CONSERVATION INNOVATION GRANTS
Final Progress Report

Grantee Name: University of Vermont	
Project Title: Phosphorus and *E.Coli* Reduction from Silage Leachate via Innovative Steel Slag Filtration	
Agreement Number: 69-3A75-9-121	
Project Director: Aleksandra Drizo	
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Period Covered by Report: September 24th, 2010 - September 23rd, 2011	
Project End Date: September 23, 2011	

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Project Purpose: 1) to test the effectiveness of a silage leachate (SL) treatment system composed of grass filter areas (GFA) and steel slag filter berms (GFA+SSB), where berms consist of phosphorus sorbing material steel slag (SSB) instead of traditionally employed crushed stone, in pollutants (in particular phosphorus (P), solids (TSS), biochemical oxygen demand (BOD), pathogens (*E.coli*) and metals and minerals reduction; 2) to assess and compare agrass filter area (GFA+ SSB) treatment efficiency with traditional conservation practices (grass filter area treatment with stone berms and vegetative buffer filter strips) currently used in Vermont for SL treatment; 3) to assess GFA+SSB treatment system economic viability and to evaluate its potential as a management strategy for SL treatment on other farms in Vermont (VT) and across the US.

Project Deliverables: The results from this project will provide the first field-based study and complete economic assessment of a low-cost, innovative technological improvement (GFA + SSB) that could significantly reduce water pollution, increase the treatment efficiency of existing BMP designs, and aid farmers in meeting more stringent water quality regulations.

Project Scope/Location: Kayhart Dairy Farm, owned by the Kayhart family, is located in Addison, VT and covers 1200+ acres. Kayhart Dairy Farm is considered a medium farm operation (MFO) according to VT and Federal Confined Animal Farm Operation (CAFO), is EQUIP eligible, and has received EQUIP support in the past. The SL treatment system was installed in the summer of 2009 to demonstrate a commitment to surpassing regulations within the state's current General Farm Permit. The SL treatment system covers a surface area of ~ 5000 ft^2 (464.5 m^2) and receives SL from roughly 1.5 acres (6,070.3 m^2) of feed bunks.

Select the applicable National Category:

X Technology Category

Select the applicable Proposal Review Group

X Water Quality-Livestock

Declaration of Environmental Quality Incentives Program (EQIP) Eligibility

1) The applicant has read and understands the responsibilities related to EQIP eligibility and payment limitations as outlined in Part III of this announcement.

X Yes

☐ No

2) The applicant and any producers that will receive direct or indirect payments through this project are eligible to participate in the EQIP program.

X Yes

☐ No

3) The applicant is requesting federal funds from other sources for the same or similar project.

☐ Yes

X No

Total Cost of Project: $ 183,276

Federal Funds Requested: $ 96,953

Brief Project Summary: Under the current VT state MFO regulatory requirements, farmers are required to eliminate any potential discharges of wastewater to surface waters of the state. In VT, approximately 70% (106 farms) are currently in need of some form of improved treatment for SL associated with contaminated storm water runoff from the feed bunks. The cost of structures to contain SL is unaffordable for most farmers and therefore cost-appropriate technologies are being sought. Based on the efficiency of Steel Slag Filter systems developed by the PI Dr Drizo and her research team at the University of Vermont (www.phosphoreduc.com) in treating other agricultural wastewater effluents over the past 9 years, we hypothesized that using a phosphorus sorbing material (steel slag aggregates, an industrial co-product from steel manufacturing industry) within berms instead of stone could significantly enhance treatment efficiency of the traditional grass filter areas currently recommended as a management practice for reducing pollutants from SL in Vermont and across the nation. The results from this project provide the first field-based technical and economic assessment of this low-cost, innovative technology, and its contribution to the treatment efficiency of the two (grass filter area treatment, GFA and vegetative filter strip, VFS) other conservation practices currently used in VT and other States. In doing so, these results will expand the current scientific and technical knowledge about best management practices (BMPs) for SL treatment and provide the first evidence of innovative ways to improve performance of the current BMPs. By integrating this new knowledge with economic and market analyses, we hope to pave the way for this innovative treatment practice implementation and governmental approvals and local, regional and national scales.

1. Results:

1.1. Water Quality

The evaluation of the GFA-SSF-VBS system treatment performance took place between September 28, 2010 and September 15th 2011, over 11 storm events that occurred in this time period.

Water quality analyses revealed that the entire GFA-SSF-VBS system (consisting of three GFAs and three SSFs and a VBS) showed excellent treatment efficiency reducing dissolved phosphorus (DP), total suspended solids TSS), *E.coli* and organic matter (BOD) by 83.1, 77.9, 62.9 and 61.2 %, respectively (Table 1 and Figure 1). In addition, analyses of the water quality before and after individual system components showed that:

i) A single GFA bed reduced DP, TSS, *E.coli* and BOD by 58.2, 60.8, 58.9, and 36 %, respectively.

ii) Addition of a single SSF berm improved DP and BOD reductions to 72.6% and 54.7 %, respectively while, TSS and *E.coli* reductions remained the same.

iii) Three GFA beds and two SSF berms achieved DP, TSS, *E.coli* and BOD reductions of 74.5, 42.0, 60.2 and 69.8 %, respectively.

iv) Given that VBS are widely recommended as a BMP across the country, our results on the assessment of VBS treatment efficiency and contribution to an overall treatment provide important scientific evidence on the effectiveness of this BMP. Results show that the VBS only reduced DP and BOD concentrations in SL runoff by less than 25% and did not reduce *E.coli* (in fact, *E.coli* concentrations were significantly higher after the VBS compared to before VBS). The VBS, however, was very effective (69.6%) in reducing TSS. Overall, the contribution of the VBS to pollutant reduction was < 5% for DP, *E.coli* and BOD, and 36.5% for TSS.

v) Silage runoff DP concentrations were extremely high, averaging 115 mg/L. Innovative grass filter area and steel slag berm treatment systems consisting of 3 GFA and 3 SSB significantly reduced DP concentrations in runoff to an average of 17.1 mg/L (e.g. 85.12%), while the combination of 3 GFAs, 3 SSBs, and a VBS further reduced DP concentrations in the treatment system discharge to an average of 11.8 mg/L.

Despite the ten fold average DP reduction achieved by the entire SL treatment system, DP concentrations measured in the effluent of the treatment area of 11.8 mg/L greatly exceed the critical concentrations of 0.1-0.2 mg/l DP for incipient eutrophication in running water (Pütz, 2008).

vi) *E.coli* concentrations in SL runoff were extremely high, averaging 5.28 x 10^6 organisms per 100 mL (MPN). While the innovative SL treatment system consisting of 3 GFA and 3 SSB significantly reduced *E.coli* concentrations in runoff to an average of 79.4 x 10^5 MPN (e.g. 85 %), the VBS and natural soil seemed to have increased *E.c*oli concentrations in the discharge back to 2.1 x 10^6 MPN, resulting in an overall reduction of only 60.25%.

In terms of meeting Lake Champlain phosphorus TMDL goals and preserving water quality, v) and vi) are the most important findings from our work.

Therefore, even with the employment of with phosphorus adsorbing materials, GFA treatment should be further improved in order to ensure greater DP and *E.coli* reduction in SL runoff before discharge. Please see section 2.1., “Suggested Improvements for the Current Vegetative Treatment Area Code 635 Practice”, page 11.

The schematic representation of the entire treatment system is shown in Figure 1, below and Appendix 1:

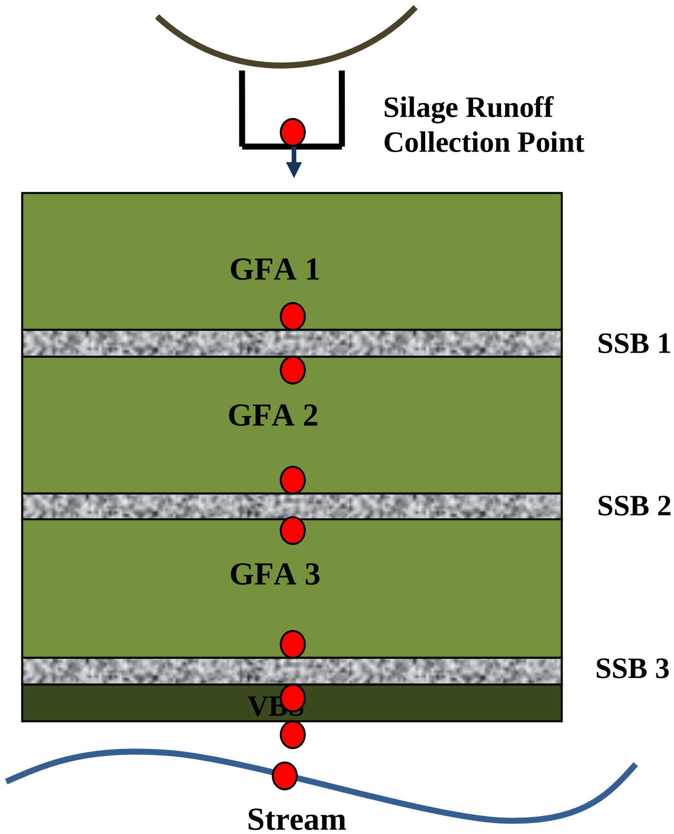

Figure 1: Silage runoff treatment area plan view. ● represents runoff sampling points.

Percentage reduction of each treatment step was first calculated for each of the individual sampling occasion, as following:

*[(influent concentration-treatment step)/(influent concentration)]*100 and then the total average for 11 storm events.*

The vegetative buffer strip (VBS) effectiveness was first calculated as:

*[(3 GFA + SSB 3 effluent - VBS)/(3 GFA+SSB 3 effluent)]*100 and then the total average for 11 storm events.*

Table 1: Average dissolved phosphorus (DP), *E.coli*, BOD and TSS percent reductions for 11 storm events occurring between 9/28/2010 and 9/15/2011.

Treatment	**DP % Reduction**	***E.Coli* % Reduction**	**BOD % Reduction**	**TSS % Reduction**
Single GFA	58.21	58.94	36.05	60.80
GFA + SSF 1	**72.57**	58.36	**54.73**	-12.01
2 GFA + 1 SSB	69.22	**66.21**	56.07	25.51
2 GFA + 2 SSB	74.61	57.74	46.79	-60.91
3 GFA + 2 SSB	***74.48***	***60.22***	**69.82**	**41.90**
3 GFA + 3 SSB	78.12	52.32	67.67	-60.42
Total Reduction	***83.08***	***62.90***	***61.18***	***77.87***
VBS % reduction				
VBS % contribution to total reduction	24.00	-38.90	22.54	69.57
	4.77	***3.88***	***4.97***	***36.49***

Total phosphorus and minerals concentrations and percent reductions achieved are presented in Tables 2 and 3, below:

Table2: Average total phosphorus (TP) and metals concentrations and percent reductions for 11 storm events occuring between 9/28/2010 and 9/15/2011.

	TP	**Al**	**Fe**	**Cu**	**Zn**	**Co**	**Cr**	**Cd**	**Ni**
Influent (mg/L)	192.6	13.9	47.6	2.36	2.5	0.14	0.15	0.11	0.26
3 GFA + 3 SSB (mg/L)	36.0	2.8	15.5	0.8	0.5	0.05	0.05	0.04	0.08
Percentage Reduction %	***81.30***	***79.6***	***67.5***	***66***	***78.7***	***65.0***	***67.2***	***61.8***	***69.1***
Effluent (mg/L)	24.3	7.0	18.5	0.6	0.6	0.03	0.04	0.03	0.07
Total Percentage Reduction %	***87.40***	***49.8***	***61.2***	***74.5***	***75.6***	***78.5***	***73.6***	***75.5***	***71.5***
VBS Percentage Reduction %	6.10	-29.8	-6.3	8.5	-3.1	13.5	6.4	13.7	2.4

Table3: Average minerals concentrations and percent reductions for 11 storm events occurring between 9/28/2010 and 9/15/2011.

	Ca	**K**	**Mg**	**Na**
Influent (mg/L)	816.0	1357.7	182.5	13.9
3 GFA + 3 SSB (mg/L)	208.5	525.3	75.7	2.8
Percentage Reduction %	***74.5***	***61.3***	***58.5***	***79.6***
Effluent (mg/L)	181.0	485.5	73.1	7
Total Percentage Reduction %*	***77.8***	***64.2***	***60***	***49.8***
VBS Percentage Reduction %	3.3	2.9	1.5	-29.7

It is important to note that although initially planned, it was not possible to employ automatic sampling and flow measuring equipment to monitor discharge volumes of the SL treatment site, thus pollutant reductions presented in Tables 1-3 are based on pollutant concentrations.

In order to estimate flow volumes for the SL treatment system, we relied on data obtained by a separate EPA 319 project in Vermont where we were able to determine the quantity of runoff generated during 10 storm events from subsurface agricultural tile drains (similar soil type, e.g. heavy clay). We discovered that as much as 4.5 m^3 was discharged from a 4" tile drain during 10 spring events occurring over a one month period between April 20th and May 20th 2011. In this CIG project we sampled SL discharged through a 4" drain pipe during 11 storm events that occurred over a 12-month period between Sep 2010 and 2011 (Figure 2).

Figure 2: Silage runoff collection point flowing by gravity towards the stream.

Thus if we assume, based on measured volumes of agricultural tile drain flows, that at least 20 m^3 of SL runoff was discharged over a 12- month period, the actual SL pollutant mass loading was extremely high (Table 4):

Table 4: Average pollutants loading (g over time), 3 GFA + 3 SSB treatment and total reduction concentrations and percent mass reductions achieved during 11 storm events occuring between 9/28/2010 and 9/15/2011.

	DRP (g)	**TP (g)**	**E.Coli (mpn)**	**BOD (g)**	**TSS (g)**	**Ca (g)**	**K (g)**	**Mg (g)**
Influent	**2,300**	**3,852**	**106.0 x 10^6**	**103,380**	**18,920**	**16,320**	**27,154**	**3,650**
3 GFA+3 SSB	***342***	***720***	***15.8 x 10^6***	***29,570***	***10,390***	***4,180***	***10,506***	***1,514***
Reduction%	**85.1**	**81.3**	**85.1**	**71.4**	**45.1**	**74.4**	**61.3**	**58.5**
Effluent	***236***	***486***	***42 x 10^6***	***30,540***	***2,180***	***3,620***	***9,710***	***1,462***
Total Reduction%	***89.7***	***87.4***	***60.4***	***70.5***	***88.5***	***77.8***	***64.2***	***60***

In addition to water quality data, we also collected steel slag aggregate samples from each of the 3 berms (middle and the ends of the berm) and compared it against untreated steel slag samples which served as control. These data are presented in Table 5, below:

Table 5: Average total phosphorus (TP) and metals concentrations (mg/kg) in untreated and each of the three steel slag berms samples taken in September 2011, at the end of the monitoring period.

Concentration (g/kg)	**TP**	**Al**	**Fe**	**Mn**	**Cu**	**Zn**	**S**	**Cr**	**Ni**
Control (untreated slag)	1.07	14.68	182.45	16.13	0.036	0.038	2.86	2.79	0.12
2011 SSB 1	*1.30*	*20.95*	*190.40*	*15.36*	*0.05*	*0.04*	*2.75*	*2.86*	*0.09*
2011 SSB2	*1.42*	*21.34*	*227.32*	*16.76*	*0.03*	*0.05*	*2.88*	*3.81*	*0.08*
2011 SSB3	*1.23*	*21.44*	*221.59*	*15.92*	*0.03*	*0.05*	*2.77*	*3.77*	*0.10*
Retained by 3 SSB*	***2.88***	***49.05***	***456.9***	***31.91***	***0.074***	***0.10***	***5.54***	***7.65***	***0.15***

*Calculated as (SSB 1+ SSB 2 + SSB 3) - Control

Control samples also contained 160.68 g/kg (Ca), 6.14 g/kg (K), 61.91 g/kg (mg) and 0.67 g/kg Ni and did not retain any significant quantities of these minerals.

1.2. Earthworms and macroporosity

Earthworms were sampled in the fall of 2010 and 2011 in the SL treatment area (Figure 1, Appendix 1). Five areas were surveyed for anecic earthworms. These worms often create excavation mounts, also called middens, that are strongly associated with their deep burrows. Deep burrows may cause preferential flow that can bypass the root zone and result in leaching of dissolved organic material as well as nutrients. Anecic earthworms in Vermont would be exclusively *L. terrestris* (common nightcrawler). They are most commonly found in ecosystems with high resource levels and the area near silage storage and their filter strips are suitable, potential habitat. The other ecotype of earthworm that makes burrows in the top most layers of the soil is endogeic worms. These tend to be unpigmented worms with the exception of *Lumbricus rubellus* (red worm).

We investigated five 50 by 50 cm quadrats for *L. terrestris* middens between the SL collection point and the first SS berm and also after the SS first berm. We also excavated these quadrats to a depth of 10 cm to check for other earthworms that may live in the top part of the soil. We noticed relatively few anecic earthworms given the resource availability in this ecosystem. Considering each nest of quadrats, there were, on average, between 6 and 12 anecic earthworms per m^2 (Tables 6 and 7). That is low given the high levels of resources. The fact that the soils were heavy clays may have been a limiting factor though and the length and frequency of inundation may also limit the numbers. While worms are not likely to drown the waters flooding the filter strip regularly may be microbially very active causing anoxia that would cause problems for the worms.

Endogeic worms in the top 10 cm of the soil were a lot more numerous and associated with roots. Most of these worms were *Apporectodea (*pink worm) species, but we also found some *L. rubellus* that are more likely to make more extensive burrow systems. Endogeic worm average abundances varied between 40 and 50 worms per m^2 (Tables 6 and 7). This is also relatively low for the resources that are available in the grass filter strip. The limitations may be similar to what we think is limiting anecic worms.

Table 6: Earthworm in September 2010. Abundances per 1 m^2

Quadrat	Before Berm		After Berm	
	Anecic	Endogeic	Anecic	Endogeic
1	8	20	16	12
2	0	64	12	56
3	12	96	12	40
4	8	16	0	32
5	4	32	0	68
Average	6.4	45.6	8	41.6

Table 7: Earthworm in October 2010. Abundances per 1 m^2

Quadrat	Before Berm		After Berm	
	Anecic	Endogeic	Anecic	Endogeic
1	4	12	12	24
2	4	24	4	36
3	8	16	8	72
4	4	92	8	36
5	12	104	16	48
Average	6.4	49.6	9.6	43.2

We also investigated macroporosity of the soils. Six cores were extracted from the soil. The cores were saturated and then water was evacuated from the cores at 5 kPa tension. This would remove water only from macropores, i.e. pores greater than 60 um in diameter. Then, the soil cores were dried and density and porosity were calculated. Porosity is defined as the total pore volume per soil volume. It describes how much water can be maximally held in the soil. Part of this storage is temporary as gravitational drainage will remove some of the water at saturation. The percent macroporosity gives an idea of the potential for preferential flow through the soil. Density varied between 1.30 and 1.35 g/cm^3, and porosity between 48 and 50%. The macropore fraction made up

9 to 13% of pore volume (Table 8). Some of that macropore volume may be associated with deep percolation if created by anecic earthworm burrows or root channels.

Overall, the density ad porosity values are not unusual for a clay loam soil at the surface of this soil type. The fact that there is a fair volume in macropores suggests that bypass flow can occur. At about 15 cm depth the soil becomes more clayey and it is likely that water is prevented from percolating much further unless earthworm burrows were to extend beyond the top 10 cm. In the excavations we noticed several large earthworm burrows extending into the clay. We did not record the numbers but likely these were extensions of the anecic burrows marked by middens at the surface.

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Table 8: Bulk density, porosity and macropore volume of top 10 cm of soil in filter strip. Porosity as a % of the total soil volume and macropores as a % of total porosity.

Core	**Porosity** g/cm^3	**% Porosity**	**% Macropores**
1	1.31	50.3	10.7
2	1.33	49.6	13.1
3	1.35	48.9	13.3
4	1.33	49.6	8.7
5	1.31	50.3	10.3
6	1.33	49.6	11.4
Average	1.32	49.7	11.2

2. ***Economic Cost-Benefit Analyses***

The relationship between nutrient runoff and water pollution has been a focus of environmental protection for many years. Animal manure, for example, has been considered a waste product that contributes to non-point pollution. When the herd size of the farm animal increases, there would be more concerns on nutrient runoff from the farms and the surrounding fields upon which the manure is spread [2]. There are many different ways to handle the wastewater/liquid produced from agricultural production, residential usage, industrial usage, and other operating systems. The costs and benefits of wastewater treatment systems can be separated into 3 aspects – environmental, economic, and social.

The environmental costs involve the interactions between people, ecology, and other living beings. For example, odors of the wastewater create negative responses for people who live closer to the source or storage of the wastewater. The nitrogen and phosphorus runoff is the major source of eutrophication of the lakes, rivers, and oceans that has greatly reduced the quality of life for living beings. The environmental benefits of reducing the agricultural wastewater pollution relies on a long term balanced waste and wastewater management system that will improve and maintain a healthy environment for all living beings.

We could not obtain the costs of the Vegetated Treatment Area, Code 635, conservation practice typically recommended for treatment of silage runoff in Vermont, neither from VT Natural Resources Conservation Service (NRCS) nor from the VT Agency of Agriculture, Food and Markets (VAAFM). According to our literature search, Vermont NRCS Standard for Vegetated Treatment Area (Acre) Code 635 is defined as "an area of permanent vegetation used for agricultural wastewater treatment" [3]. The purpose of this practice is "to improve water quality by reducing loading of nutrients, organics, pathogens, and other contaminants associated with livestock, poultry, and other agricultural operations"[3]. Design criteria for the practice recommend that wastewater runoff should be pretreated as appropriate (for example using settling basin) and designed to treat runoff volume from a 25-year, 24-hour storm event from the agricultural animal management facility. Furthermore it states that "the VTA design for processed water shall be based on the nutrient contents of the processed water and the VTA's ability to hold and uptake the nutrients".

The NY State NRCS 'vegetated treatment area standard practice 635' is a grass filter area for bunk silo 1 acre in size. As per standard, "wastewater treatment strip needs to be 1/3 acre per acre of bunk silo. Location of filter area is set perpendicular to the contours with minor shaping of the width. Stone level lip trenches shall be constructed at the top of the filter area and every 50 feet thereafter, in order to maintain sheet flow the full length of the filter area. The trenches shall be 2 feet wide by 1 foot deep by full width of filter area". The life span of a practice is estimated to 15 years and the cost of materials $11,040.77 (Table 9).

Table 9:

Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Stone for level lip trenches or gravel berms	18.2	Cubic yards	$25	$462.50
Seed (30 lbs bags)	2	bags	$75	$150
Mulch (120 bales per acre)	36	bales	$3	$108
Soil - 36" of topsoil is placed in VTA	1611	Cubic yards	$6	$9,666
Total				$10,386.5
Updated to Aug. 2008 using ENR CCI				$11,040.77

Source: Actual installations in central New York area plus professional opinion of area engineer. 2007

In addition, the equipment/installation cost is estimated at $1,275.60, labor at $53.8 and the equipment mobilization at $800, resulting in a total of <u>$13,170.15 for a bunk silo 1 acre in size</u>.

The Kayhart's Dairy Farm also employs a wastewater treatment low flow (gravity) system consisting of a 6" concrete slab in front of bunk silo to collect silage leachate and runoff and divert to a flow splitter device. Leachate is diverted (by gravity) to a waste storage facility (lagoon) through a 6" PVC pipe (Figure 2).

Typical costs of this practice recommended statewide in VT include: excavation, concrete demolition, subgrade drainfill, 6" concrete slab, reinforcing steel, concrete curbing, screens, 6" PVC pipe, seeding & mulching, erosion control and mobilization, resulting in a total cost of $1,500/acre for the materials and additional $550 for the equipment mobilization, e.g. $2,050 per acre area that needs treatment. The system at Kayharts Dairy covered a surface area of ~ 5000 ft^2 (464.5 m^2) and was designed to receive SL from roughly 1.5 acres (6,070.3 m^2) of feed bunks, thus we assume that implementation of the low flow gravity system cost was ~ $3,075, plus $19,755 for a vegetative treatment area, e.g. ~ $23,000.

The results from our project provide evidence that although the system consisting of 3 grass filter areas and 3 steel slag berms showed significant reductions in dissolved and total P, as well as in most metals and minerals and *E.coli* and BOD and TSS (Tables 1-5) the final effluent concentrations greatly exceed (110 times) the critical DP concentrations of 0.1-0.2 mg/l for incipient eutrophication in running water (Pütz, 2008). We unfortunately did not have the possibility for a paired study where stone or pea gravel would be used as berm material, however it is a well known fact that the later materials are inert to P, thus their contribution to P reduction would be very minimal. We have also shown that having a vegetative grass buffer strip at the very end of the grass filter area contributed less than 5 and 10% to pollutants reduction (except for total suspended solids).

Finally we have shown the potential for pollutants mass loading, which is extremely high for all pollutants in question (Tables 4 and 5).

2.1. Suggested Improvements for the Current Vegetative Treatment Area Code 635 Practice

Given the fairly large costs of the currently recommended BMPs, such as the SL treatment system employed at Kayhart Dairy Farm, and their minimal contribution to nutrients and other pollutants mass reduction, we propose an innovative practice for silage runoff management where P adsorbing materials could be used properly to enhance P, metals and minerals reduction from silage runoff (or heavy animal use areas).

For example, a simple, subsurface filter could be designed to receive estimated runoff flows according to Drizo et al [4-16], two patent pending technologies Dr Drizo and her co-researchers developed at the University of Vermont [13, 14] and Phosphoreduc LLC (www.phosphoreduc.com) a small business co-founded by Dr Drizo, which specializes in simple cost effective solutions for phosphorus and other contaminants reductions from a variety of wastewater and runoff sources.

Implementation of a simple PhosphoReduc filter could also reduce the area needed for a large system on a farm consisting of 3 or more grass filter areas, as the filtration material has very high and proven efficiency in reducing P, *E.coli,* TSS and many minerals and metals [4-16]. Currently the cost of the standard practice of a vegetative treatment area is $13,170 for a bunk silo 1 acre in size and the implementation of a low flow gravity runoff diversion is $2,050 per acre area that needs treatment, resulting in a total of $15,220 per acre.

The implementation of an innovative "treatment train" system consisting of a PhosphoReduc filter, a single vegetative treatment area and a trench filled with P adsorbing material and vegetated with local grasses, would be cheaper and have significantly higher performance in pollutants reduction. For example, a Phosphoreduc filter designed to treat 25 m^3 of runoff/year excavated to a depth of up to 1.2 m would require maximum 50 m^2 surface area and about 135 tons of material, or 78 cubic yards [13, 14]. The filtration material ($15/ton) and transport cost ($30/ton), result in a total cost for material and transport of $6,075.

As a comparison, currently the implementation of a vegetative treatment area to treat runoff from 1 acre requires 1611 cubic yards of soil (36 ") at $6/CY resulting in a cost of $9,666 (excluding transport costs) (Table 9).

Additional costs of a PhosphoReduc treatment system would include piping, liner, excavation and design and engineering drawings at an estimated ~ $5,000. Overall the proposed practice could be implemented for under $12,000/acre needed treatment, saving $3,000/acre to the farmer.

2.2. Current Treatment Practices – Economic and Social Aspects of the Costs

The economic costs of the wastewater treatment systems vary by the management agencies and locations. The following tables (Methods 1 to Method 9) summarized 9 methods that we have identified in different states. Although we cannot directly compare and contrast the unit costs of different treatments, we can still obtain a general idea of the economic evaluations of different systems. We must consider the producer or the local government who need the incentives to install and manage a particular system. Several common factors to consider include – lower labor requirement, elimination of a separate system to handle manure (or other waste) and wastewater from the production site (for example, the milking parlor and milk house), lower total cost of operation, and higher efficiency over long term. The economic benefits of the wastewater treatment systems could be calculated by (1) identifying alternative usage of the waste (e.g. use manure to generate power); (2) estimating the reduction of cleaning the damage of the water pollution in water ways (e.g. reducing the costs of cleaning the seaweeds in the lakes); (3) identifying the increased values of land and properties; and (4) evaluating the improvement of efficiency and value added for production and services in the long term.

The social aspect of the costs and benefits related to wastewater treatment involves the overlapping generation decision-making. Any wastewater treatment system needs time to prove the effectiveness (based on the given sources of information, we use 20-year and 5% social discount rate to assess the value of the treatment systems). There might be one single solution to reduce nitrogen and phosphorus runoff once, and every system has a tradeoff benchmark. More often, many decisions of choosing a specific treatment system are based on political orientations, preferences/constraints of funding, and dealing with short-term solutions. For any generation, the best practice should be a combination of sustainable treatments that will impose the least costs to yield the highest efficiency of the treatments.

Method 1 Use a storage tank to temporarily store concentrated silage or milk house wastewater.	Geographical Area MA Statewide		Unit For Cost Estimation Gallon Number of Units 2000
	Costs		
	Equipment/Installation (include labor and materials)	$	11,844.07
	Mobilization	$	456.00
	Total	$	12,300.07
	Cost per unit	$	6.33

Method 2 **Bunk silo 105'*105'**	Geographical Area VT Statewide	Unit For Cost Estimation Square Feet	
	Cost per Unit		
	Equipment/Installation (include labor and materials)	$	1.82
	Mobilization	$	0.05
	Operation and Maintenance	$	0.04
	Total Costs per Unit	$	1.91

Method 3 **Bunk silo 210'*210'**	Geographical Area VT Statewide	Unit For Cost Estimation Square Feet	
	Cost per Unit		
	Equipment/Installation (include labor and materials)	$	0.84
	Mobilization	$	0.01
	Operation and Maintenance	$	0.02
	Total Costs per Unit	$	0.87

Method 4 **Bunk silo 105'*105'**	Geographical Area VT Statewide	Unit For Cost Estimation Square Feet	
	Cost per Unit		
	Equipment/Installation (include labor and materials)	$	2.32
	Mobilization	$	0.05
	Operation and Maintenance	$	0.05
	Total Costs per Unit	$	2.42

Method 5 **Bunk silo 210'*210'**	Geographical Area VT Statewide	Unit For Cost Estimation Square Feet
	Cost per Unit		
	Equipment/Installation (include labor and materials)	$	0.97
	Mobilization	$	0.01
	Operation and Maintenance	$	0.02
	Total Costs per Unit	$	1.00

Method 6 **Bunk silo 210'*210'**	Geographical Area VT Statewide	Unit For Cost Estimation Square Feet
	Cost per Unit		
	Equipment/Installation (include labor and materials)	$	1.07
	Mobilization	$	0.01
	Operation and Maintenance	$	0.02
	Total Costs per Unit	$	1.10

Method 7 **Silage leachate system**	Geographical Area NY	Unit For Cost Estimation installation
	Cost per Unit		
	Materials	$	16,817.59
	Mobilization	$	473.84
	Operation and Maintenance	$	864.57
	Total Costs per Unit	$	18,156.00

Method 8 **Silage leachate system**	Geographical Area OH	Unit For Cost Estimation per payment
	Cost per Unit	
	Materials	$ 14.84
	Equipment	$ 6.05
	Labor	$ 2.98
	Mobilization	$ 1.19
	Operation and Maintanence	$ 0.72
	Total Costs per Unit	$ 25.78
	Total estimated cost for scenario	$ 5,153.83

Method 9 **Vegetated Treatment**	Geographical Area MA	Unit For Cost Estimation Square Feet Unit 6000
	Cost per Unit	
	Materials	$ -
	Equipment	$ 1.32
	Labor	$ -
	Mobilization	$ -
	Operation and Maintanence	$ 0.04
	Total Costs per Unit	$ 1.36
	Total estimated cost for scenario	$ 8,160.00

3. Accomplishments and Outputs

This project has been pioneering in terms of its specific focus on in-field evaluation of a silage leachate treatment system composed of a grass filter area integrated with steel slag berm (GFA + SSB). We conducted thorough water quality, soils and biota field sampling which enabled us to: 1) evaluate the performance of the complete system consisting of the three grass filter area (GFA) treatment beds, three steel slag berms (SSB) and a vegetative buffer strip (VBS); 2) evaluate the performance of each individual treatment step (e.g. single GFA, one GFA and one SSB, two GFA and one SSB, two GFA and two SSB, three GFA and two SSB, three GFA and three SSB; 3) perform economic comparisons of an innovative SSB treatment performance with the GFA treatment system and vegetative buffer strip (VBS), the latter two being best management practices (BMPs) recommended by the regulatory agency, the Vermont Agency of Agriculture, Food and Markets (VAAFM) for use to reduce pollution from silage leachate runoff in Vermont (VT).

4. Outcomes and Impacts

Overall, by conducting a complete assessment of a novel treatment system in reducing pollution from silage leachate, this project helped fill the technology gap that currently exists in terms of nutrient, pathogen, organic matter and suspended solids removal from agricultural runoff, addressing the significant environmental, educational and economic risks facing U.S. agriculture and water sectors. The stakeholders (Vermont Agency of

Agriculture, Food and Markets, Agency of Natural resources, US Department of Agriculture) are currently seeking best management practices to reduce phosphorus and total suspended solids loading to Lake Champlain. This need has never been more urgent than today, given the current governmental efforts in the revision of the total maximum daily loads (TMDLs) required by the Federal Environmental Protection Agency since January 2011.

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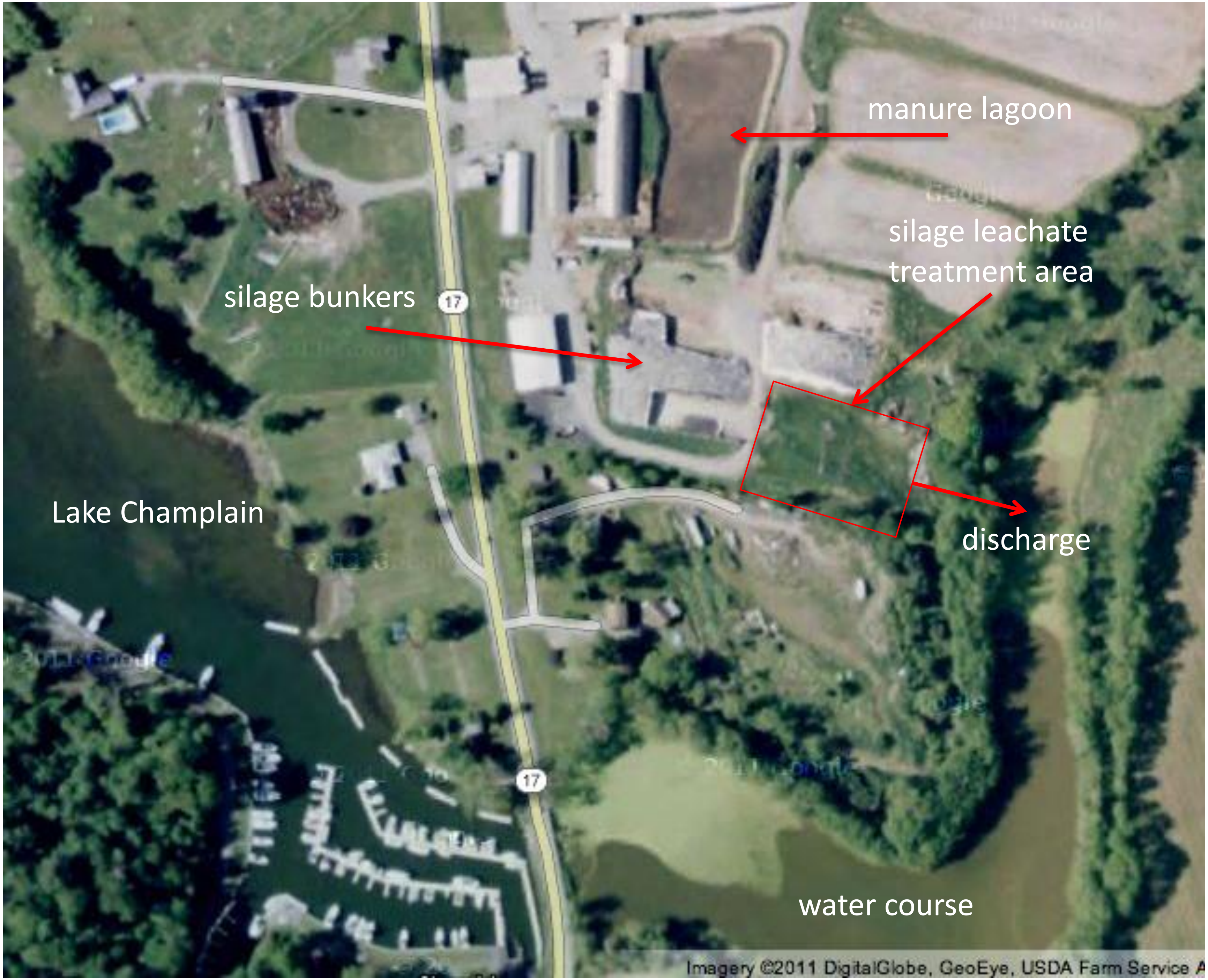
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