evaluated to make collection design recommendations.

The second phase of the research was to investigate the impact of silage storage runoff to water quality when applied to a filter strip. Two filter strip plots were installed at a USDA research farm. Each filter strip plot was excavated and lined with an impermeable membrane to catch subsurface water in order to evaluate water quality once it had leached through the system. The liner was backfilled and seeded with a native vegetated mix. Silage storage runoff was collected in a basin and metered onto the filter strip plots. Volumes were recorded for subsurface infiltration and surface runoff. Both samples were evaluated to determine water quality. One filter strip system had an additional treatment system on the front end which had an aerobic phase followed by an anaerobic phase in an attempt to increase the nitrification and denitrification before entering the filter strip system. Systems were evaluated for a number of application cycles to determine the impact to water quality before reaching ground or surface water.

Results and Discussion

Phase 1 - Runoff Characterization

Flow rate, timing of ensiling of forage, site bunker design, and amount of litter present were determined to influence silage runoff concentrations. Leachate collection played a significant role in water quality as the runoff from the site without leachate collection had a lower average pH (4.64) and higher COD values (5,789 mg L^{-1}) than the sites with leachate collection (6.09 and 5.54 pH, and 1,296 and 3,318 mg L^{-1} COD). Nutrients were also higher for the site without leachate collection TP (83 mg L^{-1}), NH_3 (68 mg L^{-1}), and TKN (222 mg L^{-1}) compared to TP (29 and 63 mg L^{-1}), NH_3 (25 and 48 mg L^{-1}), and TKN (184 and 215 mg L^{-1}) for the sites with leachate removal. Time of ensilage also played an important role in water quality with increased losses occurring within two weeks of ensilage. The most important finding for the design of treatment systems was that the water quality parameters (including nutrients) were found to be negatively correlated with flow. The resulting effect is that the storms hydrograph has a significant impact on the pollutant loading to the surrounding waterways. It was also found that loading was relatively linear throughout each storm event indicating that there is no first flush phenomenon which is found to occur with urban runoff systems. Therefore designing systems to collect the initial runoff from a system is not an efficient way to capture the greatest pollutant load. It was found that low flows throughout a storm have high pollutant concentrations and collecting low flows throughout a storm would result in the greatest load collected per unit volume.

Phase 2 – Filter Strip Assessment

Filter strips were capable of reducing pollutant concentrations when leached through the soil profile but not from surface runoff. Performance of filter strips decreased significantly in the winter months and resulted in virtually no treatment. The addition of an aerobic and anaerobic pre-treatment did not reduce the nitrogen losses as expected, which is thought to be due to the short retention time.

Conclusions/Implications/Recommendations

Flow rate, timing of ensiling of forage, site bunker design, and amount of litter present were determined to influence silage runoff concentrations. Collecting low flows throughout a storm will reduce the loading to filter strips. Collecting runoff within 2 weeks of filling will also decrease loading to filter strips. Subsurface leachate collection systems are also recommended to protect groundwater from direct leaching from silage storage areas. Filter strips can increase water quality when the water leaches through the soil profile (surface runoff concentrations are not affected by filter strips) so systems should be designed to infiltrate water when there is adequate distance to groundwater. Runoff should not be applied to filter strips when the ground is frozen or cold as treatment is poor.

Related Publications

Holly, M. and R.A. Larson. 2014. Characterization and Assessment of First Flush from Silage Leachate and Runoff. *Journal of Environmental Management*. Submitted.

Key Words

Silage Storage Runoff, Agricultural Water Quality

Funding

University of Wisconsin Water Resources Institute

Introduction

In the United States, animals are primarily grain-fed (in addition to other substrates), with over a 150 million tons of corn grain and 4 million tons of both sorghum and wheat used for feed on an annual basis (FAOSTAT 2007). The primary use of corn grain and silage in the US is for livestock feed (University of Kentucky Cooperative Extension Service 2009). Annual storage is required for over 108 million tons of corn silage and nearly 3.6 million tons of sorghum silage in addition to other silage feedstocks (USDA 2009). Silage is commonly stored in horizontal and upright silos. Stored feed supplies are typically viewed as an on-farm assets on animal feeding operations, but storage of feed produces silage leachate, a high strength waste, with significant environmental impacts. In addition, bunk silo leachate can cause up to 15% nutrient loss within feed (Wright et al. 2004) and can cause spoilage of valuable feed stocks.

Diffuse source pollution from animal feeding operations has the potential to contaminate ground and surface water. Animal feed is susceptible to transport during a precipitation or thaw event, resulting in non-point source pollution (US EPA 2003). Feedlot wastes have the potential to contaminate surface water due to runoff from impermeable surfaces or saturated soils and aquifer contamination due to leaching through permeable soils (Burkholder et al. 2007). Soil assimilation of wastewater constituents contributes to overall pollutant removal through biological and chemical oxidation, adsorption, precipitation/dissolution, and filtration (Brown and Caldwell 2007). However, recent groundwater contamination of metals can be traced back to these practices due to an overload of applied waste to soil treatment systems (Safferman et al. 2010; McDaniel 2006; Muchovej and Obreza 2001; Mokma 2007; Central Valley Regional Water Quality Control Board 2005).

Silage leachate volumes are directly related to the moisture content of the silage, but also depend on silo type, pretreatment, and degree of consolidation (McDonald 1981). Significant leachate reductions can occur with an increase in dry matter content of herbage, and regardless of dry matter leachate, volumes decreases significantly after 1 week (Bastiman 1976). Silage storage produces leachate from the moisture within the silage which is extremely acidic, has strong odors and high concentrations of biological oxygen demand (BOD) concentrations. BOD_5 ranges from 20,000 to 80,000 mg/L, twice the strength of manure slurry (Otter et al. 1991; McDonald 1991). Farm pollution incidents due to silage leachate vary from year to year, but are often the leading source of agricultural pollution (Otter et al. 1991). Improper treatment can lead to significant deterioration or burning of vegetation, resulting in channelization and erosion posing issues to surface water (direct runoff) and groundwater (high loading rates). Silage leachate travels through concrete structure and directly leaches to the groundwater below, have large impacts on groundwater quality. Application of even diluted silage leachate (BOD_5 average of 1300 mg/L) to vegetated/soil surfaces can leach into groundwater causing high levels of nitrates, an average of 45 mg/L-N for soils that have infiltrated at a foot depth (previous research currently in review for publication), which is more than 4 times the US EPA standard for nitrates in groundwater. Nitrate contamination is a leading concern for groundwater around the world, including the US. Nitrate contamination from various wastewaters, which sources include animal production facilities, have been measured at elevated concentrations in numerous countries including the United States (Kirby et al. 2003).

Additionally, silage leachate runoff containing solids, oxygen demanding waste, and excess nutrients contribute to anoxic conditions in waterways and impact surface water aquatic communities and habitats (Burkholder et al. 2007). Excess nutrient concentrations have been reported as a cause of environmental concern throughout the world. Nitrate assessment has shown that agricultural sources are a leading source of impaired waterways (US EPA 2004) and diffuse agricultural phosphorus sources are a leading contributor to this water pollution (Parry 1998). Eutrophication of waterways can occur with only small additions to phosphorus concentrations (Hart et al. 2004). Excess phosphorus concentrations result in algal blooms and decreased oxygen as it is typically the limiting nutrient for the processes producing these effects (Anderson et al. 2002). Decreased oxygen concentrations in waterways leads to fish kills and habitat destruction (Burkholder et al. 2007; Anderson et al. 2002).

Current research has investigated silage leachate in terms of effluent quantity produced (Bastiman 1976; McDonald 1981), but not had a focus on effluent quality (particularly in terms of feed sources). Current management recommendations focus on collection of silage leachate and runoff, which can become impractical. Alternatively, silage runoff has commonly been applied to agricultural vegetated filter strips in Wisconsin and around the United States. However, waste of this strength, even when diluted, has lead to nitrate and metal leaching within the soil. Current filter strip design lacks the necessary mechanisms to complete nitrogen cycling. Additions of ammonia and organic nitrogen require an aerobic phase for conversion to nitrate, which then requires denitrification (an anaerobic process) to convert to nitrogen gas. Denitrification is not providing the necessary nitrate removal to reach groundwater standards, as small concentrations of oxygen reduce denitrifications rates significantly. In addition, the addition of a reducing zone within the soil profile for denitrifcation (nitrate removal) would provide the conditions which result in metal leaching. These results indicate the need for a multi-step treatment system which provides an aerobic zone, followed by an anaerobic zone nitrate removal with a final aerobic zone to eliminate metal leaching into soil.

The science supporting the characterization, handling, and treatment of silage runoff is nearly non-existent. Regulators, producers, and those available for consultation in agricultural matters are functioning without the information necessary to make sound environmental regulation, handling and treatment design, and operational recommendations due to the lack of understanding of the issues. This research will provide the necessary data to assess current practice standards and treatment options. Objectives include:

1. Assess the water quality from bunker silage storage systems
2. Determine the impact of system design and other management and environmental conditions on the runoff water quality (including seasonal variation)
3. Determine if first flush conditions exist for silage storage runoff (to potentially separate high and low strength waste for ease of management/treatment)
4. Make recommendations for silage storage collection systems to minimize volume collected and maximize pollutant load collection
5. Evaluate surface and subsurface water quality of a filter strip and modified filter strip which receives silage storage runoff

Procedures and Methods

The project was divided into two individual research components. The first section of the project evaluated three sites to establish water quality data for bunker silage storage systems. The second section established two filter strips plots to evaluate the surface and subsurface water quality when bunker silage storage runoff was applied to vegetated treatment strips.

Runoff Characterization

The runoff from three dairy silage bunker sites was investigated over the course of one year to assess water quality characteristics.

Arlington Agricultural Research Station (AARS) is a 530-head dairy located in Dane County, Wisconsin (WI). AARS receives an average of 920 mm of precipitation and has an average monthly temperature range of -8° C in January to 22° C in July. AARS has a 5,300 m^2 silage storage area consisting of five concrete horizontal dairy bunkers with a total area of 4,100 m^2 and an operating pad of 1,200 m^2. The main crop ensiled at AARS is corn silage. In September of 2011 and 2012 the bunkers were filled with 5,000 and 4,000 tons corn silage, respectively. The remaining bunk space was filled with a total of 2,500 tons of haylage in May, June, and August in 2011 and 2012. The horizontal storage bunkers at AARS were designed with a sub-surface leachate collection system to collect any water that leached through the concrete pad. The subsurface system is a series drains below the concrete connected to pipes which run to a central collection point. Surface runoff is collected in a grated pit via gravity at the lowest point of the loading pad and silage storage area. A rectangular weir and sampler lines were placed within this pit to monitor surface runoff only at AARS.

The Dairy Forage Research Center (DFRC) is a 350-head dairy in Sauk County, WI. DFRC receives an average of 906 mm of precipitation and has an average monthly temperature range of -8° C in January to 22° C in July. DFRC's silage storage facility is a 2,400 m^2 asphalt pad with 1,600 m^2 of horizontal bunker space and 800 m^2 of operating pad area. A small portion of the asphalt pad in front of the bunker is concrete which creates a channel for transfer of storm runoff and silage leachate to a main catchment area at the lowest point of the storage area. No drains were installed in the horizontal dairy bunkers for collection of dry weather leachate. A Cipolletti weir and the automated sampler was placed at the outlet of the concrete channel to measure the flow and collect sample for water quality analysis.

The third site is a private dairy producer in Sauk County, WI and has identical averages for precipitation and temperature as the DFRC reported above. The total silage storage area is 7,900 m^2 with a bunker areas of 4,900 m^2 and an operating pad of 2,000 m^2. A majority of the forage stored in the bunkers is corn silage. Approximately 12,000 tons of corn silage was ensiled in September of 2011 and 2012. Three cuts of haylage (around 6,000 tons in total) was also ensiled in May, June, and August 2011and 2012 and approximately 1,500 tons of ryegrass was ensiled in May 2011 and the same mass again in June 2012. The horizontal bunkers at this site had small drains within the bunkers for collection of dry weather leachate. Low points on the operating pad had larger drains to collect runoff. All of the piping from these collection points were routed via underground piping to the main culvert. The culvert was used as the control structure for flow measurement and sample collection

ISCO refrigerated automated samplers (Teledyne Technologies, Inc., Avalanche Sampler) equipped with bubble level sensing (Teledyne Technologies, Inc., 730 Bubbler Flow Module) were installed at all three sites to collect runoff samples and monitor flow rates. Rainfall was recorded using tipping bucket rain gauges (Teledyne Technologies, Inc., 674 Rain Gauge). ISCO samplers were set up to activate at specified flow volumes to capture a range of storm events. This was accomplished using a runoff model to predict volumes produced from several design storms and programming the ISCO so it would have samples to cover all storms up to a 2 year, 24 hour storm in south central Wisconsin. Fourteen bottles were available for each sampling event. Samplers were set up to collect a composite sample for two subsequent sampling points. Flow rate was monitored continuously and stored at one minute intervals. Seven storms were sampled at AARS (one storm in November 2011 and six storms from April 2012 to August 2012), fourteen storms at DFRC (three storms for October and November in 2011 and eleven storms from April 2012 to October 2012), and sixteen storms were sampled (from April 2012 to October 2012) at the private producer site. Refrigerated samples were collected within 24 h of a rainfall event, stored on ice, and preserved and analyzed at the University of Wisconsin Biological Systems Engineering Department water quality laboratory according to USEPA guidelines (USEPA, 2009). Water quality parameters considered, method, and detection range are provided in Table 2.

Table 1: Water quality sample analysis parameters

Parameter	Method	Detection limit
Ammonia (NH_3)	EPA 350.1 v.2‡	0.05 mg N L^{-1}
Biological Oxygen Demand (BOD_5)	EPA 405.1†	2 mg L^{-1}
Nitrite (NO_2)	EPA 353.2 v.2‡	0.0025 mg N L^{-1}
Nitrite + Nitrate (NO_2 + NO_3)	EPA-132-A Rev. 1‡	0.004 mg N L^{-1}
Soluble Reactive Phosphorous (SRP)	EPA 365.1 v.2‡	0.005 mg P L^{-1}
pH		
Total Chemical Oxygen Demand (COD)	EPA 410.4†	1 mg L^{-1}

Total Kjeldahl Nitrogen (TKN)	EPA 351.2 v.2‡	0.15 mg N L^{-1}
Total Solids (TS)	EPA 160.3†	0.1 mg L^{-1}
† (USEPA, 2009) ‡ (USEPA, 1993)		

Nutrient concentrations and incremental hydrograph data were used to calculate nutrient loads for each storm event. The mean nutrient concentration for each individual storm at each site was calculated using Equation 1. Normalized cumulative pollution load curves, a dimensionless plot of the distribution of pollutant load, were developed to analyze nutrient loading for each site and storm event. Percentage of cumulative load was then plotted against percentage of cumulative volume for each nutrient and storm event. The shape of the plots allows for determination of the load volume response for the event and can be used to describe the strength of the first flush behavior as described by Taebi & Droste (2004).

To determine design recommendations for runoff collection, individual hydrograph and nutrient data was used to determine the fraction of pollutant collected when runoff contaminant load was partitioned according to various collection methods. The runoff collection methods include collecting a portion of the peak flow rate throughout the entire storm (two-stage flow separation), collecting the first flush (first flush collection), and collecting only low flow (low flow collection). Two-stage flow separation utilizes a primary flow control structure placed at the lowest point on the silage pad to collect a designated low flow rate throughout the storm's entire duration. A secondary flow control structure is designed to divert flows achieving a higher flow rate to a filter-strip while a portion of the flow is still diverted to a storage area. The primary flow control structure was modeled using three different sizes for low flow collection. Flow rates were determined by modeling the runoff produced for each site and separating 10%, 5%, and 1% of the calculated peak flow rate from a two-year, two-hour storm to determine the contaminant load collected. Analysis included orifices that had been designed for max capacity of 10%, 5%, and 1% of the peak flow rate. First flush collection analysis was designed evaluate the pollutant load when only the initial runoff was collected. The volume collected was the same as the volume collected from the 1% two-stage separation design above. Low flow collection evaluates the pollutant load collected when flow rate were less than 5% of the peak flow rate for the two-year two-hour design storm. This allowed researchers to evaluate pollutant load collected versus volume collected to optimize collection system design as producers want to minimize collection volumes.

Filter Strip Evaluation

Two filter strip plots were installed at the USDA Dairy Forage Research Station in Wisconsin. Each plot was 3.7m long and 1.2m wide with a slope of 1.5%. The plots were excavated at a depth of 0.9 m and lined with an impermeable pvc geomembrane and a field tile was placed in the bottom for effluent collection, Figure 1. The plots were backfilled with gravel and backfilled with soil which was 66.4% sand, 24% silt and 8.6% clay and has a infiltration 2.9 cm/h. The filter-strip was planted with a Wisconsin short native grass seed mix consisting of 40% annual ryegrass, 20% little bluestem, 20% sideoats grama, 15% Canada wild rye, 3% prairie june grass, and 2% prairie drop seed. Planted seeds were watered daily and experimental runs were postponed until vegetative establishment. One of the two field plots acted as the control and the second contained a pretreatment system which contained a 151 L aerobic tank which silage runoff flowed through prior to application on the filter strip.


Figure 1: Filter strip excavation and membrane installation (left); planted filter strips (right)

Runoff was captured from the feed storage pad at the DFRC for a rain event prior to each trial run in a large tank. Runoff was applied to the plots at the peak rate for a 2-yr 24-hr and a 25-yr 24-hour design storm for the theoretical runoff area, Table 2. The surface and subsurface water was collected following application to determine water quality. Plots received runoff from a theoretical area of a 1:1 ratio of feed storage pad to filter strip area (or feed storage pad area of 0.1 m^2). The collected runoff was then applied to the filter strips using a pump which a flow meter attached to accurately determine the volume applied. The surface runoff was captured in a tub at the bottom of the filter strip and the tile in the subsurface was connected to a 0.46 m pvc pipe with a sump pump to collect subsurface samples.

Table 2: Design storm values for application

Design Storm	Depth (m)	Volume (L)	Peak Flow (cfs)
2-yr 24-hr	0.07	310	0.0048
25-yr 24-hr	0.13	568	0.0044

Prior to application the runoff in the collection tank was sampled to determine influent concentrations and the soil moisture in the filter strips was recorded. Surface and subsurface samples were measured to determine the volume and evaluated for water quality parameters listed in Table 1.

Results and Discussion

Runoff Characterization

Average runoff concentrations for each site varied significantly although average concentrations can be useful for collection and treatment design purposes, Table 3.

Table 3: Summary of average flow weighted concentrations for each site

Site	Alkalinity mg L-1	NH_3 mg L-1	BOD_5 mg L-1	COD mg L-1	NO_2 mg L-1	SRP mg L-1	pH	TKN mg L-1	TP mg L-1	TS mg L-1
AARS	313	25	1296	2728	1.63	19	6.09	184	29	2789
Private	959	48	3318	6697	1.72	35	5.54	215	63	6261
DFRC	769	68	5789	13292	0.50	70	4.64	222	83	10943

Data was normalized and graphed to determine if a first flush existed. It was found that for all parameters loading throughout a storm was linear, which explain the absence of a first flush scenario which is commonly found in urban storm water runoff, Figure 2. It was found that the concentration was inversely proportional to flow, Figure 3. This may seem logical, however it was not expected that the concentration would rise at the end of the storm after a majority of the flow volume had passed of the impervious area.

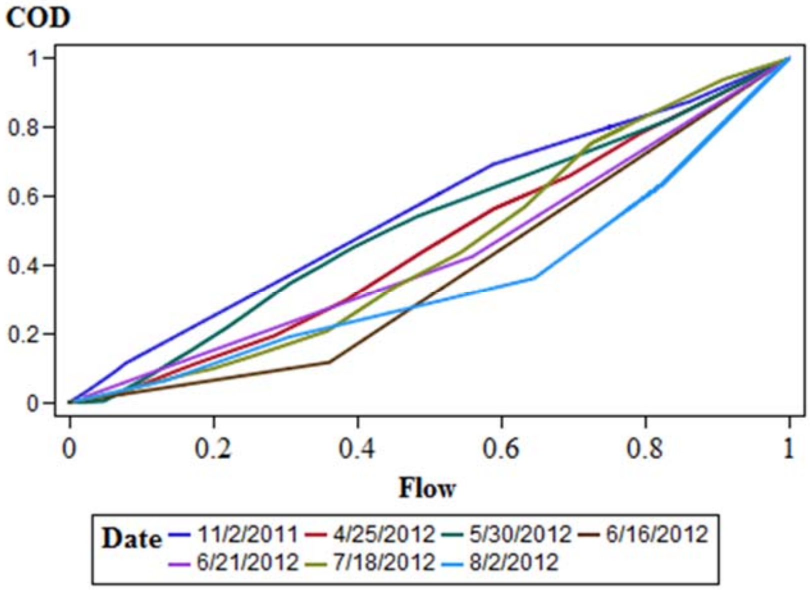

Figure 2: COD Normalized Loading Data

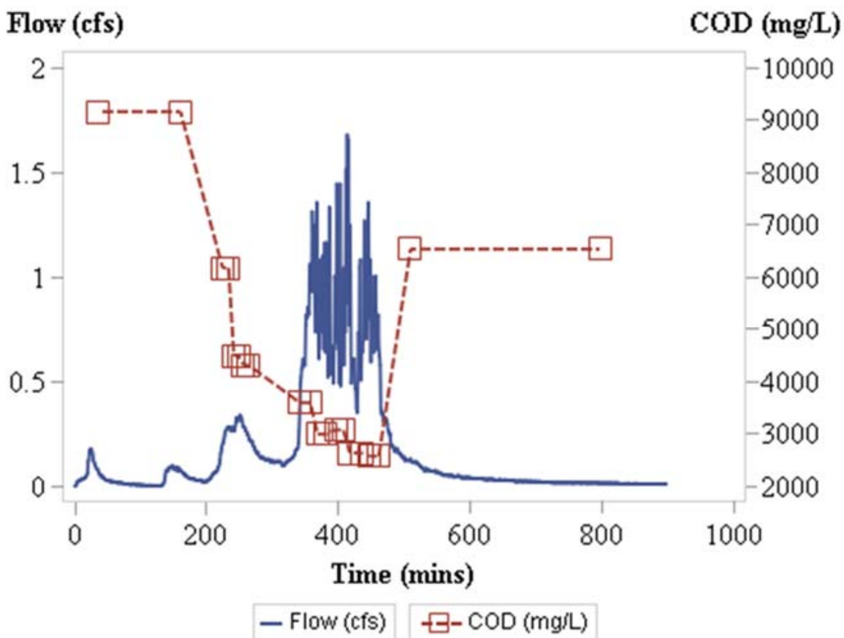

Figure 3: COD concentration versus flow

It was also found using statical methods that all water quality parameters measured except pH were positively correlated (pH was negatively correlated) indicating parameters followed the same trends, Figure 4.

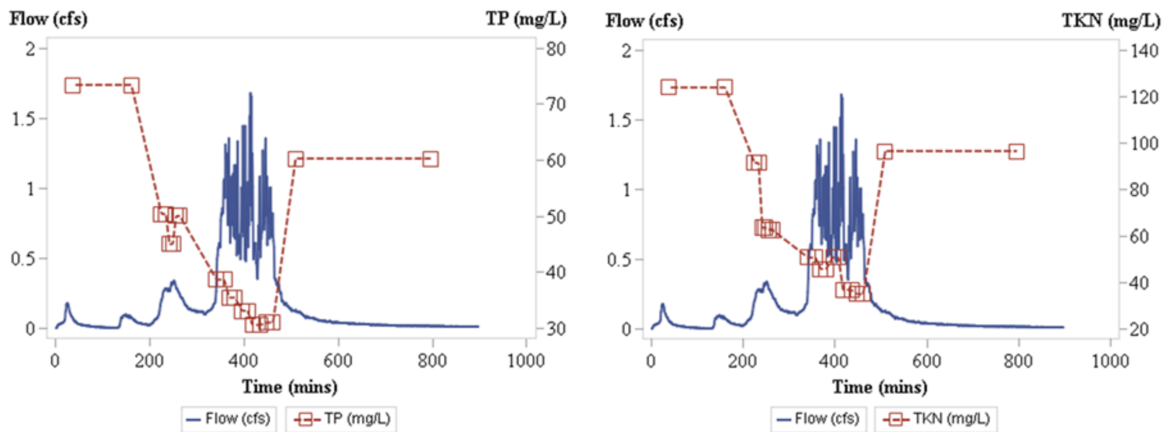

Figure 4: Flow versus concentration for TP and TKN

Three designs were analyzed to determine the percent of the load for each water quality parameter that would be collected for a specific volume, Figure 5. It was found that collecting the first flush resulted in the least load collected per unit volume. The two stage collection system collected the next greatest load for the same volume. A two stage collection system refers to collecting the low flow (1% of the peak flow rate of the 2 year 24 hour design storm) throughout the storm and diverting the higher flows to a treatment system. The third design resulted in the greatest load collection per unit volume. The third design collects low flows only (1% of the peak flow rate of the 2 year 24 hour design storm) and stops collecting when the flows exceed this value (unlike the second two stage design which collects low flows throughout the storm even during high flow period).

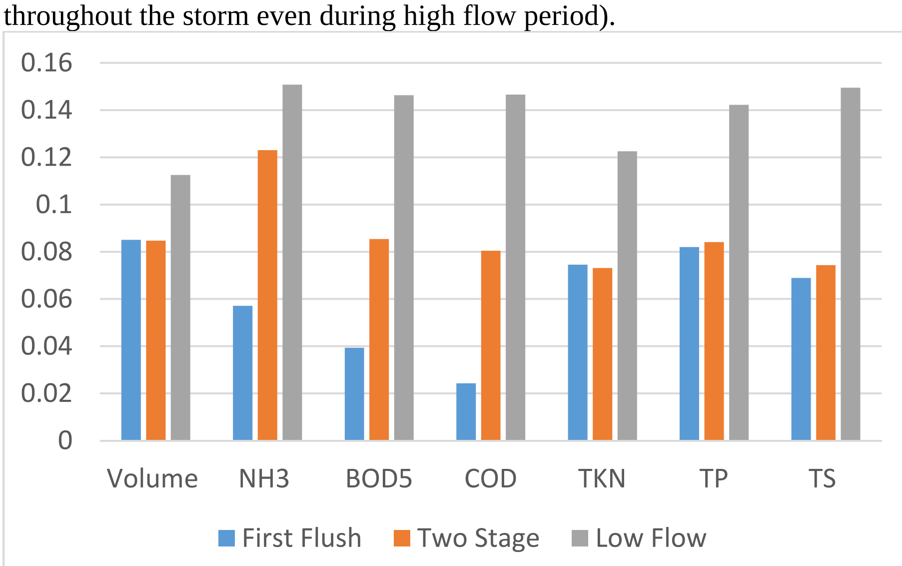

Figure 5: Evaluation of the impact of collection system design on percent loading collected for each water quality parameter

Filter Strip Evaluation

Five trial runs, three 25 year – 24 hour and two 2 year 24 hour trials were conducted from Oct-Dec. Influent to both pre-treatment and control filter-strips had a low pH (around 4). BOD_5 values were 14,000 - 28,000 mg L^{-1} on average for the influent to both filter-strips for the 25 year -24 hour design storm and 14,000 – 16,000 mg L^{-1} for the 2 year 24 hour design storm. Average influent values for COD were elevated, 20,000 – 26,000 mg L^{-1} for the 25 year – 24 hour design storm and around 41,000 -57,000 mg L^{-1} for the 2 year – 24 hour design storm. Other parameter concentrations can be found in Table 3.

Subsurface effluent from both filter-strips had an almost neutral pH (~6.5). BOD_5 concentrations were reduced to 9,000 – 6,000 mg L^{-1} for the 25 year storm event and around 9,000 mg L^{-1} for the 2 year 24-hour design storm. Average COD effluent concentrations for the 25 Year – 24 hour storm were 10,000 – 14,000 mg L^{-1} and 12,000 – 19,000 mg L^{-1} for the 2 year – 24 hour design storm, representing a reduction of ~50%. For the 25 year – 24 hour design storms, TP and Ortho-P had the highest reduction for both filter-strips with 95% reduction for ortho-P and 83-87% reduction for TP. NH_3 was reduced approximately 70%. Pre-treatment increased the BOD_5 reduction to approximately 60% whereas the control had a reduction about 30%, but did nto significant impact COD reductions. For the 2 year – 24 hour design storms, TP and Ortho-P achieved similar reductions when compared to the 25 year storm, with a 96-99% reduction for ortho-P and 84-88% reduction for TP. Again pre-treatment had a BOD_5 reduction around 54% and the control had a reduction of 38%, Table 4 & 5 and Figure 6.

Table 4: Pre-treatment and Control Filter-strip Influent and Effluent Concentrations for 2 Year - 24 Hour and 25 Year - 24 Hour Design Storms

	NH_3	BOD_5	COD	NO_2	NO_3	Ortho-P	pH	TP	TS
25 Year - 24 Hour	mg L^{-1}								
Pre Treatment Influent	140	27810	25587	0.01	0.27	170	4.1	239	22704
Pre Treatment Effluent	40	9420	13588	NA	4.45	8	6.4	33	11397
Control Influent	119	14100	20290	0.03	0.23	153	4.1	218	18156
Control Effluent	29	6233	9503	0.03	0.83	8	6.4	31	7914
2 Year -24 Hour									
Pre Treatment Influent	163	19890	57360	NA	0.22	309	3.9	449	22584
Pre Treatment Effluent	121	9075	19350	NA	0.00	2	6.6	49	13897
Control Influent	152	13890	40680	NA	0.22	222	3.9	363	19376
Control Effluent	94	8625	12445	NA	0.00	8	6.5	56	11932

Table 5:1 Average Treatment Reductions for Pre-Treatment and Control Filter-Strips for 2 Year - 24 Hour and 25 Year - 24 Hour Design Storms

	NH_3	BOD_5	COD	NO_2	NO3	Ortho-P	pH	TP	TS
25 Year - 24 Hour									
Pre Average Reduction	0.72	0.61	0.46	NA	-18	0.95	-0.56	0.87	0.37
Control Average Reduction	0.76	0.34	0.45	0.04	-1	0.95	-0.57	0.83	0.42
2 Year -24 Hour									
Pre Average Reduction	0.27	0.54	0.60	NA	1	0.99	-0.67	0.88	0.38
Control Average Reduction	0.39	0.38	0.67	NA	1	0.96	-0.65	0.84	0.38

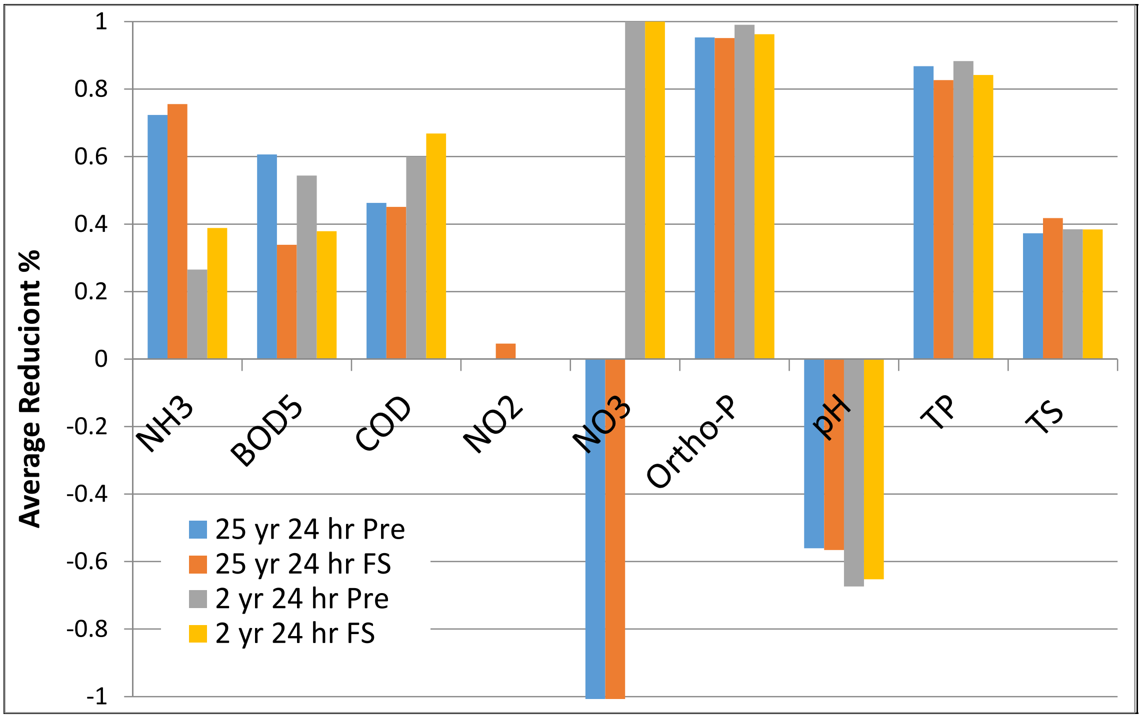

Figure 6: Average Treatment Reductions for Pre-Treatment and Control Filter-Strips for the 25 Year - 24 Hour and 2 Year – 24 Hour Design Storms

Load reductions for both filter-strips were above 60% for all nutrients analyzed except NO_3 for the pre-treatment filter-strip, Figure 7 & 8. TP and ortho-P for both filter-strips had reductions in excess of 70%. NO_3 increased in the effluent of the pre-treatment design for the 25 year storm but not the 2 year 24 hour storm. The pretreatment filter-strip had higher volumes of surface runoff and could explain the reduced loading reduction.

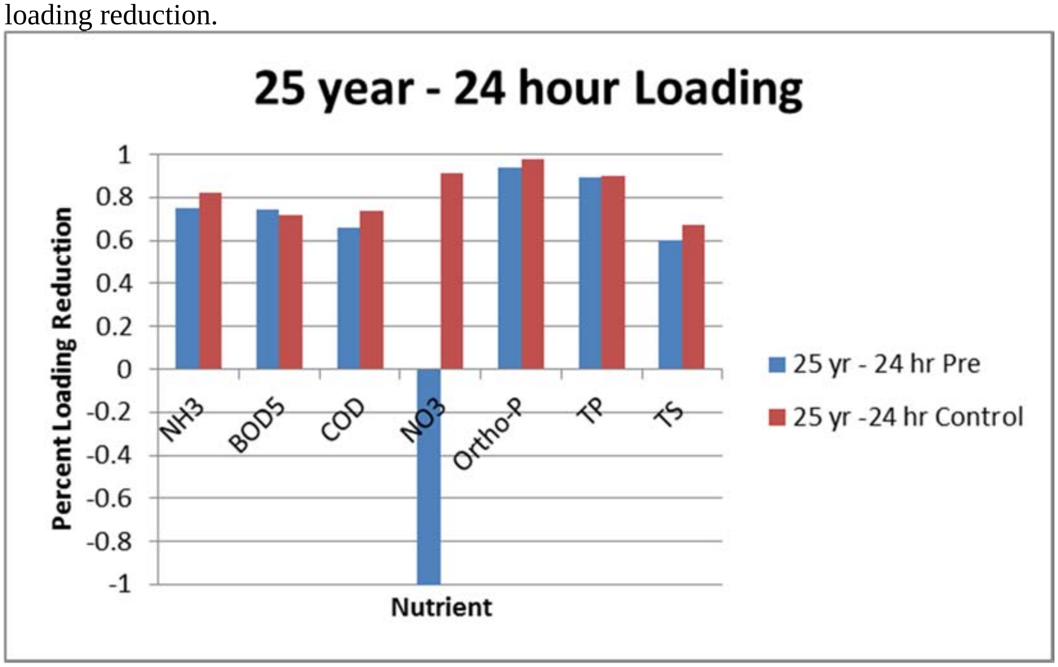

Figure 7: Load Reduction for 25 year - 24 hour design storm trials

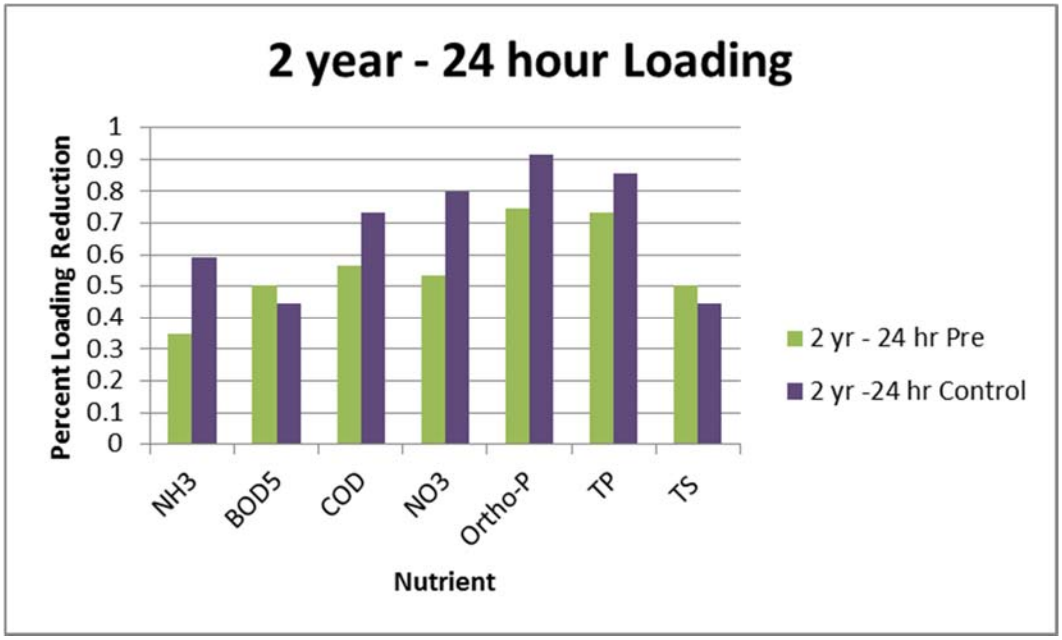

Figure 8: Load Reduction for the 2 year -24 hour design storm trials

Conclusions and Recommendations

Flow rate, timing of ensiling of forage, site bunker design, and amount of litter present were determined to influence silage runoff concentrations. Flow rate determined the strength of concentrations throughout an individual storm. Water quality parameters at all sites were negatively correlated with flow, except pH, and it is suggested that producers use separate collection and treatment systems for low and high flows. There was no presence of a first flush, and it is recommended that producers avoid system designs which capture a fraction of the initial runoff volume. Date of ensilage of forage played a significant role in determining nutrient concentrations over the year with events within two weeks of ensilage having higher nutrient concentrations. It is suggested that sites collect only low flows (1% of the peak flow of the 2 year 24 hour design storm) and route high flows to treatment systems to maximize the load collected while minimizing the volume of runoff collected.

Both filter-strip designs were effective at P removal from the influent applied for both design storms. The pre-treatment design showed evidence for more effective BOD_5 removal however, it also showed an ability to increase NO_3. Both filter-strips raised the pH of the silage runoff from an acidic to more neutral pH. Other than BOD_5 the pretreatment design was not more effective at removing and reducing nutrients. Accumulation of BOD_5 in effluent for the pretreatment displayed a possibility of nitrogen conversion however it also displays ineffective nitrogen removal. Overall, a 1:1 ratio of runoff area to filter strip area was capable of similar reduction for a 2 year 24 hour design storm and a 25 year 24 hour storm.

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Appendix A

Publications

Holly, M. and R.A. Larson. 2014. Characterization and Assessment of First Flush from Silage Leachate and Runoff. *In Review*.

Presentations

Holly, M. and R.A. Larson. 2013. Treatment of Silage Runoff with Vegetated Filter Strips. *From Waste to Worth: Spreading the Science, Denver Colorado April 2013.*

Holly, M. and R.A. Larson. 2013. Silage Storage Runoff Characterization. *From Waste to Worth: Spreading the Science, Denver Colorado April 2013.*

R.A. Larson. 2014. Runoff from Silage Storage: Characterization and Management. *Presentation to the WDNR, July 2014.*

*Numerous extension presentations have been planned and numerous will continue throughout the state in 2015