Evaluation of Site Suitability for Enhanced Infiltration Practices in Heavy-use Livestock Areas

Project Report

In Partial Fulfillment of NRCS CIG Project:

Enhanced Infiltration for Animal Waste Treatment

Agreement No. 69-1535-06-05A

February, 2010

THE UNIVERSITY OF RHODE ISLAND

University of Rhode Island
Watershed Hydrology Laboratory
Arthur Gold, Ph.D
Kelly Addy
Ben Vinhateiro
Marie Esten

Table of Contents

1.0 EXECUTIVE SUMMARY 1

2.0 OVERVIEW OF WATER QUALITY CONCERNS ASSOCIATED WITH HEAVY-USE LIVESTOCK AREAS 2

2.1 SOIL CONDITIONS 3
2.2 NUTRIENTS AND PATHOGENS 4
2.2.1 Nitrogen 4

2.2.2 Phosphorus 6

2.2.3 Pathogens……………………………………………………………………… 6

2.2.4 Salts….. 7

3.0 LOW IMPACT DEVELOPMENT 7

3.1 WHAT IS LOW IMPACT DEVELOPMENT? 7
3.2 WHAT IS ENHANCED INFILTRATION? 8
3.2 ROLE OF ENCHANCED INFILTRATION IN TREATING LIVESTOCK YARDS 9
3.3.1 Initial site suitability assessment 10

Upgradient inputs of runoff: Disconnection of runoff sources.. 10

Livestock Yard Size 11

Livestock Type and Stocking Density 12

Existing hydrology and soils.. 12

Water resource management 13

Land use constraints.. 13

3.3.2 Enhanced infiltration design considerations 13

3.3.3 Infiltrate treatment options……………………………………………………… 14

Bioreactors……………………………………………………………………………….14

Sand Filters……………………………………………………………………………….15

Bioretention or Rain Garden……………………………………………...………………………………..16

4.0 CASE STUDY – PECKHAM FARM 19

4.1 OVERVIEW.. 19
4.2 CONSTRUCTION DETAILS.. 20
4.3 RESULTS 25
4.4 CONCLUSION 29

References Cited…………………………………………………………………………...30

Appendix A………………………………………………………………………………...33

1.0 EXECUTIVE SUMMARY

In southern New England, many livestock operations are located on small-acreage farms, where land limitations often result in animal rearing at high stocking rates in confined loafing areas. Many of these farms lack appropriate infrastructure for effective nutrient management and are often located in close proximity to residential development, private wells, public reservoirs, and both coastal and freshwater wetlands. The paddocks become sources of concentrated nutrients and pathogens that pose pollution risks to neighboring surface and groundwater resources. Unique, low infiltration soil conditions form under these loafing areas due to hoof action that destroys surface vegetation, compacts soil structure, and mixes manure into the surface soil. The resulting soil surface becomes enriched in organic matter and maintains high soil moisture resulting in muck and restricted water infiltration into the subsurface during even small storm events. Under these conditions, nutrient-rich overland flow is promoted and hoof problems for the livestock may result. While roofing is one approach to minimize exposure of these paddocks to rain and surface runoff, it is often too expensive and impractical for small-scale producers. Alternatively, methods to enhance infiltration within these paddocks and reduce overland flow– particularly from common storm magnitudes that constitute the bulk of annual precipitation – should be examined to reduce pollution and minimize human and animal health risks.

The overall goal of this document is to examine the conditions where enhanced infiltration on small acreage heavy-use animal areas is well-suited and to stimulate the development and adoption of enhanced infiltration practices to augment the set of current animal waste treatment practices promoted by NRCS-RI. This document presents an overview of the nutrient management challenges facing small-acreage livestock farmers as well as the risks and concerns associated with the resulting paddock conditions. Site assessment protocols incorporate principles of Low Impact Development (LID) and bioretention design requirements to assist NRCS in determining if an enhanced infiltration practice is appropriate at a given site, what types of complementary site modifications may be needed, and what additional treatment options exist for treatment of infiltrated water. Site assessment includes the identification of site constraints, such as upgradient runoff sources and pathways; soils, stocking rates, type of animals, soil type, slope, depth to groundwater, potential surface water outlets and management issues, including the management of wetlands and existing on-site infrastructure. Modification of a site to increase infiltrative capacity can be accomplished by a suite of practices including: i) amending the soils; ii) replacement of surface soil with a pervious media such as gravels or coarse sands; and iii) placement of geotextile fabrics or pavers. **We emphasize that runoff waters and surface conditions generated from livestock areas are different than stormwater generated from commercial and residential areas. Livestock yard runoff has much higher organic load and therefore has the potential to clog LID practices at a much greater rate then in other settings. The design of any LID practices for treatment of livestock yard runoff must address the challenge of high organic loading and clogging potential of the infiltrative surfaces in the enhanced infiltration structure. Our field test results suggest onsite infiltration enhancement is not readily suited for cattle due to soil clogging, but may be more adaptable to well-managed horse operations.**

2.0 OVERVIEW OF WATER QUALITY CONCERNS ASSOCIATED WITH HEAVY-USE LIVESTOCK AREAS

Small acreage farms, such as hobbyist farms, horse farms, riding academies and boarding facilities, are often located in or within close proximity to residential areas, without buffers of woodlands and fields. These farms frequently include heavy-use livestock areas for animal feeding, handling, exercise and loafing (Burdett and Sullivan, 2005). These areas are usually located near a barn or homestead, are relatively small compared to the number of animals occupying them and are often occupied daily for long periods of time. Heavy-use livestock areas are sometimes referred to as “sacrifice areas”, areas that are intended to hold animals while pasture re-growth is allowed in other locations. In many small acreage farms, pasture areas are limited; therefore, these heavy-use livestock areas are in constant use. Often heavy-use areas are wet and muddy for extended periods, reducing the opportunity for pasture vegetation to thrive. When it rains, these areas have a high potential for contamination of water resources with bacteria and nutrients as the livestock yard surface muck promotes runoff rather than infiltration (Burdett and Sullivan, 2005).

These types of farms generally have limited infrastructure to effectively manage wastes, limited (if any) pasture and high stocking rates. In southern New England, an average one to two acres of land are needed to support one 1,000 pound horse or cow. These farm animals generate substantial manure (Table 1). For example a 1,000 pound dairy cow can produce up to 15 tons/yr of manure, while a 1,000 horse is expected to produce about 9 tons/yr (USDA, NRCS 1992). Higher stocking rates will exceed the ability of the land to support the feeding and manure management of the animals. Subsequently, wastes generated on small acreage farms have a greater potential to contaminate surrounding water resources such as groundwater, ponds and drinking water wells if not managed properly (Burdett and Sullivan, 2005).

Table 1. Typical manure and nutrient production by livestock calculated on an “as excreted” basis per 1,000 pounds of animal.

Animal	Tons/yr
Beef Cow	11.5
Dairy Cow	15.0
Horse	9.0
Lamb	7.0
Swine (grower)	11.5

Source: USDA, Agricultural Waste Management Field Handbook, 1992. Actual amount and content may vary significantly with age, feed ration, breed, and handling.

2.1 SOIL CONDITIONS

A muddy paddock (http://www.wunderground.com/blog/DataPilot/comment.html?entrynum=4)

Soil conditions in heavy-use livestock areas can pose great challenges for water infiltration. Surface soil conditions frequently do not resemble those expected for the soil series. In addition, the subsoils of livestock yards do not affect the infiltrative capacity of a cattle livestock yard site (Mielke et al., 1974; Miller et al., 2008). The type of animal accessing the livestock yard plays an important role in modification of the soil conditions and therefore water infiltration within the yard. If accessed mainly by cows or cattle, the upper soil profile generally consists of three layers:

1) a top layer enriched with manure-derived organic matter,

2) an interface of organic matter and soil, and

3) the underlying soil (Mielke, et al., 1974).

Similar layering can occur in horse paddocks – if they are not maintained. After a compacted interfacing layer of manure/soil is formed on the surface, minimal water infiltrates through this layer into the subsurface (Mielke et al., 1974; McCullough et al., 2001). McCullough et al. (2001) observed over a 9 month period that the saturated hydraulic conductivity (Ks, i.e., the ability of water to be transmitted through saturated media) in a cattle livestock yard decreased 5 to 34 times. Miller et al. (2008) found that the mean field Ks was 46 to 78% lower than the soil outside the cattle livestock yard. The soil moisture content, ratio of the mass of water in the soil to the dry weight of the soil, of the surface layer also tends to increase (McCullough et al., 2001; Mielke, et al., 1974). Soil structure (pore size distribution) declines and moisture holding capacity increases in livestock yards (Pennsylvania Small Scale Livestock Committee, 2002). These alterations in the surface soils reduce the infiltration capacity and rate of infiltration through the soil. Precipitation remains within this upper layer creating prolonged muddy conditions and high levels of runoff from the livestock yard, transporting high levels of contaminants from the livestock yards to surface waters (Table 2).

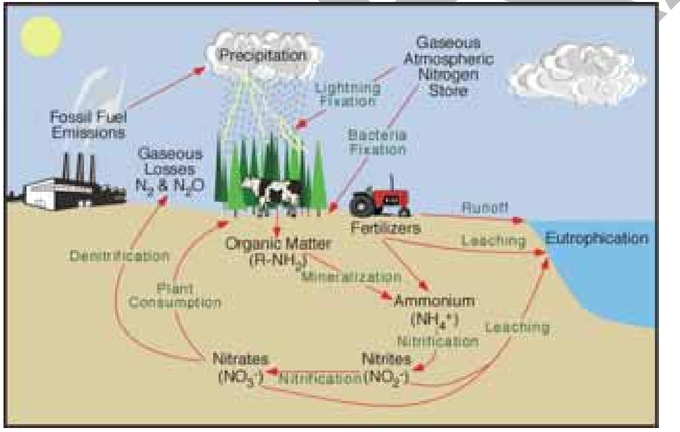
Table 2: Contaminant concentrations in runoff observed on an experimental cattle feedlot surface by Gilley et al. (2008).

Contaminant	Observed runoff characteristics
Dissolved phosphorus	1.41-3.5 kg/ha
Particulate phosphorus	10.1-15.5 kg/ha
Total phosphorus	13.5-17.9 kg/ha
Ammonia – N	.57 – 3.5 kg/ha
Total nitrogen	20.9-27.4 kg/ha
Chloride	88.1-154 kg/ha
E .coli	13.8-14.1 log CFU/ha

2.2 NUTRIENTS AND PATHOGENS

2.2.1 Nitrogen

The main inputs of nitrogen (N) to the livestock yard consist of organic N and ammonia (NH_4^+) though manure and urine. The nutrient content of animal manure is summarized in Table 3. Eghball et al. (2002) notes that approximately 58% of the N associated with beef cattle is contained in the urine, mostly as urea. Organic N rapidly nitrifies into nitrate (NO_3^-) once it infiltrates into the soil becoming extremely mobile and readily leachable into groundwater. Ammonia is usually volatilized, taken up by plants or absorbed by the soil (Jokela et al., 2004).



The nitrogen cycle
(www.physicalgeography.net/fundamentals/9s.html)

Table 3: Typical nutrient values in manure from various sources (Jokela et al, 2004). Conversion from P_2O_5 to PO_4 multiply by 1.34 (USDA, 2008).

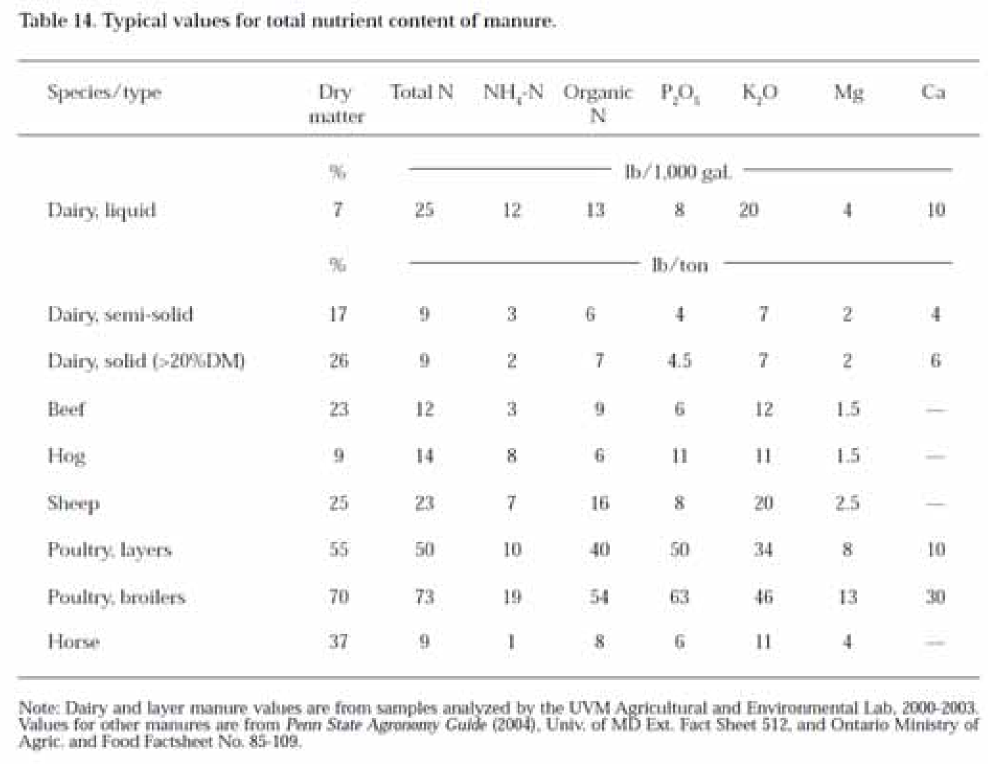


Table 14. Typical values for total nutrient content of manure.

Species/type	Dry matter	Total N	NH_4-N	Organic N	P_2O_5	K_2O	Mg	Ca
	%	lb/1,000 gal.						
Dairy, liquid	7	25	12	13	8	20	4	10
	%	lb/ton						
Dairy, semi-solid	17	9	3	6	4	7	2	4
Dairy, solid (>20%DM)	26	9	2	7	4.5	7	2	6
Beef	23	12	3	9	6	12	1.5	—
Hog	9	14	8	6	11	11	1.5	—
Sheep	25	23	7	16	8	20	2.5	—
Poultry, layers	55	50	10	40	50	34	8	10
Poultry, broilers	70	73	19	54	63	46	13	30
Horse	37	9	1	8	6	11	4	—

Note: Dairy and layer manure values are from samples analyzed by the UVM Agricultural and Environmental Lab, 2000-2003. Values for other manures are from *Penn State Agronomy Guide* (2004), Univ. of MD Ext. Fact Sheet 512, and Ontario Ministry of Agric. and Food Factsheet No. 85-109.

Environmental Threats

High levels of nitrate in drinking water sources is a health hazard and may cause methoemoglobinemia (Blue Baby Syndrome) in infants and animals, as well as reproductive problems in both animals and humans (Burdett and Sullivan, 2005). Nitrogen is the limiting nutrient of many marine systems; therefore excess levels of N can contribute to algal blooms, eutrophication and hypoxia (dead zone) in coastal waters. Heavy-use animal operations can contribute both nitrate-enriched runoff and ammonia-enriched atmospheric deposition to coastal waters.

Removal

The main processes for nitrate removal are uptake by plants and denitrification. Denitrification is the bacterial conversion of nitrate into nitrogen gas. This transformation only occurs in an anaerobic environment in the presence of an electron donor. Anaerobic conditions occur naturally in the environment in wetlands and riparian areas. Such conditions may also be fostered in the soil and groundwater by creating carbon-rich zones through the addition of wood chips or other carbon amendments. The carbon serves as an electron donor for denitrifying bacteria and its decomposition can create the anaerobic conditions necessary for denitrification.

2.2.2 Phosphorus

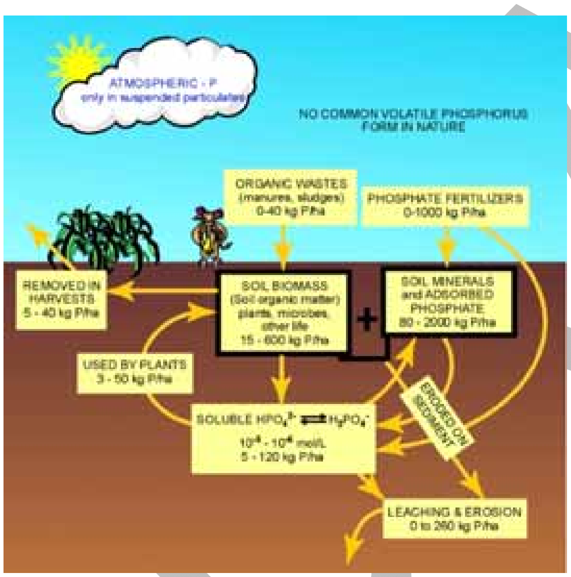
Input of phosphorus (P) to livestock yards includes: manure, sediment and feed waste. Phosphorus content of various animals was presented in Table 3. Eghball et al. (2002) notes that 96% of the P attributed to beef cattle is contained in the feces. Unlike N, P primarily adsorbs to soil particles and organic matter making it less mobile in the environment. Movement of P can occur with the mobilization of soil and sediment during a runoff event, but once infiltrated, most soils in southern New England have a large P removal capacity.

Environmental threats

Phosphorus is the limiting nutrient in freshwater systems. Therefore, P inputs into such systems can contribute to algal blooms and eutrophication.

Removal

The main processes for P removal are plant uptake and soil absorption. Infiltration filters out P-laden sediments as well as allowing dissolved P to adsorb to soil particles and become immobile.



The phosphorus cycle
(http://nutrients.ifas.ufl.edu/nutrient%20pages/BSFpages/NPcycles.htm**)**

2.2.3 Pathogens

Pathogens such as the bacteria *Escherichia coli* (*E. coli*) are generally found in animal feces rather then the urine. *E. coli* are used as an indicator microorganism; the occurrence of these bacteria indicates a risk of fecal contamination and pathogens that can cause illness may be present in the water. Research indicates that manure-born pathogens may be transported either attached to soil particles or may flow freely without attachment (Pachepsky et al., 2007).

Environmental threats

Elevated levels of bacteria in groundwater may contaminate drinking water wells and may cause surface waters to become unusable for shellfishing and/or recreational activities.

Removal

Infiltration methods should reduce pathogens by filtering ponded water within the soil media. Once in the media, extended retention times will allow bacterial levels to decline.

2.2.4 Salts

There have been reports of elevated potassium, chloride, sodium, calcium, magnesium and manganese concentrations in soils and groundwater below cattle livestock yards when pen cleaning activities remove the surface compacted soil layer (Olson et al, 2005). Beef cattle excrete approximately 75% of their potassium in the urine (Eghball et al., 2002). Inorganic salts dissolve easily into runoff and infiltrate increasing the potential for groundwater contamination.

Environmental threats

Increases in dissolved salts in groundwater may contaminate private and public drinking water wells and is often viewed as an indicator for the presence of additional contaminants.

Removal

Remediation for excessive concentrations of dissolved salts in drinking water is generally accomplished with filter technology at site-of-use.

3.0 LOW IMPACT DEVELOPMENT

3.1 WHAT IS LOW IMPACT DEVELOPMENT?

Low Impact Development (LID) refers to a group of design techniques and stormwater control methods that focus on retaining a site's predevelopment hydrologic characteristics by reducing overland flow. The methods focus on enhancing the site's ability to store, infiltrate, evaporate and detain stormwater. Methods focus on utilizing site design to sustain pre-development hydrology, rather than hard structures associated with traditional curb and gutter to stormdrain systems.

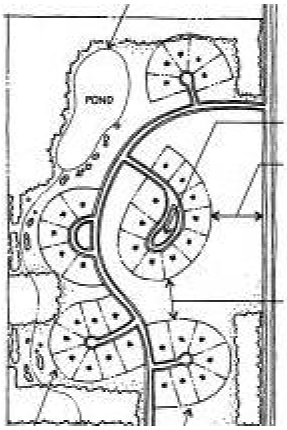
LID techniques are often broken into several categories:

- Initial site design, e.g., placement of structures in less sensitive areas, using the contours of the land in design, clearing minimal areas for construction, buffers;
- Evaporate and detain, e.g., rainbarrels and cisterns, green roofs;

- Infiltrate, e.g., dry wells, raingardens, bioretention systems, soil amendment and geotextiles; and
- Re-use/storage, e.g., rainbarrels and cisterns.

LID principals have been in use for several years across the country. The State of Rhode Island is working to adopt a new Stormwater Manual (CRMC and RIDEM, 2009) requiring that LID techniques be used in site design. Engineers and construction managers have begun to use the techniques more often as additional municipalities and agencies require them.

Examples of LID:



Conservation design methods avoid construction near sensitive areas. (RINEMO, 2009)

Rain gardens provide infiltration (CRMC and RIDEM, 2009)

Rainbarrels provide rainwater storage for later use (CRMC and RIDEM, 2009)

3.2 WHAT IS ENHANCED INFILTRATION?

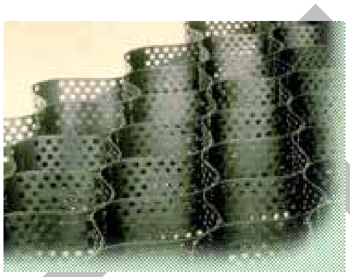
Enhanced infiltration is a method of LID in which the characteristics of a site are modified to allow for greater amounts of on-site infiltration. Modification of a site to increase infiltrative capacity can be accomplished by one or more of the following:

- Amendment of the soils;
- Replacement of surface soil with a pervious media such as gravels or coarse sands; and/or
- Placement of geotextile fabrics or pavers.

Soil amendment refers to the addition of materials to the existing or native soils to improve their ability to infiltrate water. Commonly used amendments include mulch, sand, wood chips, reclaimed rubber products and gravel. Often geosynthetics, geotextile products that come in several forms, are utilized in addition to soil amendments to provide separation between the soil amendment and the native soils, improve filtering capabilities, add stability to the soil by adding structure, or control site erosion. Geotextile materials can be either woven or non-woven and made into rolled or three dimensional grid products for various uses.

Examples of geotextile products:

AgriBlock (www.prestoproducts.com)



AgriWeb (www.prestoproducts.com)

Turf Reinforcement Mat
(www.contechess.com)

Non-woven geotextile
(www.contechess.com)

3.2 ROLE OF ENCHANCED INFILTRATION IN TREATING LIVESTOCK YARDS

Properly executed enhanced infiltration practices in a livestock yard will:

- increase the amount of rainwater flowing through the soils into groundwater;
- decrease overland runoff and sediment transport;
- decrease the amount of mud in the livestock yard; and
- reduce P and bacteria from infiltrated waters and convert organic-N to nitrate-N.

When coupled with other LID techniques for treatment of infiltrated waters, more N, P and bacteria may be removed from the water. There are several design characteristics that will determine if enhanced infiltration can play a role in treating livestock yards. **Of critical importance to this topic, we emphasize that runoff and waters generated from livestock areas are different than stormwater generated from commercial and residential areas. Livestock yard runoff has much higher organic load and therefore has the potential to clog LID practices at a much greater rate then in other settings. Therefore, the design of any LID practices for treatment of livestock yard runoff must address the challenge of high organic loading and clogging potential of the infiltrative surfaces in the enhanced infiltration structure.**

3.3.1 Initial site suitability assessment

An initial site suitability assessment must be undertaken to assess if an enhanced infiltration practice is appropriate at that site, identify the types of complementary site modifications that may be needed, and determine what additional treatment options exist for treatment of infiltrated water. The site assessment includes the identification of site constraints, such as upgradient runoff sources and pathways; soils, stocking rates, and type of animals, soil type, slope, depth to groundwater, potential surface water outlets and management issues, including the management of wetlands and existing on-site infrastructure.

<u>Upgradient inputs of runoff: Disconnection of runoff sources</u>

Before employing more advanced techniques to enhance infiltration in heavy-use livestock yards, the first step should be to remove any off-site sources of water that are currently running onto the site. Areas that may contribute runoff to a livestock yard often include:

- roof downspouts,
- paved areas,
- sidewalks,
- hard packed roads or
- upslope areas draining into the livestock yard.

Rooftop runoff should be collected using a gutter and downspout system. The downspouts can then be directed away from the livestock yard to allow for infiltration over a grassy surface, connected to a subsurface infiltration system or connected to a rainbarrel or cistern to collect the water for future re-use. Collected water can be stored and later used for irrigation. If water is running into the livestock yard due to the slope of the surrounding area, a grassed berm can be used to redirect runoff away from the livestock yard. Commercially available products, such as silt fences or coconut fiber rolls, may also be effective in redirecting runoff. An earthen berm may be an affordable solution. Any efforts to redirect water should be done to minimize other problems, such as erosion.

Examples of methods of disconnection:

An earthen berm can be used to receive runoff and temporary store the water until it infiltrates. (http://faculty.msmary.edu/envirothon/current/guide/Image41.jpg)

Rain on this barn is captured in a gutter system that directs water into a perforated drainage pipe allowing for infiltration. Larger storms pass the water into a bioretention basin. (http://www.escrutgers.com/rlp/water_management.htm)

A rainbarrel is a cheap and efficient way to capture rooftop runoff. (www.rainwaterbarrel.org)

Livestock Yard Size

The size of the livestock yard may dictate the design alternative available for enhanced infiltration. It may not be practical to retrofit the entire livestock yard if it is very large; in this case the focus should be on the areas with the greatest potential for generating contaminated runoff. These areas include:

- feeding/watering areas
- preferred defecation areas
- low areas where runoff tends to focus or pond

Livestock yards with horses are a likely candidate for enhanced infiltration (UMD, agnr.umd.edu).

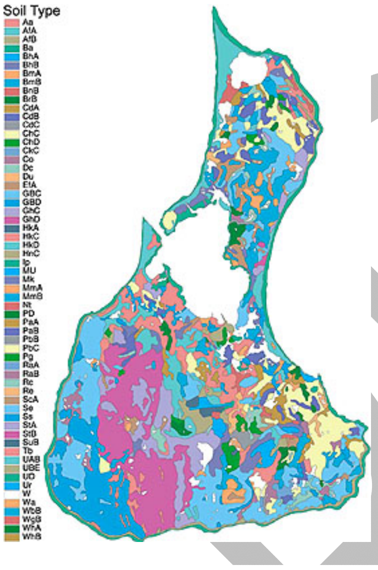
Livestock Type and Stocking Density

As the density of animals in a livestock yard increases, the potential for generating contaminated runoff increases, the likelihood for the soil to be packed tightly increases, and the ability for the land to support these animals decreases. On average, one to two acres of land are needed to support one 1,000 pound horse or cow (Burdette and Sullivan, 2005).

The type of animal (i.e., horses, cows, sheep, etc.) is also an important consideration when determining the suitability of a site for enhanced infiltration. **The use of enhanced infiltration for sites with cattle/cows is not recommended** due to the formation of a dense low permeability layer of manure and soils that prevents efficient infiltration (Mielke et al, 1974, Miller et al., 2008) or clogs geosynthetics in enhanced infiltration systems. Horses loafing areas are more likely candidates for enhanced infiltration, particularly when combined with regular surface cleaning.

Existing hydrology and soils

Soils and existing site drainage play important roles in considering enhanced infiltration at a site.



Soil map for Block Island, RI
(http://www.fas.org/irp/imint/docs/rst/Sect15/Sect15_11.html)

Soils – Existing soils should be assessed to determine infiltrative capacity. Low permeability soils will need to be amended to promote infiltration. Areas already modified by heavy livestock use will often exhibit low infiltrative capacity and surface soils will also need to be amended – or in some cases removed and replaced with fresh, permeable media.

Water table – If the water table at the site is near the surface installing tile drainage can lower the water table and provide a collection point for infiltrating water. The collected water can then be treated further. Additionally, the increased distance between the surface and water table can provide additional water quality benefits by providing a greater travel pathway for water to infiltrate through the soils. If the water table is fairly deep, then it may be possible to allow the water to infiltrate into the soils without collection and treatment.

Drainageways – Existing drainageways can be utilized to move runoff from a livestock yard to another offsite location for more traditional treatment such as treatment ponds. Tile drainageways can also be retrofitted to provide water quality treatment, such as a woodchip trench to promote denitrification.

Erosion – The site should be assessed for the location of any especially erodible soils that should be avoided and left undisturbed.

Water resource management

The location of existing water resources, such as wellheads, surface water bodies and wetlands, is an important consideration when siting enhanced infiltration at a heavy-use livestock yard. A priority should be placed on the protection of these resources. Water resources can be impacted by increases in sediment load due to erosion or contamination from direct runoff or discharge of treated runoff. State and federal regulations may limit what areas are available for treatment or disturbance when working on a site near regulated wetlands or water bodies. When assessing a site, any of the following water resources could be impacted:

- Private or public wells and associated regulated buffers;
- Fresh and/or coastal wetlands and associated regulated buffers; and
- Streams, lakes, reservoirs or estuaries and associated regulated buffers.

Land use constraints

As some treatment options require the use of land adjacent to the livestock yard, it is important to determine what areas are available for use as well as any constraints on these areas. Use of adjacent land may include construction of a treatment pond, placement of treatment trenches or temporary storage of runoff for infiltration.

3.3.2 Enhanced infiltration design considerations

After the initial site suitability assessment has been completed, the goal of the infiltration should be refined, the type of enhanced infiltration design selected, and the infiltrate water’s endpoint with or without additional treatment determined.

The selected infiltration practice must be:

- Appropriate for the animal of interest - the selected material must provide comfortable and functional footing for the target livestock;
- Able to withstand heavy livestock use;
- Provide a stable surface for machinery;
- Managed properly to remove accumulated manure;
- Enhance infiltration of as much runoff as possible on the site;
- Discharge treated effluent safely and effectively onto surface or into GW system;

- Reduce muddiness; and
- Be affordable.

Once infiltration at the site has been enhanced the water now infiltrating into the soils should be treated to remove the high levels of N expected from a livestock area. The infiltrate can be either treated on-site or transported to an off-site location for treatment.

Subdrain systems or tile drainage play an important role in either the treatment of water on-site or the transport of infiltrate off-site. At a location where the water table is closer to the surface infiltrated water may encounter an area of low dissolved oxygen where denitrification may occur. If the water table is lowered due to tile drainage, the tile drainage outlet can provide a location for the collection and subsequent treatment of water.

3.3.3 Infiltrate treatment options

There several options for the treatment of infiltrated water from a livestock yard. Treatment should focus on the removal of nitrate-N as this will generally be the nutrient of interest in coastal watersheds.

<u>Bioreactors</u>

Bioreactors are passive technologies that have been recently developed to overcome the carbon limitation of denitrification for enhanced nitrate removal. Carbonaceous material is added to a trench to intercept groundwater flow. To date, wood-particle media, i.e., wood chips, in particular has been the most widely used material in field trials and has shown an ability to deliver consistent longer term (5 - 15 yr) nitrate removal, while requiring minimum maintenance (Robertson et al. 2000; Schipper and Vojvodic-Vukovic, 2001; Schipper et al. 2005; Jaynes et al. 2008; Robertson et al. 2008; Robertson et al. 2009). These bioreactors, also referred to as denitrification trenches, denitrification walls, or denitrification beds (Schipper et al., in press), provide the anaerobic conditions and carbon source required for anaerobic denitrifying bacteria to thrive and subsequently remove N. The trench intersects groundwater; as water passes through the trench nitrate is denitrified and transformed to N gas. Nitrate removal rates within walls may be limited by low rates of nitrate loading; as most walls removed virtually all the nitrate (Schipper et al., in press).

Placement of woodchips into a trench to prepare a bioreactor system – Univ. of MN

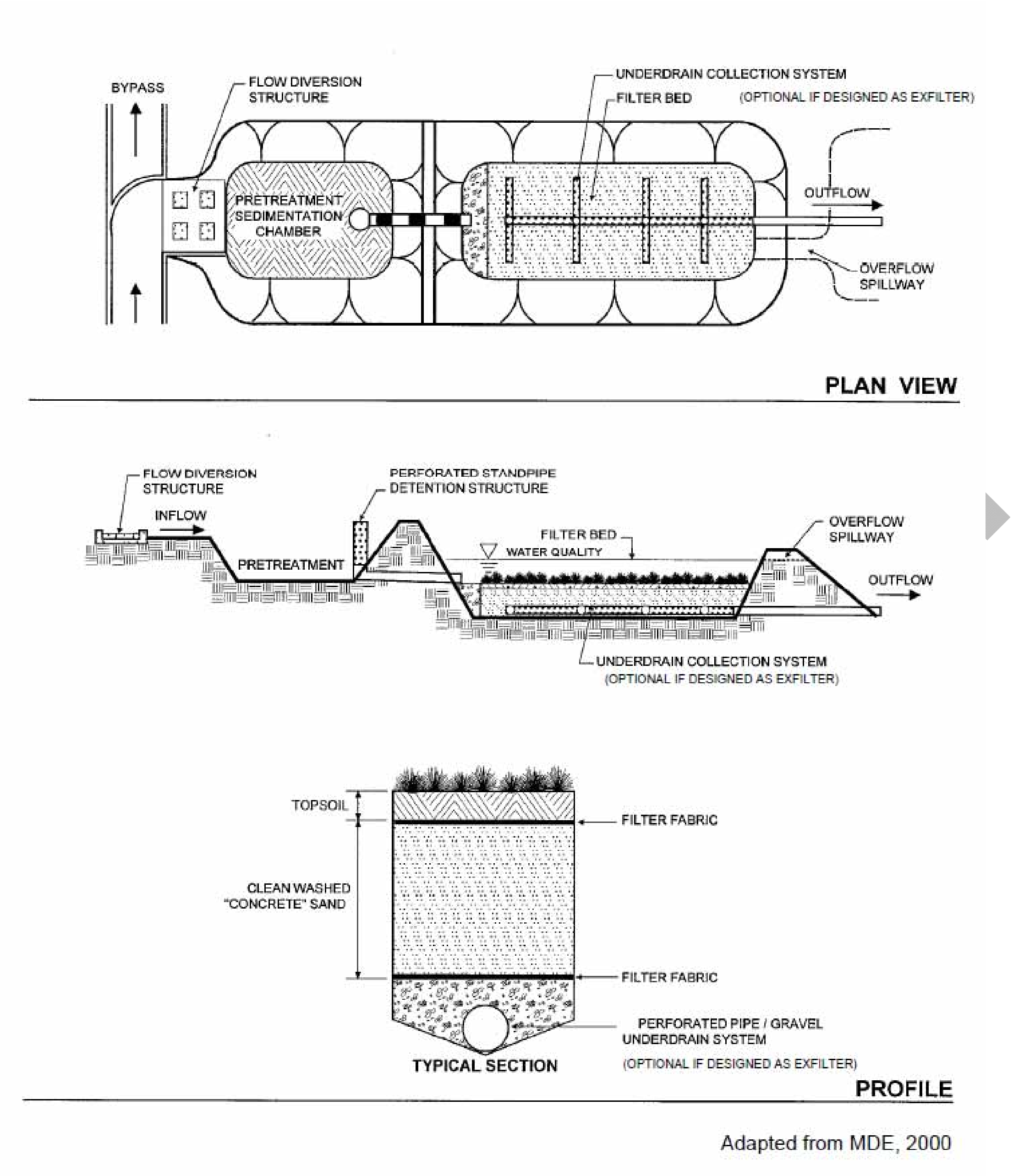
Bioreactors are recommended for use in sandy soils with shallow water tables to provide the appropriate conditions for infiltration and denitrification. In addition to wood chips, other carbon sources have proven effective for nitrate-N removal including: wood chips amended with soybean oil, cornstalks and cardboard fibers (Greenan et al, 2006). Bioreactors may vary in their efficiency seasonally. When nitrate was non-limiting in several bioreactor studies, the nitrate removal rates increased with temperature (Robertson et al., 2008; Robertson et al., 2009, Warneke et al., in press, Cameron and Schipper, in press). In climates with cold winters, alternative stormwater management strategies may need to be implemented in the winter to manage N off-site transport from heavy-use livestock areas.

Most of the research on bioreactors has focused on the nitrate removal function, but some measurements of other contaminants has occurred. Monitoring of four sawdust beds treating septic tank effluent in Ontario (Robertson et al. 2005), showed that over several years of operation, E. coli levels generally remained below detection in the reactor effluents (<10 cfu 100 mL-1) with only a few break-outs. Of the N forms, only nitrate seems to be removed to any large degree with little removal of organic nitrogen or ammonium (Robertson et al., 2005; Schipper et al., in press). To date, there has been little evidence that wood-based bioreactors remove phosphate from effluents (Robertson et al., 2005; Jaynes et al., 2008; Schipper et al., in press). However, the addition of other amendments to bioreactors (e.g. iron slag), has resulted in considerable phosphate removal from treated septic tank effluent (Baker et al., 1998; Robertson, 2000) and streams (McDowell et al., 2008).

If bioreactors are used in combination with enhanced infiltration practices on heavy-use livestock areas, the stormwater runoff non-point source of pollution becomes a point source with infiltrate water being piped into the ground and through a bioreactor unit for remediation. Once water passes through the bioreactor it can either continue along its natural flowpath if in an open-ended system or collected at the end of a closed system and released into the natural soil near it or collected and released at another location.

Sand filter

A sand filter provides treatment of N as well as metals and, to a lesser extent, pathogens (CRMC and RIDEM, 2009). Sand filters can be designed as surface, underground or perimeter systems. The main disadvantages of a sand filter system are the high maintenance costs and the need for an effective pre-treatment system. Water flowing into the sand filter must be effectively pre-treated to remove large particles that have the potential to clog the system and subsequently necessitate expensive maintenance. Use of a sand filter for final treatment of infiltrate generated in a livestock yard should be carefully evaluated to determine if the water entering the system will be of acceptable quality for the system to handle.



Adapted from MDE, 2000

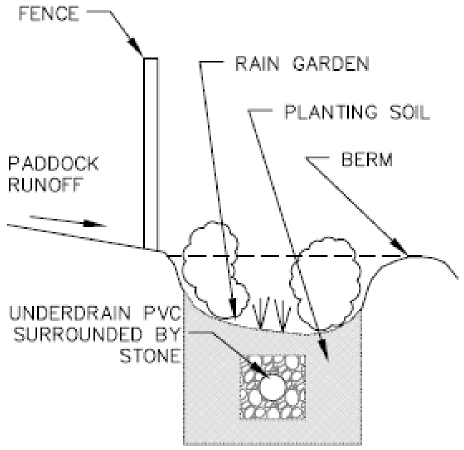
Typical schematic of a sand filter system (CRMC and RIDEM, 2009)

Bioretention or Rain Garden

Rain gardens or bioretention cells are areas where water is allowed to collect in a shallow depression and infiltrate through a conditioned planting bed into the ground or a subsurface collection system. The planting bed soils are generally supplemented with mulch or other soils.

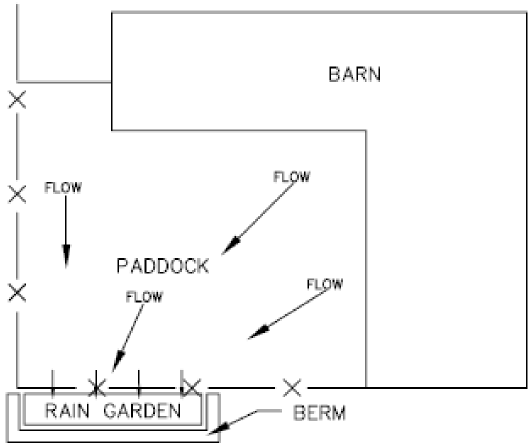
Nitrogen, P, metals and, to a lesser extent, pathogens are removed as the water infiltrates through the rain garden. The infiltrated water is then allowed to either continue infiltrating into the groundwater or is collected in an underground drainage system for transport off-site. Runoff entering the rain garden system must be pre-treated to prevent clogging, an important consideration for runoff from a livestock yard.

Rutgers University is using a rain garden on their horse farm to treat water coming from a paddock. Runoff from the horse paddock flows over adjacent grassed areas, offering pre-treatment, before discharging into a stone lined inlet and ultimately into the rain garden. The rain garden consists of a depression approximately 2 feet deep filled with 1 ft of crushed stone, covered with landscaping fabric and 6 inches of soil and approximately 3 inches of hard wood mulch (Walsh, 2009). The rain garden also receives roof top runoff from the adjacent barns via an underground discharge pipe. Most of the roof runoff is infiltrated in the perforated drainage pipes leading from the barn to the rain garden before entering the rain garden.



RAIN GARDEN CROSS SECTION

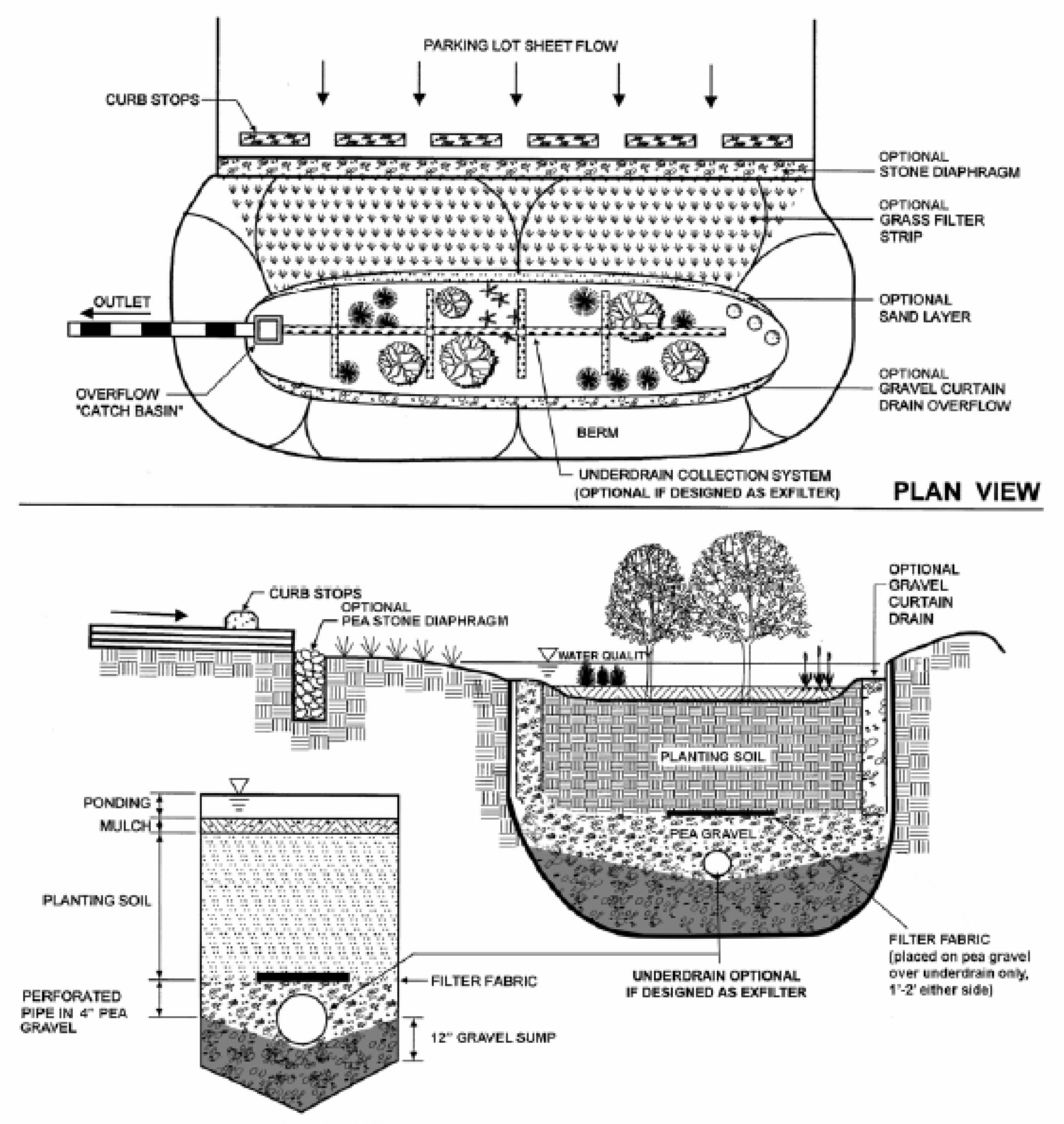
NOT TO SCALE



RAIN GARDEN PLAN VIEW

NOT TO SCALE

Rutgers University Rain Garden
(http://www.escrutgers.com/rlp/water_management.htm, Rutgers, 2009)



Typical rain garden schematic (CRMC and RIDEM, 2009)

4.0 CASE STUDY – PECKHAM FARM

4.1 OVERVIEW

The University of Rhode Island's cattle handling training paddock at Peckham Farm was selected as a test location for the implementation of LID methods for reducing the runoff from heavy-use livestock yards. The Peckham Farm site was not ideal due to expected soil surface clogging associated with cattle operations, but it was the only option available and did provide an opportunity to move through all the site assessment, design, installation and evaluation procedures needed to gain experience with the adaption of LID methods for heavy-use livestock areas. It was selected only after extensive efforts to locate a cooperator with horse operations within Rhode Island failed to generate a pilot site where LID methods could be implemented within the project timeframe. LID methods currently in use on developing lands throughout the Northeast were adapted for use in heavy-use livestock areas in Rhode Island.

The methods sought to enhance infiltration and reduce the extent of overland flow – particularly from common storm magnitudes that constitute the vast majority of precipitation events and the bulk of annual precipitation. Enhancement of infiltration should lead to reduced volumes of polluted runoff from heavy-use livestock areas. Reduced runoff volumes should permit the use of smaller treatment and storage volumes for waste lagoons or wastewater treatment strips, thereby improving the costs and efficiency of land-based treatment systems.

In the summer of 2008, two types of bioinfiltration filters were constructed and evaluated at a cattle paddock at the University of Rhode Island Peckham Farm. The first was a highly permeable gravel-filled geo-grid overlying 10" of highly uniform coarse sand. The second was a geotextile fabric (the "Cow Carpet") topped with a high-permeability gravel. Both filters were installed in strips along the heaviest-use area of the cattle paddock that is used to train Animal Science majors at URI's Peckham Farm. The surface of both filters was visually scored for wetness, muddiness and surface condition and compared to an untreated reference zone within the same paddock on regular intervals (i.e. after storm events) for approximately 15 months.

In addition, the geo-grid system was underlain by a collection trough above an impermeable liner to permit transport, collection and monitoring of the quality and quantity (tipping bucket that triggered a counter) of the resulting leachate. This leachate was then directed to a gravity-fed woodchip-filled bioreactor. The final leachate could be sampled for water quality before discharging into a subsurface disposal trench. The woodchip bioreactor is a management practice being investigated in tile drained croplands that is intended to promote denitrification and reduce nitrate-N levels (See Section 3.3.3 Infiltrate Treatment Options).

After initial construction and after maintenance to remove top layers manure-soil mixture performed in August 2009, infiltration on the area with LID practice improved based on visual observations compared to the untreated portion of the livestock area. However, over time with cow activity at the site, water logging of surface soils in the area of the LID practice occurred. Over our time of sampling February to November 2009, only 1.1 to 12.6 % of the rainfall, calculated with Kingston rain station data and site dimensions, actually infiltrated and flowed into the collection trough – indicating that most of the water was still running off the site or infiltrating elsewhere. Water that was able to infiltrate into the bioreactor exhibited a high level of treatment, with nitrate-N and TN levels dramatically decreasing.

The enhanced infiltration method appears to be promising, but the type of animal placed in the infiltration area is extremely important. Our results indicate that these methods should not be recommended for cattle or cow heavy-use areas as the manure composition and management result in a compacted livestock yard surface that reduces infiltration rates rapidly following installation and cleaning. This method may be acceptable for horses and other smaller animals such as goats. Our bioreactor results were promising for reducing off-site nitrate contamination. Where infiltration of runoff on the site is enhanced in a meaningful fashion the bioreactor should reduce nutrient and pathogen concerns from the livestock yards.

Initial view of the project site. Note that there is little vegetation within the paddock area. This is typical of a heavy-uselivestock area.

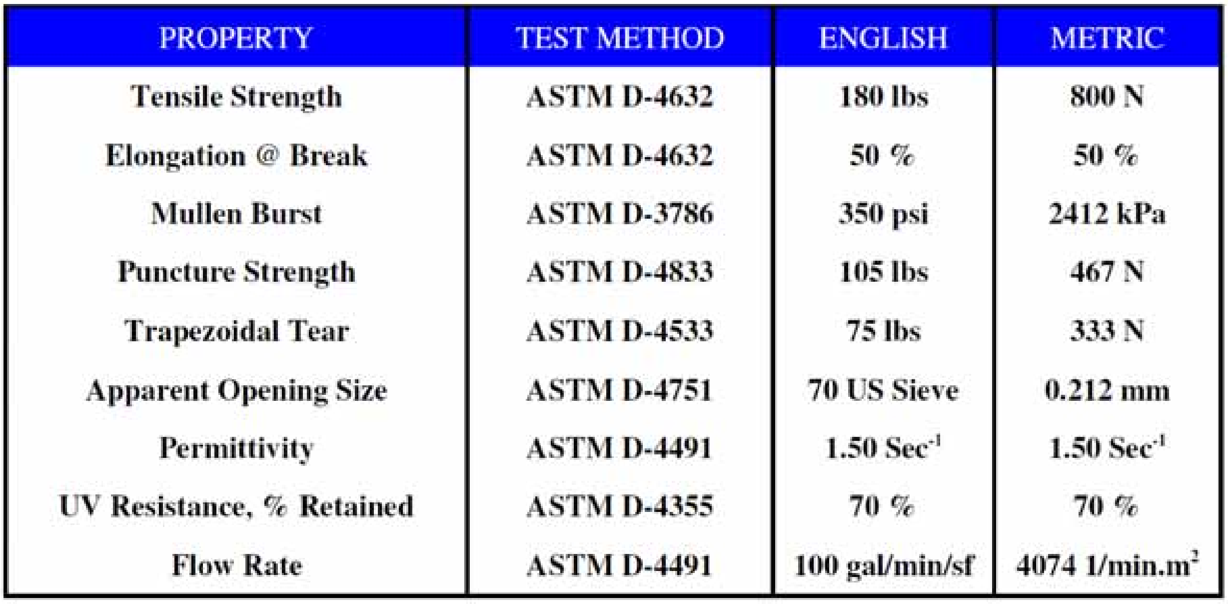
The grassy area between the fence and road was utilized for placement of the woodchip filled bioreactor.

4.2 CONSTRUCTION DETAILS

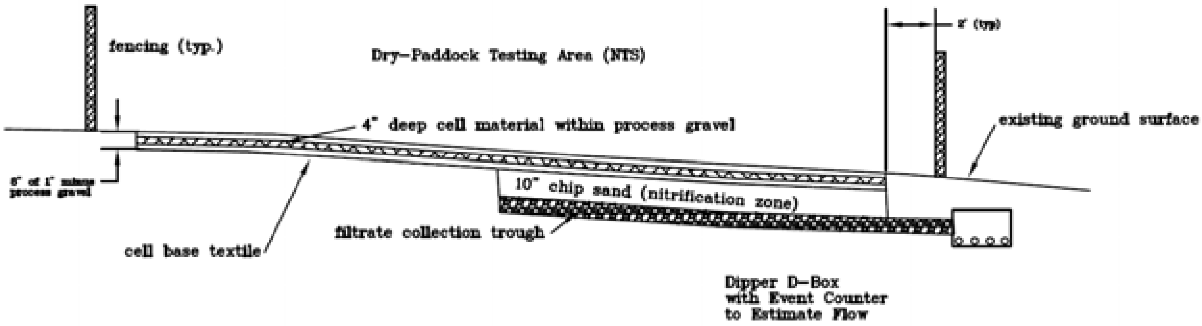
Two test areas in the most heavily used areas of the livestock yard were selected for placement of enhanced infiltrative systems. The first test strip consisted of three Agriweb geo-grid panels, approx. 9’2” wide X 19’5” long X 4” deep that were placed lengthwise to create a 60’ strip that ran slightly down-gradient along the northern edge of the paddock, where feeding and water troughs make this area prone to heavy-use. The geogrids sit on a non-woven geofabric, allowing for separation of materials. The geo-grids were filled with a high-uniform media (3/4" minus process gravel) and topped with an additional 4” of the same media. Below the non-woven geofabric, an additional 10" of chip sand were *(Details of SAND QUALITY to be added to final doc)* placed underneath to assist in filtration and nitrification. The lower 30’ of this geo-grid strip is underlain by a collection system, constructed of a 4” X 30’ perforated PVC pipe around clean pea stone with a 6’wide impermeable liner underneath. This transports the leachate into a tipping bucket fitted with an event counter, allowing for volume estimates and sampling before entering the bioreactor. The leachate then flows into an impermeable woodchip-filled bioreactor (3' wide X 2' deep X 7 ½' long) trench, that is located immediately outside of the paddock. The bioreactor trench was intended to provide the retention time and carbon source necessary to reduce nitrate levels via the process of denitrification. A sample port was incorporated into the outlet of the bioreactor in order to determine any changes in nutrient content within the bioreactor. The treated leachate is then discharged into the subsoil through a pipe-on-stone dispersal trench (3' X 6" X 12').

A second test strip, approx. 15' wide X 60' long, was constructed adjacent to the first, without the geogrid panels, chip sand, or collection trough. Instead, a NRCS Class 1 non-woven geofabric (US Fabrics "Cow Carpet") was used on its own to create a barrier between the 8" of aggregate on top and the soil below. The "Cow Carpet" (US 180NW) is a non-woven needle punched geotextile made from 100% polypropylene staple filaments. This same non-woven fabric was used to underlay the Agriweb geogrids in the first strip. The purpose of the Cow Carpet is to permit farmers and NRCS to gain awareness of the decrease in surface wetness (a surrogate for enhanced infiltration) that might result from a simpler and cheaper alternative to the geo-grid and media replacement.

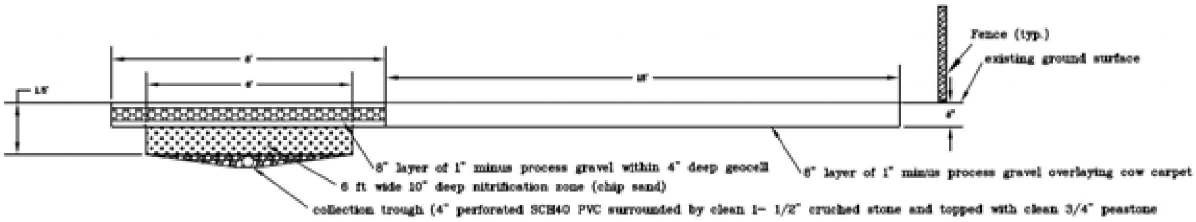
Cow Carpet Specifications (as taken from their cow_carpet.pdf)



PROPERTY	TEST METHOD	ENGLISH	METRIC
Tensile Strength	ASTM D-4632	180 lbs	800 N
Elongation @ Break	ASTM D-4632	50 %	50 %
Mullen Burst	ASTM D-3786	350 psi	2412 kPa
Puncture Strength	ASTM D-4833	105 lbs	467 N
Trapezoidal Tear	ASTM D-4533	75 lbs	333 N
Apparent Opening Size	ASTM D-4751	70 US Sieve	0.212 mm
Permittivity	ASTM D-4491	1.50 Sec^{-1}	1.50 Sec^{-1}
UV Resistance, % Retained	ASTM D-4355	70 %	70 %
Flow Rate	ASTM D-4491	100 gal/min/sf	4074 1/min.m^2



Schematic of Dry-Paddock Testing Area



Section of the deeper area of the dry-paddock design

Test area installation images

Areas where livestock yard will be retrofitted are outlined in white

Excavation of area to be retrofitted

First test area is excavated and an impermeable liner is placed along the native soils. A drainage pipe is then placed along the middle of this cut to collect water infiltrating through the system. Crushed stone is placed over and around the drainage pipe over which geotextile is placed. Chip sand is placed over this geotextile (see image) and separated from the overlying geogrid system by another layer of geotextile.

Process gravel is placed over the geotextile, the geogrid system is then placed and backfilled with additional process gravel.

The second text area is retrofitted by placement of geotextile over the native soils and then backfilling with process gravel.

The final test infiltrative areas after both systems are installed.

Another view of the final installation

Water infiltrating into the first retrofitted area with the drainage pipe will flow into a woodchip bioreactor. The bioreactor consists of an impermeable geotextile liner filled with woodchips. Its function is to denitrify the infiltrating water.

Woodchips utilized in the bioreactor

Once filled with woodchips, the bioreactor is backfilled with native soils.

The bioreactor outlet is placed into a bed of crushed stone overlain by geotextile and soils.

The bioreactor influent can be sampled from the distribution box which is accessed from the manhole.

4.3 RESULTS

To test the effectiveness of the bioinfiltration study at URI Peckham Farm, we wanted to address two questions:

1. Did the enhanced infiltration system enhance runoff infiltration into the ground? If not, what were the factors that diminished its effectiveness?
2. Did the bioreactor reduce nutrient loads in the groundwater?

To answer the first question, we used the Kingston, RI rain gauge data to determine the volume of rainfall that fell within the modified area. We compared the total volume from rainfall with the quantity of water that then infiltrated into the ground and passed into the bioreactor. Infiltrated volume was recorded through the use of a counter connected to a tipping bucket. Each bucket tip was equal to 0.165 ft^3 of water. The volume of infiltrated water in each bucket tip, expressed as a mean depth across the drainage area (12.5 ft X 32 ft) of the site, represented a depth of 0.005 in of rainwater. We could then divide the inches of water infiltrated by the inches of rain to determine the percentage of water infiltrated. We monitored 14 rain events between April to May of 2009 and between September to November of 2009. The mean percentage of rain infiltrated into the bioreactor was 6.6% (3.0 S.D., Table 4). We can not simply conclude that the remainder was lost in surface runoff since we did not measure losses from evaporation. Visual observation of the surface soil in the paddock was that it was mucky with manure and feed waste accumulated – with minimal differences between the zones with and without enhanced infiltration. The muck and feed waste layer was scraped off, removing the manure/soil slurry, at the end of April 2009 and again in August 2009. The condition of the field was drier following site scraping but returned to mucky conditions almost immediately when the cows returned to the site in September 2009. More details on the animals and management of the livestock yard can be found in Appendix A. It appears that the texture of the manure and the hoof action of the cows prevented the enhanced infiltration system from working effectively.

Table 4. Infiltration and rainfall depth on the Peckham Farm Enhanced Infiltration Pilot Study during various monitoring periods.

Date	# of tips	Infiltration (in)	Rainfall (in)	% of rain infiltrated*
4/13/09	5	0.025	0.62	4.0
4/30/09	1	0.005	0.07	7.1
5/1/09	2	0.010	0.21	4.7
5/5/09	4	0.020	1.88	1.1
9/11/09	1	0.005	0.25	5.9
9/28/09	5	0.025	0.71	3.5
10/2/09	9	0.045	1.68	2.7
10/5/09	8	0.040	1.41	2.8
10/7/09	2	0.010	0.23	4.3
10/20/09	8	0.040	1.94	2.0
10/26/09	10	0.050	1.54	3.2
11/3/09	25	0.124	1.41	8.8
11/20/09	42	0.208	1.65	12.6
11/24/09	12	0.059	0.95	6.3

*Loss to surface runoff is less than expected from the difference between rainfall and infiltration, since losses to evaporation were not accounted for.

We collected groundwater samples above and below the wood chip bioreactor on numerous occasions between February to May 2009 and September to November 2009. We analyzed these samples for NO_3-N, Total N (TN), NH_4-N, Dissolved P (DP) and Total P(DP) (Table 5). Most of the N was in the nitrate-N form (nitrate-N range: 57 to 237 mg N/L in the samples from above the wood chip bioreactor). The presence of N mostly as nitrate-N is evidence that the infiltration system generated aerobic conditions and performed that function as expected.

Tipping bucket and groundwater sampling port upgradient of wood chip bioreactor at URI Peckham Farm

Groundwater sampling port downgradient of wood chip bioreactor at URI Peckham Farm.

Mean (S.D.) nitrate-N and TN removal rates were 93% (11%) and 86% (9%), respectively. In the winter and spring of 2009, ammonium-N concentrations were below our detection limits. In fall of 2009, ammonium-N concentrations of the bioreactor inflow and outflow ranged from 80 to 140 µg N/L and 40 to 1,680 µg N/L, respectively. In some cases there was a gain in ammonium-N in the bioreactor outflow, but we generally observed ammonium-N removal rates from 46.7 to 80.6%. Inflow concentrations of DP and TP ranged from 130 to 690 µg P/L and 260 to 4,910 µg P/L, respectively. Outflow concentrations of DP and TP ranged from 16 to 690 µg P/L and 600 to 5,500 µg P/L respectively. On a few occasions we observed DP removal through the bioreactor, but we also noted gains in DP. We never observed TP removal through the bioreactor – in line with other studies.

Due to the sampling design, we were unable to collect a sterile water sample from the bioreactor outflow. In Table 6, we report the inflow total coliform bacteria counts, which in most cases are elevated– but much higher in the fall 2009 when up to 9 heifers occupied the paddock as compared with winter/spring 2009 when no more than 3 heifers were on the paddock. At high stocking rates with cows, the enhanced infiltration techniques were not able to generate dramatic decreases in the levels of total coliform. The spring data, with lower stocking rates provide more promising indications that the filtration and aerobic environment with the amended media and geogrid can reduce total coliform. Unfortunately, we are unable to report on the bacterial reduction generated from within the bioreactor. However, other research indicates that it such wood-chip bioreactors may reduce bacterial loads. Robertson et al. (2005) found that *E. coli* levels generally remained below detection in a bioreactor treating septic tank effluent. In other systems, Larney et al. (2003) found that more than 99.9% of total coliform and *E. coli* was eliminated within seven days of composting cattle manure from feedlot pens with cereal straw or wood chips. Jowett and McMaster (1995) tested an on-site wastewater treatment system using a sphagnum peat biofilter with 87.8% and 96.8% reduction in total coliform and fecal coliform, respectively. Another peat based system for on-site wastewater treatment demonstrated more than 99% reduction in fecal coliforms (Talbot et al., 1996).

Table 5. Nutrient Removal through bioreactor at URI Peckham Farm.

Date	% Nitrate-N removed	% Total N removed	% Ammonium-N removed	% Dissolved P removed	% Total P removed
2/27/09	97.8		No detect	-	
2/28/09	95.1		No detect	-	
3/7/09	67.2	71.2	No detect	-	-
3/9/09	98.2	77.1	No detect	-	-
4/10/09	60.7		No detect	-	-
4/11/09	97.1	84.4	No detect	-	
4/13/09	73.1	87.7	No detect	14.9	-
4/30/09	84.0	87.0	No detect	-	-
5/1/09	98.4	85.9	No detect	10.8	
5/5/09	80.2	86.7		-	-
5/8/09	97.7	84.8		-	-
9/10/09	99.0	90.3	80.6	-	-
9/11/09	100.0	95.4	-*	-	-
9/16/09	99.9	88.6	44.5	84.2	-
9/16/09	99.9	88.5	-		-
9/17/09			-		-
9/22/09	100.0	94.7	46.7	91.3	-
9/24/09	99.6	96.1	49.9	86.1	-
9/29/09	100.0	66.0		-	-
10/5/09	99.4	89.7	-	95.6	-
10/7/09	99.3	87.1	-	80.3	-
10/13/09	98.9	86.0	-	-	
10/20/09		76.7	-	58.4	-
10/26/09	99.2	81.6	-	91.6	-
11/20/09	99.4	68.7	-	55.0	-

* “-“ indicates higher nutrient concentration in the bioreactor outflow than inflow.

Table 6: Bacterial counts in infiltrated water entering the bioreactor

Spring Date	Total Coliform Forming Units (CFU)/100 ml water	Fall Date	Total Coliform Forming Units (CFU)/100 ml water
2/27/09	2,2 x 10^3	9/11/09	2.4 x 10^4
2/28/09	6 x 10^2	9/16/09	4.7x 10^4
3/7/09	8 x 10^3	9/22/09	4.4 x 10^4
3/9/09	1.8 x 10^4	9/23/09	1.2 x 10^5
4/10/09	--	9/24/09	3.7 x 10^5
4/11/09	1.4 x 10^3	9/28/09	1.3 x 10^5
4/13/09	3.0 x 10^2	10/1/09	2.5 x 10^5
4/30/09	1.5 x 10^3	10/6/09	2.9 x 10^5
5/1/09	7.0 x 10^2	10/9/09	2.5 x 10^5
5/5/09	3.0x 10^2	10/23/09	1.7 x 10^5
5/8/09	7.0 x 10^2	11/20/09	1.8 x 10^5
		10/23/09	1.9 x 10^5

4.4 CONCLUSION

In our case study test of enhanced infiltration design in a heavy-use cow livestock area, the technique did not dramatically generate infiltration into the subsurface. However, the water that was infiltrated and passed through the bioreactor had a dramatic decrease in nitrate-N levels. We suggest that this enhanced infiltration – bioreactor design may be quite effective in reducing stormwater runoff and nitrate-N loads from heavy-use livestock areas populated with other animals than cow/cattle. Cow/cattle operations are not recommended for the type of enhanced infiltration techniques discussed in this report.

References Cited

Baker, M.J., D.W. Blowes, and C.J. Ptacek. 1998. Laboratory development of permeable reactive mixtures for the removal of phosphorus from onsite wastewater disposal systems. Environmental Science and Technology 32: 2308-2316.

Burdette, H.K. and W.M. Sullivan. 2005. Livestock on Small Acreages, Fact sheet 1 and Livestock yards and Manure Storage Areas on Small Acreages, Fact sheet 2; Small Acreage Livestock Series.

Cameron, S.C. and L.A. Schipper. In press. Nitrate removal and hydraulic performance of carbon substrates for potential use in denitrification beds. Ecological Engineering.

CRMC and RIDEM. 2009. Public Review Draft - Rhode Island Stormwater Design and Installation Standards Manual.

Eghball, B., B.J. Wienhold, J.E. Gilley and R.A. Eigenberg. 2002. Mineralization of manure nutrients. Journal of Soil and Water Conservation 57: 470-473.

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. Transactions of the American Society of Agricultural and Biological Engineers 51:675-684.

Greenan, C.M., T.B. Moorman, T.C. Kaspar, T.B. Parkin and D.B. Jaynes. 2006. Comparing carbon substrates for denitrification of subsurface drainage water. Journal of Environmental Quality 35:824-829.

Jaynes, D.B., T.C.Kaspar, T.B. Moorman, and T.B. Parkin. 2008. In situ bioreactors and deep drain-pipe installation to reduce nitrate losses in artificially drained fields. Journal of Environmental Quality. 37: 429-436.

McCullough, M.C., D.B. Parker, C.A. Robinson and B.W. Auvermann. 2001. Hydraulic conductivity, bulk density, moisture content, and electrical conductivity of a new sandy loam feedlot surface. Applied Engineering in Agriculture. 17:539-544.

McDowell, R.W., A.N. Sharpley, and W. Bourke. 2008. Treatment of drainage water with industrial by-products to prevent phosphorus loss from tile-drained land. Journal of Environmental Quality 37:1575-1582.

Mielke, L.N., N.P. Swanson and T.M. McCalla. 1974. Soil Profile Conditions of Cattle Feedlots. Journal of Environmental Quality 3:14-17.

Miller, J.J., T. Curtis, F. Larney, B. Olson, T. McAllister and B.M. Olson. 2008. Physical and chemical properties of feedlot pen surfaces located on moderately coarse- and moderately fine-textured soils in southern Alberta. Journal of Environmental Quality 37: 1589-1598.

Jokela, B., F. Magdoff, R. Bartlett, S. Bosworth, and D. Ross. 2004. Nutrient Recommendations for Field Crops in Vermont. The University of Vermont Extension.

Jowett, E.C. and M.L. McMaster. 1995. On-Site wastewater treatment using unsaturated absorbent biofilters. Journal of Environmental Quality 24:86-95.

Larney, F.J., L.J. Yanke, J.J. Miller, and T.A. McAllister. 2003. Fate of coliform bacteria in composted beef cattle feedlot manure. Journal of Environmental Quality 32:1508-1515.

Olson, B.M., J.J. Miller, J. Rodvang and L.J.Yanke. 2005. Soil and groundwater quality under a cattle feedlot in Southern Alberta. Water Quality Research Journal Canada 40:131-144.

Pachepsky, Y.A., A.K. Guber, D.R. Shelton and O.T. Yu. 2007. Effect of manure on fecal coliform attachment to soil and soil particles of different sizes. Applied and Environmental Microbiology 73:3363-3370.

Pennsylvania's Small Scale Livestock Committee. 2002. Factsheet: Mud Management for Small Scale Livestock Operations.

Robertson, W.D. 2000. Treatment of wastewater phosphate by reductive dissolution of iron. Journal of Environmental Quality 29:1678-1685.

Robertson, W.D., D.W. Blowes, C.J. Ptacek, and J.A. Cherry. 2000. Long-term of performance of in situ reactive barriers for nitrate remediation. Ground Water. 38:689–695.

Robertson, W.D., G.I. Ford, and P.S. Lombardo. 2005. Wood-based filter for nitrate removal in septic systems. Transactions of the American Society of Agricultural Engineers 48:121-128.

Robertson, W.D., C.J. Ptacek, and S.J. Brown. 2009. Rates of nitrate and perchlorate removal in a 5-year-old wood particle reactor treating agricultural drainage. Ground Water Monitoring and Remediation 29:87-94.

Robertson, W.D., J.L. Vogan, and P.S. Lombardo. 2008. Nitrate removal rates in a 15-year old permeable reactive barrier treating septic system nitrate. Ground Water Monitoring and Remediation 28:65-72.

Schipper, L.A., G.F. Barkle, and M. Vojvodic-Vukovic. 2005. Maximum rates of nitrate removal in a denitrification wall. Journal of Environmental Quality 34: 1270-1276.

Schipper, L.A., W.D. Robertson, A.J.Gold, D.B. Jaynes, and S.C. Cameron. In press. Denitrifying bioreactors - an approach for reducing nitrate loads to receiving waters. Ecological Engineering.

Schipper, L.A. and M. Vojvodic-Vukovic. 2001. Five years of nitrate removal, denitrification and carbon dynamics in a denitrification wall. Water Research. 35:3473–3477.

Talbot, P., G. Belanger, M. Pelletier, G. Laliberte and Y. Arcand. 1996. Development of a biofilter using an organic medium for on-site wastewater treatment. Water Science and Technology 34:435-441.

USDA, NRCS. 1992. Agricultural Waste Management Field Handbook.

USDA, NRCS, Part 651 – Agricultural Waste Management Field Handbook, March 2008, 210-V1-AWMFH.

Walsh, Sean. Rutgers University, Environmental Science Dept. Personnel communication on September 17, 2009.

Warneke, S., L.A. Schipper, D.A. Brusewitz, I.R. McDonald, and S.C. Cameron. In press. Nitrate removal and its controlling factors in a denitrification bed. Ecological Engineering.

APPENDIX A

URI Peckham Farm – Enhanced infiltration system for livestock yard.

Management Timeline

- Installed end of August 2008
- Hay Feeder placed directly over center of geo-textile and gravel strip – September 2008.
- Early September through end of October 2008: 10 dairy heifers (approx. 500 – 750 lbs. each)
- Early November through Thanksgiving, 2008: 9 beef cattle (600 – 700 lbs. each)
- January 12th – February 20th 2009: 9 dairy heifers (500 – 750 lbs. each)
- Feb. 20th – April 13th 2009: livestock yard vacant
- April 13th – April 24th 2009: 4 beef cattle (600 – 700 lbs. each)
- **April 24th – May 1st 2009: Livestock yard vacant - feeder removed from center of geo-textile and gravel strip. A layer of manure and feed waste had built up since September 2008 and was scraped off during this time.**
- May 1st – end of May 2009: 3 heifers (mixed dairy and beef)
- June – End of July 2009: 3 heifers and 3 goats
- August 1st – September 1st 2009: 11 sheep
- September 11, 2009: Hay feeder placed back over center of geo-textile and gravel strip:
- September 11 – October 7, 2009: 9 dairy heifers (approx. 500 – 750 lbs. each)
- October 10 – 13th, 2009: 4 dairy cows
- October 19th – November 19th, 2009: Beef cattle
- November 19th – December 15th, 2009: 3 heifers and 4 goats.