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EVALUATING THE EFFECTIVENESS OF WEEP BERM SYSTEMS FOR TREATING RUNOFF FROM A HORSE MUCK COMPOSTING OPERATION

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EVALUATING THE EFFECTIVENESS OF WEEP BERM SYSTEMS FOR
TREATING RUNOFF FROM A HORSE MUCK COMPOSTING OPERATION

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Biosystems and Agricultural Engineering in the College
of Engineering at the University of Kentucky

By

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Lexington, Kentucky

2012

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ABSTRACT OF THESIS

EVALUATING THE EFFECTIVENESS OF WEEP BERM SYSTEMS FOR TREATING RUNOFF FROM A HORSE MUCK COMPOSTING OPERATION

Two contour weep berms systems were designed and implemented to evaluate their performance at mitigating water quantity problems from a horse muck composting operation. The field-scale study focused on the hydrologic response of a standard contour weep berm and a modified contour weep berm. The modified contour weep berm incorporated a woodchip trench upgradient of a typical standard contour weep design. Monitoring occurred from July 2011 through spring 2012. Eight storm events produced measureable runoff for the standard contour weep berm; however, only five storm events produced measurable runoff for the modified contour weep berm. The largest storm event occurred on November 27, 2012 with rainfall depth of 49.0 mm. This storm event generated a total runoff volume of 183.1 m³ and 188.5 m³ for the standard and modified contour weep berms, respectively. All runoff produced from the storm events during the monitoring period was completely detained and infiltrated. No runoff was released from the horse muck composting facility through the passive dewatering system to down-gradient vegetative filter strips during the monitoring period.

KEYWORDS: Hydrology, Infiltration, Cumulative Frequency, Horse Muck, Composting,

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December 14, 2012

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For my family, especially my Papaw

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The Commonwealth of Kentucky is blessed with natural resources, particularly waterways. Kentucky has more than 143,000 km of rivers and streams and over 5,235 km² of lakes and wetlands within and along its borders. Protecting these natural resources is of great importance to the state as these waterbodies are used as drinking water sources, tourist destinations, and mediums for transportation among other things. Nonpoint source pollution (NPS), which is pollution originating from diffuse sources, is the largest impairment to the quality of Kentucky's waterbodies (KYDOW; USEPA, 2012). The agricultural industry has been identified as one of the largest contributors to NPS in the state in part due to runoff exposed to animal wastes. This exposure occurs largely from the land application of wastes but also occurs when rain is exposed to stored manure.

In central Kentucky, the storage and management of horse muck is of particular concern due to the high numbers of horses within this region. It is estimated that Kentucky as a whole has over 200,000 horses from racing Thoroughbreds to pleasure horses (USDA, 2009). Each horse is estimated to produce over 50 lbs of waste and up to 20 lbs of bedding per day (Higgins et al., 2008). Annually, Kentucky horse farms produce an estimated 1.8 million tons of manure and urine, not including bedding. The type of bedding used will vary based upon the type and size of the farm. A standard Thoroughbred operation will use straw or hay for bedding while sport horse operations will use wood shavings or sawdust.

Disposal of waste and used bedding is often done via land application, storage piles, or shipping the materials offsite. Land application is frequently done as it is the most economical; however, the amount of muck applied to the land is limited by soil nutrient requirements and available land. With the high price of real estate in central Kentucky, many operations do not have sufficient land area to dispose of the horse muck their operation generates. Some facilities place their horse muck in storage piles. Unfortunately, these piles degrade slowly. Runoff from the piles is also a concern due to nutrient and pathogen levels. Other operations transport all or a portion of their horse muck offsite for composting or repurposing (e.g. baling for landscape applications). Offsite transport is costly particularly as the price of fuel increases.

Due to these challenges, some horse operations are now turning to onsite composting as a means of disposing of their horse muck. Horse muck composting involves the conversion of a waste product into a useful soil amendment. This soil amendment can be applied to fields during the growing season, or horse operations can sell the finished product. Composting is feasible for small operations (1-3 horses) as well as large ones. For operations with larger numbers of horses, and hence more horse muck with which to contend, windrow composting is a feasible option (Higgins et al., 2008). In central Kentucky, these windrow composting operations are often established on an unlined grass field near barns housing the horses. Frequent equipment traffic from the placement of horse muck, windrow turning, watering, and the removal of finished compost compacts the land in between the windrows meaning runoff volumes and peaks may increase from this land use change.

Runoff from these composting fields is normally uncontrolled. This is of concern as this runoff likely contains high levels of nutrients and pathogens. If a control system is used, it is likely a vegetative filter strip (VFS) that unfortunately is frequently mowed to maintain a landscaped appearance. Frequent mowing reduces the trapping efficiency of the VFS due to low vegetation height and soil compaction from frequent equipment and human traffic. Also, this mowing can create preferential flow paths in VFSs through repeated patterns and tire ruts. Preferential flow paths on the surface create concentrated flow versus diffuse flow; hence, treatment efficiency is reduced.

One method of reducing runoff quantity or volume and peaks from these horse muck composting operations is to use a weep berm system. As discussed in Chapter 2, weep berms have been successfully used largely in the construction and mining industries to control runoff volume and peak flows and to improve water quality. It may be possible to further improve water quality treatment, particularly of nitrogen and phosphorus, through the incorporation of a wood chip trench.

1.2 OBJECTIVES

Research was conducted to design, implement and evaluate the hydrologic performance of two different contour weep berm systems at the Victory Haven Training Center, which is

located in Lexington, KY. Data acquisition and analysis focused on accomplishing the following three objectives:

1. Design and implement a standard and modified contour weep berm at a horse manure composting facility (Chapter 2).
2. Conduct a cumulative rainfall frequency analysis for Lexington, KY (Chapter 3).
3. Evaluate the hydrologic performance of a standard contour weep berm and a modified contour weep berm (Chapter 3).
4. Compute an average curve number for a horse compost operation (windrow) located on unlined grass field with a windrow composting operation (Chapter 3).

1.3 ORGANIZATION OF THESIS

Chapter 1 is an overview of the research problem and objectives. Chapter 2 provides a detailed description of work to satisfy objective 1. Chapter 3 provides a detailed description of work to achieve objectives 2, 3, and 4. Future work is discussed in Chapter 4.

CHAPTER 2: CONTOUR WEEP BERM DESIGN PROCEDURE

2.1 INTRODUCTION

Runoff (i.e. excess precipitation) transports pollutants from terrestrial systems to down-gradient lakes, rivers, streams, and other water bodies. Pollutants acquired and transported from agriculture, construction, and urban runoff include fertilizers, grease, herbicides, insecticides, nutrients, oil, pathogens, sediments, and heavy metals (USEPA, 1996). As of 2010, 53% of rivers and streams and 69% of lakes surveyed were impaired in the United States (USEPA, 2012). The USEPA (2012) found that the three leading contributors to stream and river impairment are pathogens, sediments, and nutrients while mercury, nutrients, and PCBs (polychlorinated biphenyls) are the leading contributors to lake impairment.

Nonpoint source pollutants (NPS) impair water bodies through various means. Pathogens enter runoff through contact with feces from domesticated animals, wildlife and stored and composted horse muck amongst other things. Pathogen levels exceeding regulatory standards based on desired use can result in human illness (drinking water standards: Fecal Coliforms (FC) 0 colonies /100 mL; Primary Contact Waters: FC 200 colonies/100 mL; Secondary Contact Waters: FC 1,000 colonies/100 mL) (401 KAR 10:031. Section 7). These pathogens can be ingested through drinking, recreational activities, or other forms of water contact. NPS pollution can also contribute high levels of sediment, which can negatively affect aquatic life. High sediment loads reduce fish spawning rates, hunting success, and can result in death of fish and other aquatic organisms (Walters, 1995; Wood and Armitage, 1997; Henley et al., 2000; Sutherland et al., 2012). Sedimentation also decreases the operational life of reservoirs and increases costs for municipal water supplies (Wood and Armitage, 1997). Sediment is also linked to various nutrient problems. Nutrients can adhere to sediment particles until soil chemistry allows nutrient release based on water, sediment and atmospheric conditions (Toy et al., 2002).

NPS pollution from nutrients can have major negative impacts on water quality. Nutrient loading from the eastern United States has contributed to the formation of a hypoxic zone located in the Gulf of Mexico (Goolsby et al., 1999; Goolsby and Battaglin, 2000; Powers, 2007). Excess nutrients from NPS pollution allow algal bloom formation. In

the Gulf of Mexico, sediment oxygen demand and algal formations have devoid an area of 16,700 km² of oxygen (Turner et al., 2008). High nutrient loads from NPS have also lead to eutrophication in lakes. Eutrophication can negatively impact aquatic life and, in severe cases, destroy all aquatic life. Eutrophication occurs when excess nitrogen or phosphorous are added to a water body when the concentration of nitrogen and/or phosphorus was once absent or very low (i.e. limiting meaning their low concentration or absence prevented algal growth). Determining whether nitrogen or phosphorus is the limiting nutrient will typically depend on the type and size of a water body. For areas dominated by NPS pollution, phosphorus is the limiting nutrient in rivers, streams, freshwater estuaries and large lakes (Thomann and Mueller, 1987). Nitrogen is the limiting nutrient for NPS polluted saline estuaries and for many water bodies dominated by point source pollution (Thomann and Mueller, 1987). Excess nitrogen and phosphorus are not only health concerns (Santamaria, 2006) but area also economic concerns as water municipalities spend money, resources, and time to reduce sediment and nutrient levels to meet drinking water standards (Schultz et al., 1995). To lessen impacts associated with NPS pollution, best management practices are implemented.

2.2 VEGETATIVE FILTER STRIPS

Vegetative filters strips (VFS) are a simple and economical best management practice (BMP) frequently used in agriculture. Vegetated filter strips are sections of land containing grass or other plants installed amid or down-gradient of agricultural areas to reduce erosion and trap contaminants (Wenger, 1999; NRCS, 2008; NRCS, 2010). Erosion prevention and trapping of sediments occur in VFS by using the vegetation to reduce runoff velocity, which reduces erosivity and consequently facilitates the removal of pollutants in suspension through filtration and infiltration. VFS provide many benefits for remediating some of the negative effects associated with NPS pollination. Evidence of this has been shown in a simulated feedlot study where total suspended solid (TSS) reductions for orchard grass strips of 4.6 m (15 ft) and 9.1 m (30 ft), located down-gradient, averaged 81% and 91%, respectively (Dillaha et al., 1988). Dillaha et al. (1989) conducted a similar experiment down-gradient of fertilized, bare cropland using strips of 4.6 m (15 ft) and 9.1 m (30 ft) obtaining average TSS reductions of 70% and 84%, respectively. Another study using a 9.1 m (30 ft)

filter strip on a poultry waste amended site obtained a sediment reduction of 99% for one simulated rainfall event (Coyne et al., 1994). Another experiment with grass filters of widths 4.6 m (15 ft) and 9.1 m (30 ft) positioned down-gradient of liquid nitrogen or chicken waste obtained sediment reduction averages of 66% and 82%, respectively (Magette et al., 1989). These studies have shown that implementation of VFS are effective at reducing sediment loading. However, all of these studies were conducted over a short period of time with simulated loadings rates.

Long-term filter strip studies have been conducted using sediment fingerprinting techniques to determine deposition of sediment among riparian buffers. Lowrance et al. (1986) determined the highest amount of sediment deposition at 30 m (98 ft) with the largest quantity of clay particles occurring at 80 m (262 ft) based on a 21-year period. Another study showed that nearly 50% of sediment was captured more than 100 m (328 ft) into buffer strip (Cooper et al., 1988; Wenger, 1999). Copper et al. (1987) suggested that buffer strips may need to be 30-100 m (98-323 ft) wide to effectively reduce sediment. Davis and Nelson (1994) recommend a buffer strip width of 30 m (98 ft) to minimize impacts. Long-term sediment retention requires increased VFS widths to maintain sediment reduction rates after continued exposure to sediment loadings.

Studies have also been performed to evaluate the effectiveness of VFS for nutrient load reductions. Phosphorus is a major nutrient that has been studied because of its association with eutrophication. VFSs have been successful at reducing total phosphorus from simulated feedlots by 71.5% and 57.5% with orchard grass filter strips of widths 4.6 m (15 ft) and 9.1 m (30 ft), respectively (Dillaha et al., 1988). Average total phosphorus reductions on a bare, fertilized cropland were shown to be 61% for a grass filter strip of 4.6 m (15 ft) and 79% for a grass filter strip of 9.1 m (30 ft) (Dillaha et al., 1989). Another study found a total phosphorus reduction of 50%, and a soluble phosphate decrease of 20% (Daniels and Gilliam, 1986). A riparian buffer strip of 50 m (164 ft) had a 73% decline in soluble phosphate and 84% decrease in total phosphorus. Some of the above studies have indicated reductions in soluble phosphate, while other studies have observed net increases in phosphate in groundwater (Wenger, 1995). Phosphorus can exit VFS by biological uptake, absorption onto soil and organic particles, precipitation with metals, or further release into surface and groundwaters (Lowrance, 1998).

Nitrogen is another major nutrient studied with respect to reduction potentials associated with VFS. In the studies previously discussed which were conducted by Dillaha et al. (1988), total nitrogen removal rates of 67% and 74% were achieved with 4.6 m (15 ft) and 9.1 m (30 ft) grass filters from simulated animal feedlots. Total nitrogen removal rates for grass filter strips adjacent to fertilized cropland of 4.6 m (15 ft) and 9.1 m (30 ft) were 54% and 73%, respectively (Dillaha et al., 1989). Magette et al. (1989) showed average total nitrogen removal rates of 0% and 48% for 4.6 m (15 ft) and 9.1 m (30 ft) grass filter strips. Another study determined VFS reduced nitrogen by 90% with use of a 4.6 m (15 ft) strip and by 96-99.9% with use of a 9.1 m (30 ft) strip (Madison et al., 1992; Castelle et al., 1994). Vegetated filter strip effectiveness at reducing total nitrogen does not accurately represent the effectiveness at reducing nitrate in runoff. In the study conducted by Dillaha et al. (1988), nitrate levels in runoff increased in both the 4.6 m (15 ft) and 9.1 m (30 ft) grass filter strips by at least 15%. Nitrate additions in the Dillaha et al. (1988) study is speculated to be the result of nitrogen cycling from upgradient animal feedlot and overall low mean nitrate influent concentrations. In another study, a grass filter strip 27.1 m (89 ft) in width effectively removed 8% of nitrate from animal feedlot runoff (Young et al., 1980).

Vegetated filter strips are effective at reducing sediment, total phosphorus, and total nitrogen from NPS over short periods. However, soluble nutrients in runoff, like phosphate and nitrate, are not reduced or minimally reduced by VFS (Wenger, 1995). Long-term effectiveness of VFS has been questioned for nutrients and sediment. Vegetated filter strips can become saturated with nutrients and sediment over time until nutrient and sediment reductions are negligible. Vegetation removal through harvesting can potentially be used as one method to further extended VFS design life by acting as an output for nutrients. VFS effectiveness at reducing sediment and nutrients will vary based on site characteristics such as: rainfall intensity, slope, soil type, and vegetation height. While VFS can be quite effective at remediating runoff, limitations to their implementation exist, namely with input constituent concentrations and the even distribution of flow across the BMP. Runoff excessively laden with pollutants such as sediment and nutrients may require treatment methods prior to release onto VFS to extend the life and potential pollutant reduction rates of the VFS. But perhaps more important, VFS require the even distribution of runoff across the strip itself. This means that for a VFS to function as design, the runoff must enter the

system evenly distributed as sheet flow and not centralized as concentrated flow. The requirement of sheet flow is perhaps one of the greatest challenges to effectively managing VFS. The creation of preferential flow paths, whether through erosion, deposition or other means such as tire ruts from equipment, greatly diminishes the treatment effectiveness of VFS. Another limitation of VFS is that while these BMPs provide water quality benefits, they do not provide water quantity benefits. Vegetated filter strips do not reduce discharged volumes or peaks.

2.3 CONTOUR WEEP BERM

One way to overcome the difficulties of establishing and maintaining sheet flow in VFS and to provide water quantity benefits in the form of reduced the volume and peak of runoff is through a contour weep berm. A contour weep berm is an innovative BMP, which combines VFSs or a forested riparian buffer in combination with an experimental structure providing runoff control (Figure 2.1). Currently there are two types of weep berms in operation: contour and gradient. Gradient weep berms are employed in mining operations and will not be further discussed (Warner et al., 2012). Contour weep berms are low earthen berms constructed with a passive dewatering system in conjunction with a down-gradient vegetative filter strip (VFS) or riparian buffer perpendicular to runoff (Figure 2.2). A contour weep berm intercepts, stores, and infiltrates all runoff from storm events below a designated quantity. Runoff from larger storm events not exceeding the contour weep berm crest will be intercepted allowing sediment and nutrients to settle out of suspension before being infiltrated and partially released through a passive dewatering system to the VSF. Storm events with runoff exceeding the crest elevation will exit by infiltration, a passive dewatering system, and over the crest, which mimics a long broad crested weir.

Contour weep berms have been implemented for NPS pollution from construction sites and agricultural lands. At construction sites, contour weep berms have been shown to be 100% effective at reducing sediment runoff (Sturm et al., 2007). In addition, in simulated agricultural runoff, a contour weep berm was effective at trapping 96% of all effluent (Barnett et al., 2010). This study also showed that a contour weep berm is effective at decreasing nutrient concentrations in runoff. But the authors found that the contour weep

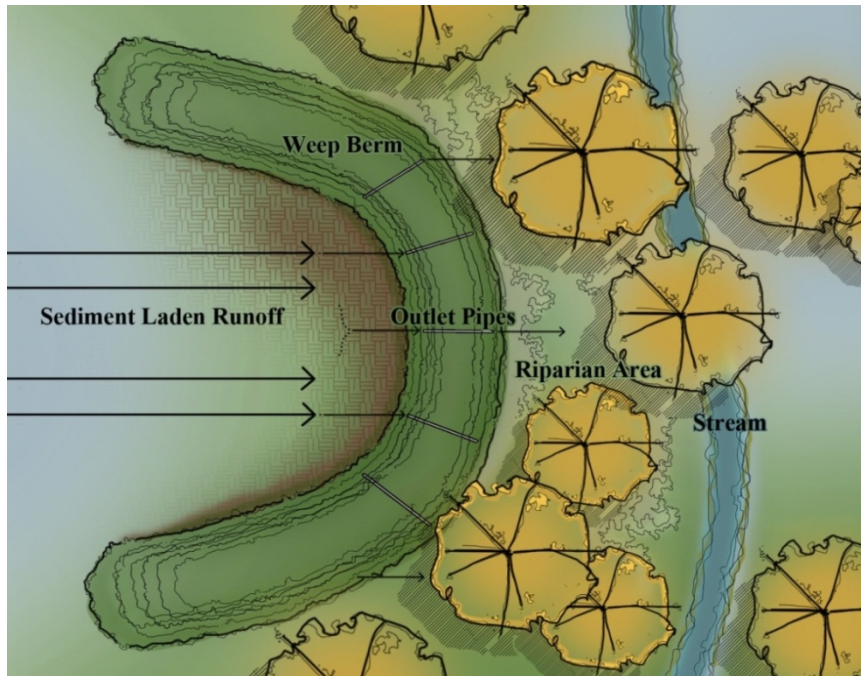


Figure 2.1: Contour Weep Berm in Conjunction with a Riparian Buffer Treatment System.

Source: Warner et al. (2012).

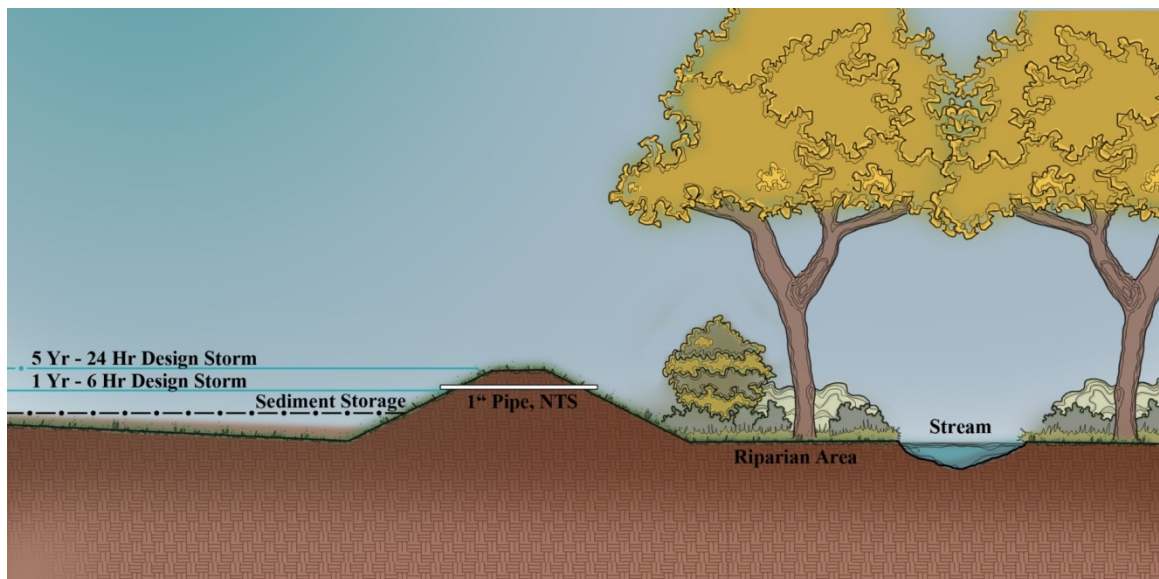


Figure 2.2: Cross-sectional View of a Contour Weep Berm System.

Source: Warner et al. (2012).

berm was ineffective at reducing nitrate levels in the runoff water. A lack of nitrate reduction in runoff merits further research into contour weep berms and using them in combination with bioreactors to investigate their utility for reducing nitrate.

2.3.1 Wood Chip Bioreactors

Vegetative filter strips largely depend on the settling velocity of sediment to deliver nutrient reductions whereas wood chip bioreactors promote microbial activity to capture and/or transform nutrients. A wood chip bioreactor is a trench, wall, or bed which is installed in a stream, tile drain, or other water source that use woodchips as a carbon substrate to promote microbial activity (Schipper et al., 2010). Currently, two different designs are used depending on the NPS pollution: denitrifying beds and denitrifying walls. A denitrifying bed is a structure installed underneath a tile-drain or stream allowing discharge from a NPS contributor to flow through the wood chip to a down-gradient drain. Robertson and Merkley (2009) obtained a typical nitrate removal range of 11 to 220 mg N m⁻² h⁻¹ depending on temperature, flow rate, and influent nitrate concentration. A denitrifying wall or denitrifying trench is a trench excavated down-gradient of the discharge source and backfilled with wood chips and a soil cover. Nonpoint source pollution infiltrates the soil column into shallow groundwater, flows down gradient perpendicular to the denitrifying wall, and passes through the wall into down-gradient water sources. Moorman et al. (2010) observed nitrate removal rates for a denitrifying wall ranging from 8.2 to 34.4 mg N kg⁻¹ wood d⁻¹. Denitrifying bioreactors need an anaerobic environment where microbes utilize nitrogen and other nutrients as an electron donor (Schipper et al., 2010). Wood chip bioreactors are a beneficial BMP used for nutrient management, and can be combined in conjunction with other BMPs. However, difficulties arise in controlling microbial processes because of temperature, temporal variation, influent nutrients, water level, and flow rate (Schipper et al., 2010).

2.3.1 Weep Berm Design Parameters

Contour weep berm systems require the calculation of several design parameters including length, side slope, top width, VFS width, and outlet type and dimensions. Designers determine these parameters with consideration of regulatory standards, structural

stability, and specific design requirements. Designers need to approximate values for these parameters before calculating contour weep berm storage requirements.

2.3.1.1 Site Characteristics

Site characteristics are an important part of designing a contour weep berm system. Site characteristics include land slope, soil type, NPS contributor, property boundaries, and other features. These site characteristics are used to approximate contour weep berm position for capturing and treating runoff. Contour weep berm position is estimated based on the site characteristics influencing the contour weep berm length, which can be adjusted during the design phase to accommodate desired capacities.

2.3.1.2 Side Slopes

Minimal side slopes of 2:1 (Horizontal: Vertical) are necessary to maintain structural stability and prevent erosion (NRCS, 2003; NRCS, 2005). Additionally, side slopes should be constructed to facilitate access for construction equipment, farm implements, and mowing equipment. Typical zero-turn lawn mowers have a 15 degree slope maximum incline rating, thus requiring a 4:1 side slope (Scarlet et al., 2006; Exmark Lawn Equipment, 2012). Therefore, if convenience of mowing is desired, a 4:1 side slope can be implemented for berm design thereby increasing structural integrity without increasing erosion. Steeper side slopes can lead to potential mower rollovers. Specific equipment owner's manuals should be consulted before traversing any contour weep berm side slopes.

2.3.1.3 Top Width

The required top width for a contour weep berm is minimally designed to maintain structural stability. Minimal top width requirements vary based on the heights and soil type. Table 2.1 contains typical top width values based on height for earthen dikes (NRCS, 2005). Organic soils are defined as soils with a greater than 20 percent concentration of organic matter, whereas all other soils are mineral soils. Top widths should optimally be designed to meet minimal requirements and design requirements. A design requirement may include access for maintenance or a walking path atop the contour weep berm for aesthetic viewing.

Table 2.1: Minimal Contour Weep Berm Top Width Requirements.

	<u>Mineral Soil</u>			<u>Organic Soil</u>		
Height (ft)	0 to 3	3 to 6	6 to 12	0 to 2	2 to 4	4 to 6
Min. Top Width (ft)	4	6	8	4	6	8

2.3.2 Design Storm

A design storm is a precipitation event associated with a return interval and duration. Typical design return intervals for BMPs range from 1 to 100 years with durations ranging from 0.5 to 24 hours based on design type and flooding risks (NRCS, 2004; LFUCG, 2009a). Regulations vary from federal, state, and local governments on the required design storm event used to design BMPs. Currently, regulations on the required size of contour weep berms do not exist although common design storm event sizes have been established.

A design storm event of 1-year 6-hrs is commonly employed to determine the passive dewatering system outlet invert elevation (Warner et al., 2012). The crest elevation is frequently calculated using a 2-year 24 hour storm event (Warner et al., 2007) although the 5-year 24-hour event is also used (Warner et al., 2012). Rainfall values for design storm events can be determined from TP 40 maps (Hershfield, 1961) for the eastern US. These TP 40 maps exist for return periods of 1, 2, 5, 10, 25, 50, and 100 years with durations of 0.5, 1, 2, 3, 6, 12, and 24 hours. Additionally, design storm values can be found in local and state storm water design manuals for common design storms (NRCS, 2004; LFUCG, 2009b). These values can be modified using the Nation Resource Conservation Service (NRCS) rainfall pattern to have a different duration based on curve distributions of 24-hr rainfall events (NRCS, 1972).

Another method that can be used to determine a desired storm event is cumulative frequency analysis. Warner et al. (2007) recommended an outlet invert elevation equivalent to a cumulative rainfall frequency of 85 percent. Cumulative rainfall frequency analysis provides a percentage of storms expected not to exceed a given precipitation level. The cumulative rainfall frequency analysis can be based on the number of storm events or the total precipitation produced by a given bin (e.g. 1 cm) of storms. A storm event frequency analysis allows more flexibility in selecting a design storm by providing a greater possibility of precipitations and a more accurate potential estimation of volume infiltrated per year. Also, it enables easier determination of corresponding volume capacities to rainfall events.

A storm event frequency analysis is achieved by obtaining daily precipitation measurements for the given area over at least 20 years. Daily rainfalls are multiplied by a coefficient of 1.13 to convert to 24 hour rainfall events (Huff and Angel, 1992). The 24-hour rainfall events are ranked and placed in appropriate ranges based on rainfall amount. A cumulative 24 hour rainfall event frequency can be plotted and used to determine appropriate rainfall events for the contour weep berm outlet invert and crest elevation.

2.3.3 Contour Weep Berm Storage

Contour weep berm storage is the total volume stored up-gradient of the contour weep berm before exceeding crest stage. The required storage capacity is based on the estimated runoff volume and sediment storage. Depending on NPS sediment loading rates, contour weep berm sediment storage may be minimized. Additionally, a cut-fill design is impractical and unnecessary if soil is readily available and not cost prohibitive. Methods to determine the individual areas of contour weep berm storage are discussed below.

2.2.3.1 Estimated Runoff Volume

Contour weep berm runoff volume analysis can be conducted upon the completion of the designated rainfall event selection. The SCS curve number (CN) method is commonly used in estimating runoff volume. The method uses a CN to represent infiltration based on soil type and land cover/use. Soil types are separated based on hydrologic soil group (HSG) into one of the four groups based on infiltration. Group A has the highest water transmission rate of greater than 7.62 cm/hr (0.3 in/hr) and D has the lowest water transmission rate not exceeding 0.127 cm/hr (0.05 in/hr) (SCS, 1972). The land cover/use parameter combines land use (i.e. agriculture, forest, residential, and urban), vegetative cover (i.e. grass, coniferous trees, and corn), and condition for a qualitative description to describe land surfaces. Hydrologic soil group and land cover/use are employed to select a CN which ranges from 0 to 100. The higher the curve number, the greater the proportion of the precipitation from an area exits as surface runoff. The closer the curve number to zero, the higher the proportion of precipitation intercepted, stored, and infiltrated (SCS, 1972).

A composite CN can be generated for a specific site using GIS or by hand. A composite number is necessary to obtain an accurate estimate of the overall curve number if

a land use or hydrologic soil group change occurs within the project area. A composite CN is calculated by determining the CN for each of the areas with the same land use and HSG. Then the CNs are combined together and normalized by area. The summation of the area's CN will provide a more accurate representation of the infiltration or CN. For projects with several land uses and HSG the analysis can be conducted in GIS.

After obtaining a CN for the drainage area, the CN method analysis can be performed to obtain an estimate of runoff depth. Runoff depth is calculated using equations 2.1 and 2.2.

$$Q = \frac{(P - \lambda)^2}{(P - \lambda + S)} \quad (\text{eqn. 2.1})$$

$$S = \frac{25400}{CN} - 254 \quad (\text{eqn. 2.2})$$

Q=runoff depth (mm)

P= precipitation (mm)

λ = initial abstraction coefficient

S=maximum soil water retention parameter (mm)

CN = curve number

Equations 2.1 and 2.2 are provided in metric units. The initial abstraction coefficient is commonly assumed to be 0.2, though it has been found that initial abstraction coefficients can range from 0.01 to 0.18 (Schneider and McCuen, 2005; Taylor et al., 2009). Another value recommended to represent initial abstraction coefficient is 0.05 (Hawkins et al., 2002; Taylor et al., 2009). If desired, literature can be referenced to determine initial abstraction coefficient for specific site characteristics. Contour weep berm runoff volume analysis needs to be conducted to determine both the outlet invert and crest elevation.

2.2.3.2 Sediment Storage

Sediment storage is the volume required to store a desired quantity of sediment. Sediment storage may not be required for applications that have limited sediment in surface

runoff, typically areas where the contour weep berm is installed for runoff volume control and/or nutrient concerns. For most construction site or land disturbance applications, sediment storage will be a necessity. The amount of sediment storage will vary based on regulations and design requirements. The minimal sediment storage for a sediment basin is 63.0 m³/ha (900 ft³/ac) based on the NRCS conservation practice standard for sediment basins (NRCS, 2002). Checking with local and state requirements may be necessary to make sure there are not minimum sediment storage capacity requirements. Larger sediment storage volumes will typically require less frequent cleanout. Also, when the sediment storage capacity is greater, there is more storage availability for holding runoff prior to sediment deposition.

2.3.4 Passive Dewatering Systems

Passive dewatering systems can be sized with various pipe systems. A volume analysis for the desired storm event to establish invert outlet stage can be calculated using the SCS method. Invert stage is adjusted for sediment storage, if required. Passive dewatering peak flow rates can be calculated by determining the infiltration capacity of the down-gradient grass filter system while saturated. The area of a grass filter strip in combination with the saturated infiltration rate can be used to calculate the maximum infiltration flow rate into a grass filter during saturated conditions. The steady state grass filter infiltration rate in conjunction with the VFS width can be used to select the maximum allowable discharge through the passive dewatering system. The number, type and size (or dimension) of outlets can be determined using maximum design discharge for the passive dewatering system.

2.3.4.1 Pipe Outlets

Pipe outlets are normally constructed of schedule 40 PVC pipe (

Figure 2.3: Option A). Pipe sizing can vary based on design needs. Large diameter pipes through contour weep berms can simplify construction, but discharge needs to be diffused over the entire grass filter length to obtain optimal VFS performance. Smaller pipes can be used in a greater quantity, eliminating the need for a diffuser system, but can be problematic due to the uneven settling of pipes during construction. Depending on pipe size, slope, and headwater

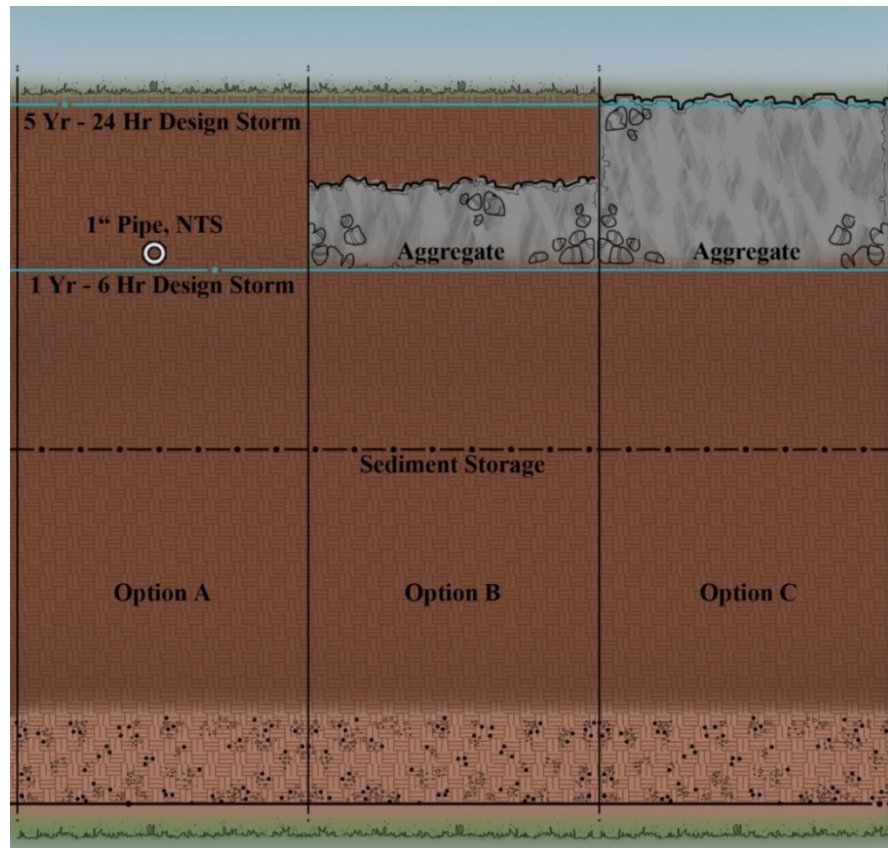


Figure 2.3: Contour weep berm Outlet Options (Option A: Straight Pipe and Option B&C: Rock Lenses). *Source: Warner et al. (2012).*

elevation, flow calculations can be determined to estimate the appropriate number of pipes needed to obtain the passive dewatering system’s design flow rate.

2.3.4.2 Rock Lenses

A rock lens is a layer of rock through the contour weep berm positioned with the bottom of the rock lens at the desired outlet design storm event. If a rock lens is used, the designer needs to determine the width and height of the rock lenses as well as the aggregate rock size (Warner et al., 2012). Outlet configuration examples can be seen in Figure 2.3, Option B and Option C.

2.3.4.3 Drainage Pipes for Partial or Complete Dewatering

Small diameter pipe(s) can be installed above ground elevation or sediment storage with valves or stoppers located at the down-gradient end through the contour weep berm. These pipes enable the release of ponded water below the passive dewatering system invert. If infiltration rates decrease up-gradient of the contour weep berm, drainage pipes enable water to be release to avoid extended periods of water ponding. Also, pipes can be used to increase passive dewatering flow rate to incorporate infiltration capacity of vegetative filter strip before invert or during large storm events to reduce overtopping potential.

2.4 CASE STUDY: VICTORY HAVEN

Victory Haven is a thoroughbred training facility in Lexington, KY averaging 200 horses but with a capacity of 300. It is estimated that the average daily muck production is 8 tons per day for an annual total of 2,920 tons. An on-farm horse manure composting operation has been operational for approximately six years. The compost operation is located on an approximately 3.7 ha (9 ac) grassed field with an ephemeral stream flowing through the middle of the field. The ephemeral stream drains to an unnamed perennial stream that in turn drains to an unnamed tributary of Cane Run. Prior to this experiment, a mowed VFS was the only BMP employed to treat runoff from the compost operation. Victory Haven's composting operation was identified as a pollutant source in the development of the Cane Run watershed based plan, which was funded by a 319(h) grant.

Two different contour weep berm systems were implemented at the Victory Haven Training Center to determine the effect of adding a trench has on hydrology and water quality for the treatment of runoff from this composting operation. It was randomly chosen that a standard contour weep berm design was to be implemented on the east side of the ephemeral channel while a modified contour weep berm design would be implemented on the west side of the ephemeral channel (Figure 2.4). The Victory Haven site provided an opportunity for the comparison of a woodchip bioreactor (modified contour weep berm design) versus a standard contour weep berm system with no bioreactor to determine the efficacy of the management and treatment of runoff by such BMPs. A summary of the design parameters of each contour weep berm is provided in Tables 2.2 to 2.4. These design parameters will be discussed in detail in the following sections.

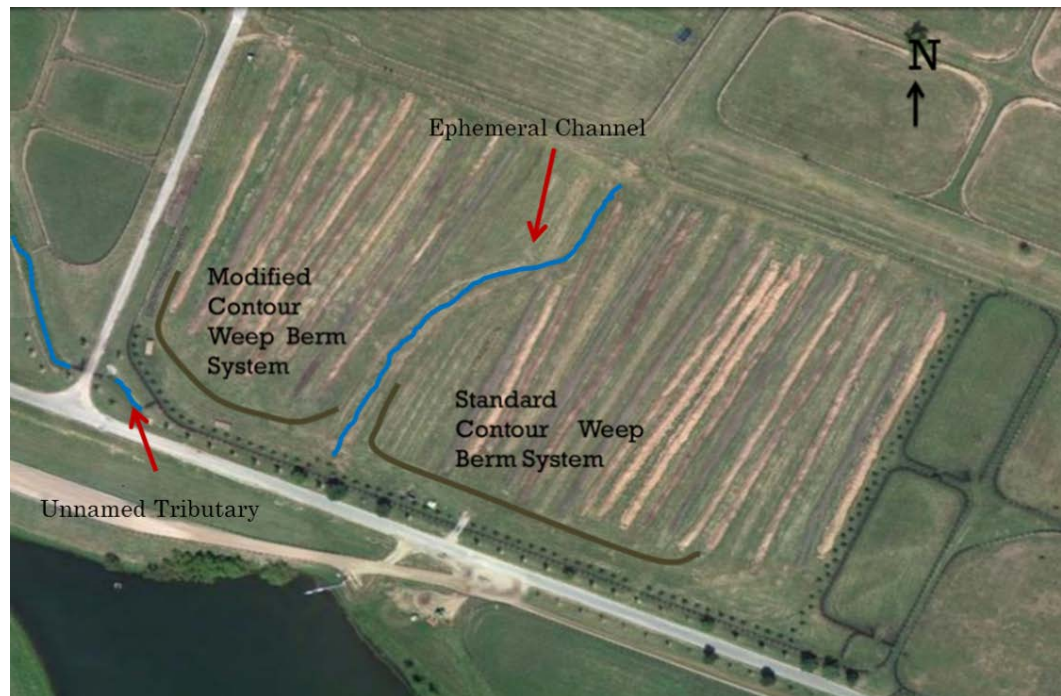


Figure 2.4: Aerial Photo of Horse Manure Composting Facility with Contour Weep Berm Locations. *Source: Google Earth.*

Table 2.3: Design Parameters for the Dimensions of the Contour Weep Berms.

Contour Weep Berm	Drainage Area (ha)	Side Slopes (H:V)	Top Width (m)	Grass Filter (m)	Berm Length (m)
Standard	1.7	3:01	1.2	6.1	137
Modified	1.5	3:01	1.2	6.1	111

Table 2.4: Design Parameters of the Passive Dewatering and Drainage Systems.

Contour Weep Berm	Passive Dewatering System				
	Pipe Diameter (cm)	Quantity	Pipe Spacing (m)	Slope (%)	Length (m)
Standard	10.2	3	30.5	0.01	2.4
Modified	10.2	3	22.9	0.01	3
Contour Weep Berm	Drainage System				
	Pipe Diameter (cm)	Quantity	Pipe Spacing (m)	Slope (%)	Length (m)
Standard	2.5	3	30.5	0.01	3
Modified	2.5	4	22.9	0.01	2.7

Table 2.5: Design Parameters for the Outlet Invert and Crest Elevations.

Contour Weep Berm	Passive Dewatering System Invert Elevation				Crest Elevation			
	Design Storm (cm)	Runoff Depth (cm)	Stag e (cm)	Stora ge (m ³)	Design Storm (cm)	Runoff Depth (cm)	Stag e (cm)	Stora ge (m ³)
Standard	6.4	1.4	54	250	7.9	2.3	72	404
Modified	6.4	1.4	32	217	7.9	2.3	55	352

2.3.1 Site Characteristics

A topographic survey was performed to determine topographic features, property boundaries, location of trees, culverts, fence lines, and composting pile locations (Figure 2.4). The facility has a fence surrounding all sides and incorporates pine trees within the fence on the south and west sides of the site. Soil series within the site varies; however, based upon the USDA Web Soil Survey and surface soil samples analyzed and the University of Kentucky Regulatory Services, the majority of the soils are silt-loam in texture. Land slopes of the site are downward sloping towards the perennial stream. The NPS pollution for perennial stream is considered runoff from the approximately 30 compost windrows with an approximate size of 4 m by 130 m (13 ft by 425 ft) (width and length) (Figure 2.4). These windrows are parallel to the slope, which allows runoff to flow down-gradient. The berm position was determined for capture and remediation of runoff from the composting windrows. Both contour weep berms were positioned perpendicularly down-gradient of the windrows and up-gradient of the fence and pine-tree boundary.

To prevent any runoff from lands upgradient of the composting operation from entering the field, a woodchip berm was created along the most upgradient portion of the field. This woodchip berm redirected incoming runoff, from the upgradient field, to the ephemeral channel. Waters from the ephemeral channel passed under a road culvert before entering a roadside ditch and then discharging into a perennial UT tributary to the Cane Run (Figure 2.5).



Figure 2.5: Ephemeral Stream Flows through Culvert before Entering Roadside Ditch.

2.3.1.1 Compost Operation Observations

The compost operation consisted of 30 compost windrow: 12 each upgradient of the standard and modified contour weep berms and 6 upgradient of a swale. The swale was adjacent to the standard contour weep berm. This swale carried water from the eastern portion of the field, and as such, the standard contour weep berm was not constructed across the swale. The compost rows varied in width from 3.0 to 4.6 m (10 to 15 ft) and height (maximum of 2.4 m or 8 ft) depending largely on the age of the compost. Finished compost windrows were typically no taller than 0.9 m (3 ft). Older compost had undergone greater levels of degradation, and as such, created smaller windrows (Figure 2.6). Sizes varied somewhat as a dump truck was used to transport the horse muck from the muck storage units to the field. Placement of the horse muck in windrows using the dump truck created imprecise windrow shapes.



Figure 2.6: Variation in Compost Windrow Size and Age.

During the composting process, a portion of the aged material was combined with newer material while the remainder was stored uncovered along a farm road adjacent to the west end of the field. Demand for finished compost varied throughout the year with higher demands occurring during the spring and fall with almost no demand during the winter months. During the winter months, it is also common for the number of horses trained at the Victory Haven training facility to decrease. Many horses were transported to Florida or similar locales during the winter months.

Over the course of the study, it was observed that the compost would either absorb rainfall or repel it depending on compost age. The horse muck used to create the compost rows has large amounts of straw. It was observed that this straw absorbed little rainfall; however, the loose and uncompacted nature of the newly formed windrows resulted in the little runoff. Fully composted rows were observed to have greater amounts of runoff. These results are similar to those found by Weber et al. (2011). The authors noted that runoff volumes were lowest in new compost (mixture of straw and dairy cow, horse and

sheep manures) but increased with compost age as bulk densities increased and porosity volumes decreased.

Soil compaction was another issue observed at the composting operation. The locations of the windrows never varied. And as such, the equipment always traveled the same paths. Compost is typically delivered to the operation along the down-gradient end of the standard contour weep berm and from the upgradient end of the modified contour weep berm. When the compost is finished, it is removed with a tractor equipped with a front end loader or a skid steer. Continued scooping of the compost was also seen to compact the ground. When runoff occurred, it tended to flow along the windrows in a concentrated manner (Figure 2.7).



Figure 2.7: Runoff Flowing Alongside Compost Windrow.

2.3.2 Side Slopes

The contour weep berm side slopes needed to allow for mowing access and composting operations as well as considering spatial constraints to ensure minimal disruption of compost storage. Optimally, 4:1 side slopes were more desirable for mowing; however, space limitation dictated the slightly steeper side slopes. Victory Haven Training Center was unwilling to change their composting operation, and sought to preserve as much composting area as possible. Therefore, 3:1 side slopes were used to accommodate mowing, while also preserving composting area.

2.3.3 Top Width

Based on a berm height of less than 0.9 m (3 ft) a top width of 4 ft was applicable. Soils utilized for contour weep berm construction were silt loams with organic matter concentrations less than 20 percent (NRCS, Web Soil Survey, 2010). Results from soil tests, which were performed at the University of Kentucky Regulatory Services, indicated that the content of the upper layer of soil had organic matter content between 7 and 9 percent.

2.3.4 Vegetative Filter Strip

A vegetative filter strip was installed ranging in width from 6.1 -7.6 m (20 -25 ft). Vegetative filter strip width was based on minimizing the necessary area for contour weep berm systems and the literature previously discussed. Infiltration rates were determined for both VFS for saturated conditions using the Green-Ampt infiltration model (refer to Chapter 3). Standard contour weep berm VFS infiltrated discharge was conservatively modeled at $4.7 \text{ m}^3\text{hr}^{-1}$, while the modified weep berm VFS infiltrated discharge was conservatively modeled at $1.0 \text{ m}^3\text{hr}^{-1}$. Variations in the VFS infiltrated discharge are partially based on differences in contour weep berm length. However, variance is related to differences in soil texture among the contour weep berms.

2.3.5 Outlet and Crest Design Storms

A 91% frequency was the outlet design storm for this site so that 91% of annual precipitation from storm events would be fully infiltrated. A 91% frequency equates to a 64 mm (2.5 in) of precipitation and approximate storm recurrence interval of 1-year 24-hours.

The 2-year 24-hour design storm was selected for determining the contour weep berm crest elevation. This equates to 79 mm (3.1 in) based on Lexington, KY rainfall data (Bonnin et al., 2006). This design storm was also used by Warner et al. (2007). Importantly, the 2-year 24-hour storm detains over 94% of Lexington, KY storms before discharge may occur over the crest of the contour weep berm. Larger storm events would require more storage capacity which, given the compost facility space constraints, was not available.

2.3.6 Outlet Stage Discharge Relationships

Outlet discharge for both standard and contour weep berms were determined based on culvert flow analysis. Culvert flow through pipes was modeled as m^3hr^{-1} using both inlet and conduit controlled conditions for each stage increment of 3.0 cm (0.1 ft). Outlet discharge for each contour weep berm was then based on the smallest flow rate determined from either inlet or conduit conditions. Stage-discharge relationships were then plotted for both the standard and modified contour weep berms (Figure 2.8 and 2.9).

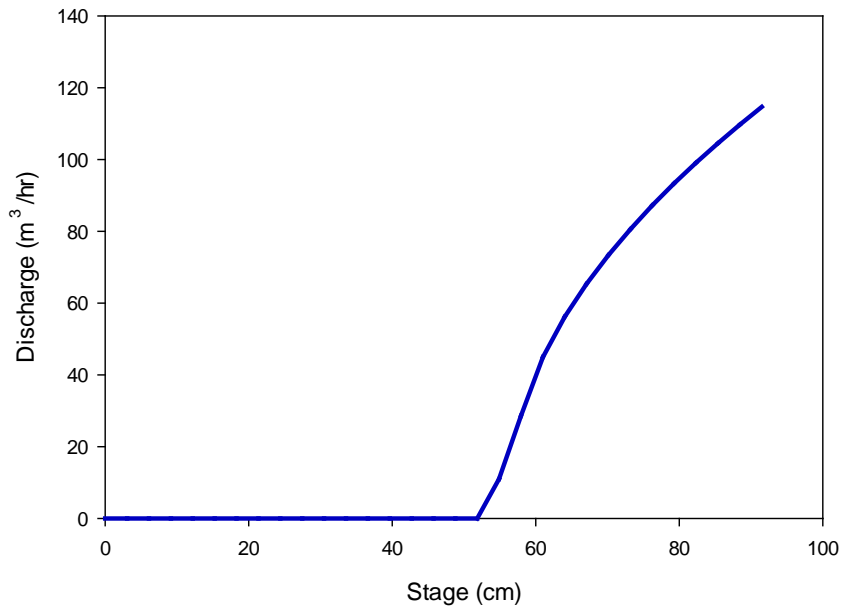


Figure 2.8: Standard Contour Weep Berm Discharge through Passive Dewatering System.

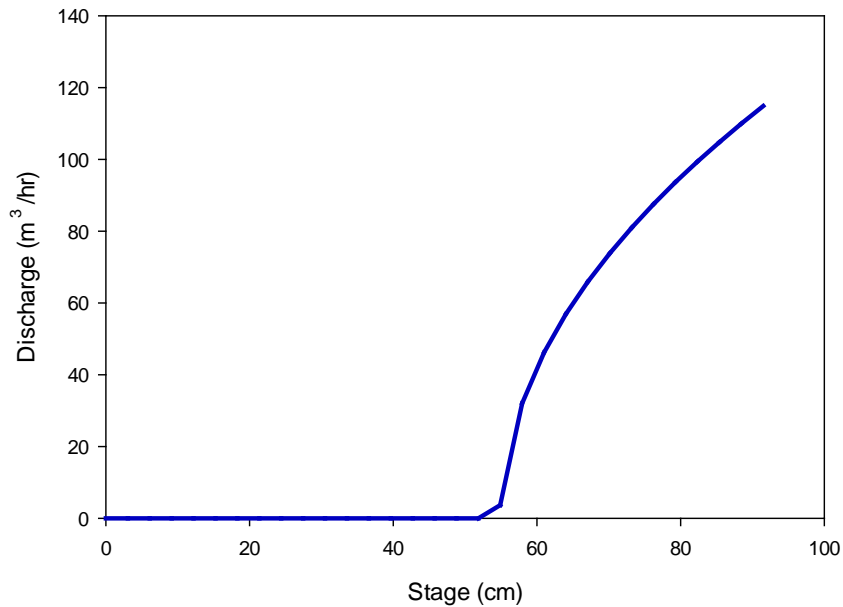


Figure 2.9: Modified Contour Weep Berm Discharge through Passive Dewatering System.

2.3.7 Contour Weep Berm Runoff Storage

The SCS curve number method was used to estimate the runoff volume associated with these design storms. First, the NRCS Web Soil Survey was used to establish which soil series were present at the site (NRCS, Web Soil Survey, 2010). The HSG for each series was normalized based on land area, which resulted in a HSG of C for the site. The HSG of C indicates that the water transmission rate is approximately 0.254 cm/hr (0.1 in/hr) (SCS, 1972). This grade was used in combination with the land cover type, pasture land, to arrive at a CN of 73 using a table of runoff curve numbers (SCS, 1986). This CN is similar to one obtained by Tollner and Das (2004). The authors computed an effective monthly CN of 81 for a composting operation in Georgia. However, this yard waste composting operation was located on a pad comprised of compacted clay and overlain with 25 mm diameter aggregate.

The outlet design storm (91% frequency) has a runoff depth of 0.56 cm (0.22 in) (eqn. 2.1 and eqn. 2.2). Based on the same drainage area for each contour weep berm previously discussed, the runoff volume for the modified contour weep berm was calculated to be 84.5 m³ (0.07 acre-ft) and 97 m³ (0.08 acre-ft) for the standard contour weep berm.

There is limited disruption of the soil, so no sediment storage allowances were deemed necessary.

For the crest design storm (2-year 24-hour), the runoff depth required for the contour weep berms was calculated (eqn. 2.1 and 2.2) to be 2.3 cm (0.9 in). The runoff volume for each contour weep berm was established based on drainage area and the runoff depth. Drainage area for the modified contour weep berm was ~1.5 ha (3.7 ac) and the drainage area for the standard contour weep berm was ~1.7 ha (4.3 ac). These areas were determined using GIS and the topographic survey of the site. For the modified contour weep berm, the runoff volume was 352 m³ (0.29 acre-ft) and for the standard contour weep berm, the runoff volume was 404 m³ (0.33 acre-ft).

A cut-fill design was implemented on the modified contour weep berm, but not on the standard contour weep berm. The modified contour weep berm utilized a cut/fill design with the excavation of a 0.9 m (3 ft) wide by 0.9 m (3 ft) deep trench (Figure 2.10). These trench dimensions were determined based on literature review and the bucket width of the available excavation equipment (Schipper et al., 2010). The soil removed was placed down-gradient of the trench and used in berm construction.



Figure 2.10: Modified contour weep berm excavated trench for woodchip bioreactor with excavated soil positioned on contour weep berm footprint.

2.3.8 Passive Dewatering System

The passive dewatering system selected for these contour weep berms used PVC pipes. PVC pipes were used since they are inexpensive. Pipe diameter was 10.2 cm (4 in) and three pipes were installed in each berm. Pipes were positioned approximately equidistant and spanning the length of the berm. Using a larger diameter pipe allowed for easier install, less piping requirement (eliminating additional cost), and less settling potential. With a larger diameter pipe discharge will be concentrated and not diffused throughout the length of the VFS and the possibility for down-gradient erosion is increased. Taking these factors into consideration, a diffuser system was connected to the straight pipes on the down-gradient side of the berm to allow drainage diffusion over a larger area of the VFS.

Diffuser systems for passive dewatering system were created from perforated 10.2 cm (4 in) ADS pipe, typically used for drainage of agricultural lands. A “T” connection made from ADS pipe was connected to each of the 10.2 cm (4 in) PVC pipe located through the contour weep berms. The “T” connections were also connected to two 15.2 m (50 ft) sections of ADS pipe (Figure 2.11). The ADS pipe was positioned along the contour weep berms with a slight slope to allow for greater diffusion. Each section of ADS pipe was held in place using claps anchored to wood stakes and capped to prevent discharge from flowing out the ends.

The diffuser system was tested using a static head tank to determine if it would hinder discharge rates determined for the 10.2 cm (4 in) PVC pipe. The static head tank was set to simulate flow rates anticipated and beyond given stage elevations upgradient of both contour weep berms. The diffuser system completely discharged flow rates from the static head tank through less than 7.6 m (25 ft). However, static head tank velocities were higher, in order to obtain the desired passive dewatering system discharges from a 7.6 cm (3 in). Therefore, a factor of safety was used to accommodate changes in diffuser pipe discharge from slower velocity to confirm that the passive dewatering system is inlet controlled.

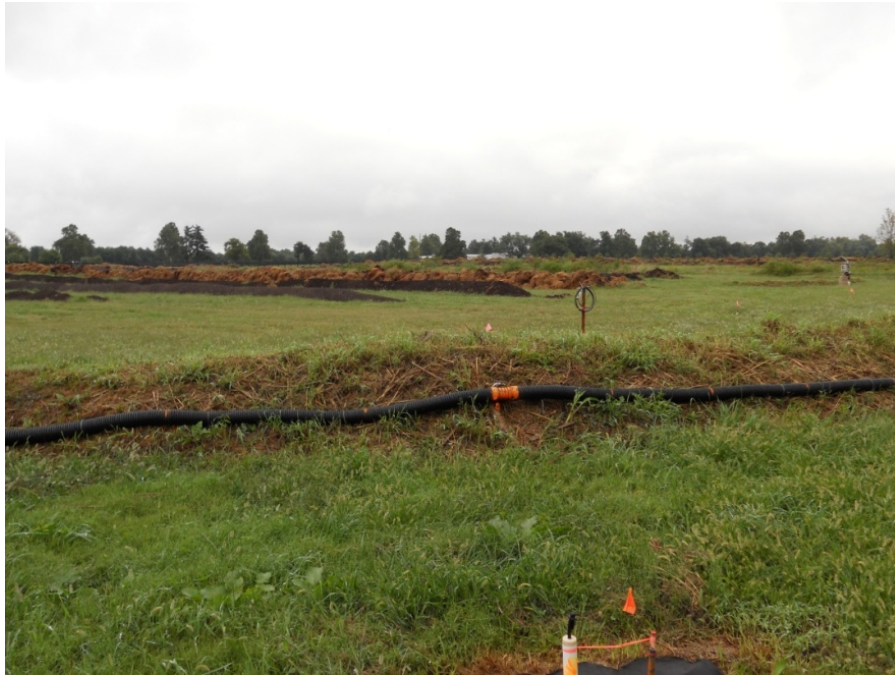


Figure 2.11: Contour weep berm Passive Dewatering Down-gradient Diffusion System.

Dewatering drainage pipes (PVC) were also installed based on concerns with ponding issues associated with reduced infiltration rates based on biofilm formation and sediment buildup (Atkinson, 2010). Three dewatering drainage pipes, 2.5 cm (1 in) in diameter, were installed in each berm equidistant from each other and within 15.2 cm (6 in) of the up-gradient ground surface (Figure 2.12).

2.3.9 Computer Aided Berm Design

To begin designing both the modified and standard contour weep berms, the topographic survey of the site was uploaded into ArcGIS in point format. Using the site characteristics delineated in the survey, such as tree location and fence boundary, the furthest down-gradient position was established. Then, due to space limitations, the contour weep berm design was constructed moving from the down-gradient towards the up-gradient. Thus, using a VFS ranging from 6.1-7.6 m (20-25 ft), the furthest down-gradient position was offset up-gradient. That up-gradient position was then considered the down-stream toe of each contour weep berm. The top width of each berm was 1.2 m (4 ft) based on a height less than 3 ft, as previously addressed. With an average contour weep berm height of 0.8 m (2.5 ft) and 3:1 side slopes, the overall width at the ground surface was calculated to be 5.8



Figure 2.12: Drainage Pipe for Completely Dewatering the Contour Weep Berms.

meters (19 ft). Then, using GIS, the up-gradient VFS boundary was offset 5.8 m (19 ft) in order to create an approximate up-gradient contour weep berm edge.

The point format of the survey and using the ArcGIS toolbox, the “create TIN” tool was utilized to convert the point data to triangular irregular networks (TIN) (Figure 2.13). Next, each drainage area, for both standard and modified contour weep berms, was delineated to create a polygon. Polygons were created to establish the storage capacity of each contour weep berm based on an estimated length. Using the polygons created for the storage capacity, the polygon volume function in GIS was used to determine the volume for a given z-coordinate (elevation). The elevation was modified to determine the required height necessary for storage of the designated storm volume. Once the z-coordinate is established, this acts as the elevation for both the invert outlet and crest design storms, with respect to each storm volume requirements.

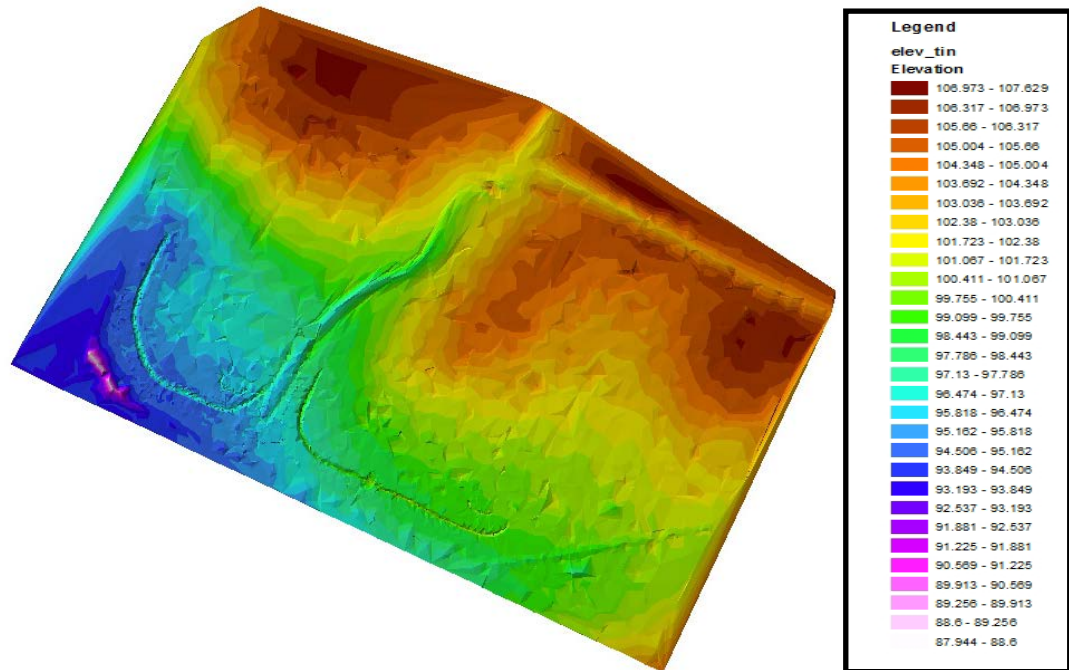


Figure 2.13: ArcGIS TIN created for Victory Haven based on site survey. *Elevations in legend are in feet.*

Berm lengths varied based on the site contours and were adjusted to obtain the required storage capacity. The crest elevation was used to taper the end of the berms to preclude runoff bypassing around the edges of the contour weep berm. The length of the modified contour weep berm was determined to be ~ 111 m (365 ft) and the standard contour weep berm was ~ 137 m (450 ft).

2.3.10 Construction

Construction of a contour weep berm system was done with Case BH016 loader backhoe excavator and Bobcat 763 skid steer loader. Pre-existing vegetation and grasses, where the contour weep berm was positioned, were excavated with a bucket of a skid steer loader to prevent seepage and contour weep berm instability. As up-gradient soil compaction will affect the efficiency of the contour weep berm while down-gradient soil compaction will reduce the grass filter strip effectiveness, soil disturbance down-gradient was minimized during construction.

The modified contour weep berm wood chip trench was installed after pre-existing vegetation was removed. A backhoe was employed to excavate soil up-gradient of the

contour weep berm to specified wood chip trench design dimensions. Excavated soil was positioned down-gradient on the modified contour weep berm footprint. One immediate benefit of the modified contour weep berm is that the excavated soils are used to construct the berm itself. This means that less soil needs to be hauled to the site. In this project, the trench produced about 0.8 m³ of soil per unit length of 1 m. Based on the weep berm dimensions, about 2.7 m³ of soil were needed per unit m. About 30 percent of the soil required to construct the berm was obtained from the trench. Sand was added, using a skid steer loader, into the trench to a depth of 15.2 cm (6 in). The sand was used because the cups of suction lysimeters were installed in the sand to sample water from the trench. Then, the trench was filled with wood chips from a landscaper delivery truck, and leveled with a skid steer loader (Figure 2.14). The skid steer loader was then used to spread and mound soil over the wood chips in the trench in order to limit potential settling problems. The soil was added over the woodchips to help maintain a more anaerobic environment. Figure 2.15 shows a cross-section of the wood chip trench with sand and topsoil layers.

Contour weep berm construction was conducted in a manner to obtain structural stability. Soils utilized for constructing contour weep berms were greater than 10 percent clay content and greater than 20 percent silt and clay content as recommended by Warner et al. (2012) consisting of silt loams and silty clay loams. Soils were layered to loose soil depth not exceeding 20.3 cm (8 in) and compacted using the tracks of skid-steer loader (Figure 2.16) (LFUCG, 2009a). Wheeled equipment and equipment with a bucket are useable for construction, though greater care is needed to avoid uneven soil compaction. The contour weep berm crest was surveyed during construction to obtain a level surface with tolerances of ± 7.6 cm (0.25 ft) to maintain the contour weep berms ability to act as a long broad crested weir (Warner et al., 2007).

Three different methods were employed to install a pipe passive dewatering system. Dewatering drainage pipes for both contour weep berm systems were installed during construction of the contour weep berms. Caution was taken during the remainder of construction to prevent pipe bowing from equipment compaction, which could affect the passive dewatering system. Pipes can also be upgraded to schedule 80 PVC pipe to reduce bowing potential. To install pipes after the completion of the contour weep berm, a bucket was used to excavate the berm at desired pipe locations, followed by positioning pipes and



Figure 2.14: Modified Contour Weep Berm Wood Chip Trench with Excavated Soil Down-gradient for Berm Construction and Extra Soil Up-gradient for Contour Weep Berm Construction.

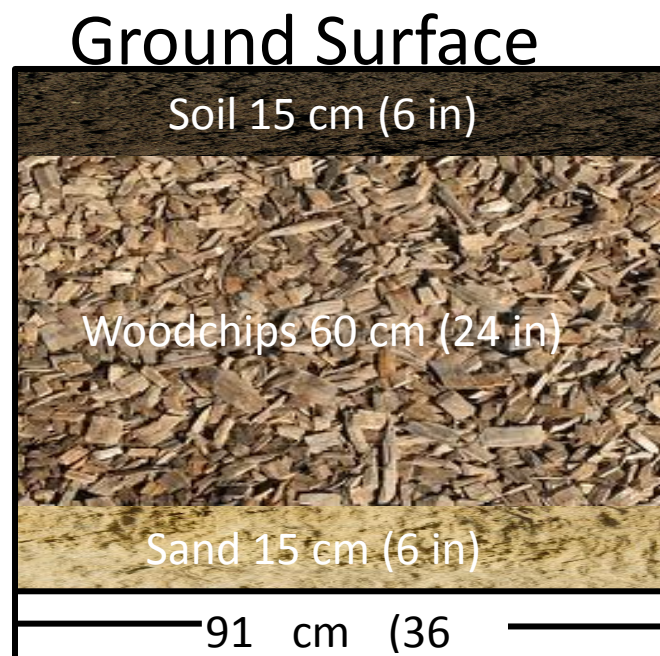


Figure 2.15: Woodchip Trench Cross-section.



Figure 2.16: Modified contour weep berm construction using a skid steer loader.

finally back filling and compacting around the pipes. This method was employed when installing large diameter pipes for modified contour weep berm, and would be discouraged when a design requires many small diameter pipes.

Upon contour weep berm completion, erosion prevention practices were implemented. Grass seed was placed atop the berm and other disturbed soils to allow for vegetation growth to help minimize eroding (Figure 2.17). Erosion matting was placed over the entire berm, to reduce further erosion caused by raindrop detachment and overtopping. Plastic in erosion matting was avoided as it can become entangled around wildlife, weed-eater heads and mower blades. Bentonite clay was installed around both contour weep berm passive dewatering systems to avoid sheet flow and soil erosion.

2.3.11 Maintenance

Minimal maintenance is necessary for contour weep berms although mowing is the largest constraint. Victory Haven's contour weep berms have side slopes exceeding 15 degrees making it unsuitable for riding lawnmowers (Exmark Lawn Equipment, 2012).



Figure 2.17: Modified contour weep berm system with erosion matting and seed after construction.

Therefore, contour weep berm maintenance was conducted using a weed-eater to accommodate side slopes and to prevent damage of passive dewatering system. In general, required trimming will vary depending on the passive dewatering system incorporated into the contour weep berm and mower accessibility. Mowing and trimming can be nearly eliminated if tall native vegetation or wild flowers are incorporated into the design. Another maintenance factor is sediment removal; including sediment storage in the design will limit the potential frequency at which excess sediment buildup will need to be removed. Other maintenance includes checking the passive dewatering system for clogging and erosion.

2.4 SUMMARY

Contour weep berms were the desired BMP for attenuating runoff from this horse manure compost site. In order to design the contour weep berm systems for the Victory Haven site, topography, soil type, and operational site constraints were taken into account. Vegetative filter strips, side slopes of the berms, and top width of the berms were also

assessed before sizing each contour weep. Passive dewatering systems for both standard and modified contour weep berms were constructed to completely detain 91 percent of annual rainfall for Lexington, KY. Crest elevation was sized for a 2-year 24-hour storm event for both contour weep berms. Using site characteristics and design parameters, a composite CN of 73 was utilized to establish runoff volumes associated with both the modified and standard contour weep berms. Runoff volumes were then used to calculate necessary height and length of each berm in GIS. The established height of both standard and modified contour weep was approximately 0.8 m (2.5 ft), while the length varied. The standard contour weep berm length was approximately 137 m (450 ft), while the approximate length of the modified contour weep was 111 m (365 ft). Using the contour weep berm blueprints created in GIS as well as the design of the passive dewatering systems, construction of the contour weep berms was completed.

CHAPTER 3: HYDROLOGY

3.1 INTRODUCTION

A contour weep berm is a low earthen berm constructed perpendicular to runoff. It is equipped with a passive dewatering system that allows for the slow release of stored runoff, from larger design storms, to a down-gradient vegetative filter strip (VFS) or riparian buffer. These structures have been incorporated into construction and agricultural sites to reduce water quantity of runoff released off site and to down gradient streams. In addition, contour weep berms can improve water quality by reducing sediment and sediment bound nutrients from polluting down gradient water sources (Warner et al., 2012). Atkinson (2010) found a reduction in water quantity of approximately 69 percent from a contour weep berm positioned down gradient of a horse muck storage facility. However, infiltration durations exceeded design standards of 72 hours. The opportunity for mosquito breeding was increased due to standing water. The standing water resulted from the formation of biofilm which reduced infiltration rates.

Contour weep berms designs require specific parameters to allow for the determination of design storm event volumes. In order to determine the runoff volume required for a contour weep berm, a designer needs to determine the specific design storms; both crest evaluation and invert outlet elevation. Crest elevation is typically set to be a design storm of 2 year 24 hour, while the outlet evaluation has varied (Warner et al., 2012). Warner et al. (2012) recommended an outlet design storm event of 1 year 6 hour, while Sturm and Warner (2008) suggested an outlet design storm event of allowing for complete detainment of 85 percent of storm events. A cumulative frequency analysis allows for more design storm event options compared to a return interval design storms. Also, cumulative frequency analysis provides for a better understanding of how many storm events will be completely detained by the contour weep berm.

Similar to Atkinson (2010), this chapter will discuss the hydrology related to two contour weep berms implemented to intercept runoff from a horse muck composting facility in Lexington, KY. A standard contour weep berm was positioned onsite and a modified contour weep berm, which is the standard design with the addition of a woodchip trench

upgradient of the contour weep berm, was also installed. The woodchip trench was installed to improve water quality and to reduce infiltration durations.

In order to design the contour weep berms, a composite curve number was required. However, limited research has been conducted with various results to determine a curve number for compost. Wilson et al. (2004) conducted research to determine that for compost situated on uncovered gravel, a curve number could range from 44 to 95. Kalaba et al. (2007) calculated a range of 50 to 70 for composting operations based on laboratory results from Wilson et al. (2004). The authors concluded that an effective curve number for a composting operation on gravel was approximately 75. Event based curve numbers for a windrow compost operation on a sand-gravel pad ranged from 42 to 100 (Tollner et al., 2012). Tollner et al. (2012) calculated an average curve number of 78 for the composting operation.

This chapter focuses on developing a cumulative rainfall frequency analysis for Lexington, KY to determine a design storm event for the placement of an invert passive dewatering system. Also, water quantity of a standard contour weep berm was compared to modified contour weep berm. Lastly, event based curve numbers were determined for both weep berms systems to provide an average curve number for a horse muck composting facility on an unlined grass paddock.

3.1.1 Objectives

The objectives of this chapter were to:

1. Develop a cumulative rainfall frequency analysis for Lexington, Kentucky.
2. Evaluate the hydrologic performance of a standard contour weep berm and a modified contour weep berm.
3. Compute a curve number for horse compost on unlined grass pasture.

3.2 METHODS

3.2.1 Site Characteristics

The study site is located at Victory Haven Training Center (VHTC), which is located in Fayette County, Kentucky (latitude 38°06'07.3"N; longitude 84°27'55.2"W) and is within the

watershed of the Cane Run. The Cane Run is a 303(d) listed stream due to high levels of sedimentation/siltation, pathogens, and nutrient/organic enrichment (KDOW, 2010). Presently, the University of Kentucky is engaged in coordinated effort with stakeholders throughout the watershed to implement best management practices (BMPs) as part of a watershed based plan to help reduce agricultural and non-agricultural nonpoint sources of pollution. The VHTC was one facility identified in the watershed based plan as a source of nonpoint source pollution (largely pathogens and nutrients).

The VHTC typically boards 200 thoroughbred houses, with capabilities of boarding 33 percent more, and as such is a large generator of horse muck (Figure 3.1). It is estimated that the VHTC composts approximately 50 percent of this muck onsite with the remaining 50 percent baled and shipped offsite for disposal. Based on estimates provided by Higgins et al. (2008) a horse is capable of generating 50 lbs of manure, 10 lbs of urine, and 20 lbs of soiled bedding per day, it is estimated that the VHTC composts approximately 1,460 tons of horse muck per year (Figure 3.2). All of the composting occurs on a 3.6 ha (9 ac) unlined grass paddock. The grass paddock is divided near the center by an ephemeral stream. The ephemeral stream drains runoff from a farm located to the north to a perennial stream. The perennial stream (UT to UT to Cane Run) is located immediately down-gradient of the VHTC compost facility (Figure 3.3).

The average land slope at the VHTC compost facility is 2 percent. Four different soil types underlay the compost facility: Donerail silt loam (HSG C), Huntington silt loam (HSG B), Lanton (Dunning) silty clay loam (HSG D), and Bluegrass-Maury silt loam (HSG B) (Figure 3.4). Average annual rainfall at the site is 117 cm (46 in) with the maximum typically occurring in July and the minimum typically occurring in October. Average annual temperatures are typically highest in July at 86°F (30°C) and lowest in January at 24°F (-4°C) (NCDC, 2002)



Figure 3.1: Horses Training in the Morning at the Race Track at the Victory Haven Training Facility. *Source: Hillary Otte.*



Figure 3.2: Horse Muck Composting at Victory Haven Training Facility.



Figure 3.3: Aerial Photo of Horse Muck Composting Facility with Contour Weep Berm Locations. *Source: Google Earth.*

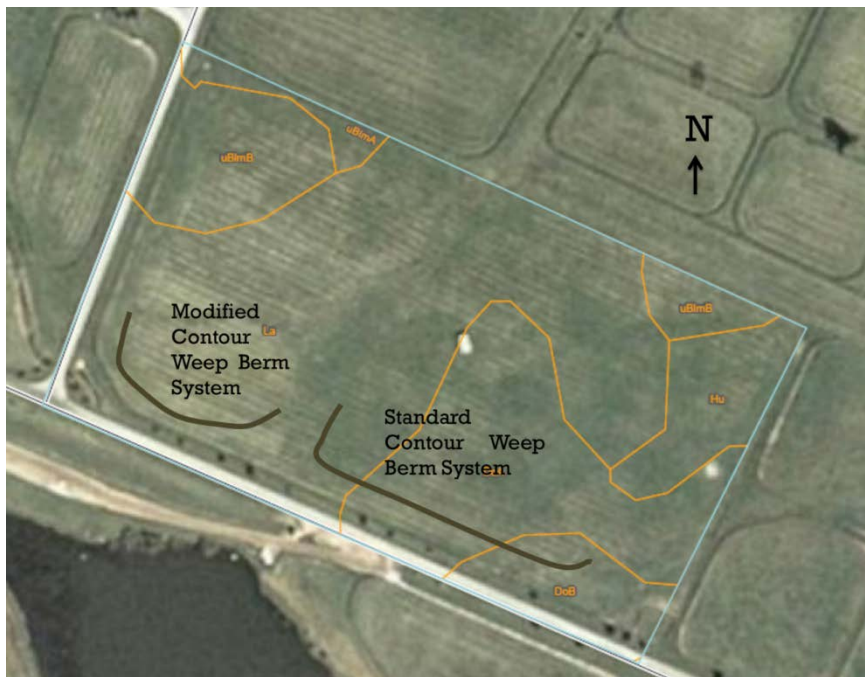


Figure 3.4: Soil types located at Victory Haven's composting facility. La=Lanton, uBlmB and uBlmA= Bluegrass-Maury, DoA and DoB= Donerail, and Hu=Huntington; *Source: NRCS, Web Soil Survey, 2010.*

3.2.2 Treatments

The treatments consisted of a contour weep berm, as described by Warner et al. (2012) and a modified contour weep berm. The modified contour weep berm used at this site incorporates a 0.9 m by 0.9 m (3 ft by 3 ft) (width and depth) trench into the design. The trench consists of 15 cm (6 in) of sand topped with 61 cm (24 in) of wood chips, and then 15 cm (6 in) of topsoil and is located immediately upgradient of the contour weep berm. Since the VHTC compost facility is divided by an ephemeral stream, a contour weep berm (standard design) was installed on one side of the channel while a modified contour weep berm was installed on the other. The standard contour weep berm is located east of the ephemeral channel while the modified contour weep berm is located to the west of the ephemeral channel. Drainage areas for the standard and modified contour weep berms are 1.7 ha (4.3 ac) and 1.5 ha (3.7 ac), respectively. The majority of the soils underlying the standard contour weep berm are Donerail (HCG C) while those underlying the modified contour weep berm are largely Lanton (HSG D) (Figure 3.4) (NRCS, Web Soil Survey, 2010)

3.2.3 Hydrologic Data Acquisition

3.2.3.1 Rainfall

3.2.3.1.1 Contour Weep Berm Hydrologic Performance

Rainfall data were collected using a Rain Collector II tipping bucket gage (Davis Instruments Corporation, Hayward, CA) equipped with a HOBO Pendant Event data logger (Onset Corporation, Bourne, MA). The tipping buckets recorded every 0.25 mm (0.01 in) of precipitation with corresponding date and time stamps. Rainfall data were collected at the VHTC from July 2011 to June 2012 (Table 3.1). In the event of equipment failure, daily rainfall data from the University of Kentucky Agricultural Weather Center (UKAWC) (UKAWC Grid Observed Precipitation) were used.

Table 3.1: Characteristics of Storm Events for Study Period.

<u>Date</u>	<u>Depth (mm)</u>	<u>Duration (hr)</u>	<u>Average Intensity (mm hr⁻¹)</u>	<u>5-day Prior (mm)</u>	<u>10-day Prior (mm)</u>
July 22, 2011 ¹	31.2	3.2	9.8	58.9	59.4
July 25, 2011 ^{1,2}	10.9	16.4	0.7	33.8	92.7
August 3, 2011 ^{1,2}	38.6	2.0	19.3	5.6	19.1
August 13, 2011	12.7	1.1	12.1	0.3	4.8
August 25, 2011	13.0	0.6	23.6	0.3	3.8
September 4, 2011	42.9	3.3	13.0	0.0	0.0
September 4, 2011	15.5	14.7	1.1	42.9	42.9
September 5, 2011	15.2	14.1	1.1	58.4	58.4
September 6, 2011	7.1	15.3	0.5	73.7	73.7
September 7, 2011	6.1	8.8	0.7	80.8	80.8
September 14, 2011	12.2	10.4	1.2	0.0	46.0
September 19, 2011	24.6	13.7	1.8	12.2	12.2
September 26, 2011	29.5	6.2	4.8	6.4	31.2
October 13, 2011	10.4	4.1	2.5	1.5	1.5
October 18, 2011	38.1	1.1	34.6	0.0	14.0
October 19, 2011	10.4	11.7	0.9	38.1	51.8
October 26, 2011	24.9	9.3	2.7	1.0	49.5
November 3, 2011	19.8	9.7	2.1	0.8	26.4
November 15, 2011	5.6	8.5	0.7	0.0	0.5
November 15, 2011	10.9	8.5	1.3	5.6	6.1
November 16, 2011	15.7	11.5	1.4	16.5	17.0
November 20, 2011	11.4	11.6	1.0	29.5	35.1
November 22, 2011 ¹	31.5	15.8	2.0	35.3	51.1
November 27, 2011 ¹	49.0	9.6	5.1	31.5	50.3
November 28, 2011 ¹	11.7	7.1	1.7	65.5	99.3
December 5, 2011 ¹	40.4	3.8	10.8	0.3	65.0
December 15, 2011	9.9	9.7	1.0	0.0	41.9
December 21, 2011	6.9	3.0	2.3	0.0	10.2
December 22, 2011	8.9	6.4	1.4	6.9	16.8
December 27, 2011	25.1	15.2	1.7	10.2	17.0
January 11, 2012	17.5	6.1	2.9	0.0	0.0
January 17, 2012	17.8	4.5	4.0	5.6	43.4
January 23, 2012	17.5	2.6	6.7	2.0	21.6
January 26, 2012	15.7	9.7	1.6	19.3	39.1
February 1, 2012	14.0	1.6	9.0	2.8	37.8
February 4, 2012	9.4	9.2	1.0	0.3	0.3
February 14, 2012	5.6	8.5	0.7	0.8	12.4

Table 3.1: Continued.

<u>Date</u>	<u>Depth (mm)</u>	<u>Duration (hr)</u>	<u>Average Intensity (mm hr⁻¹)</u>	<u>5-day Prior (mm)</u>	<u>10-day Prior (mm)</u>
February 16, 2012	6.6	9.9	0.7	5.6	8.1
February 23, 2012	10.9	6.9	1.6	1.0	13.2
February 29, 2012	21.1	12.8	1.7	0.3	12.2
March 2, 2012	8.6	2.4	3.7	23.4	34.5
March 5, 2012	5.8	7.3	0.8	32.3	32.3
March 8, 2012 ^{1,2}	20.3	9.3	2.2	7.6	39.6
March 17, 2012	13.5	1.1	12.2	0.5	29.2
March 23, 2012	9.9	3.5	2.8	0.0	18.8
April 4, 2012	7.6	6.1	1.3	4.8	7.9
April 21, 2012	15.2	7.4	2.1	2.3	4.8
May 5, 2012	15.5	6.3	2.5	1.8	7.6
May 7, 2012	9.7	1.1	8.8	15.7	21.3
May 8, 2012	6.6	2.4	2.8	25.4	31.0
May 12, 2012	25.4	22.9	1.1	16.8	14.2

¹Denotes runoff producing storm event.

²Did not produce runoff for the modified contour weep berm.

A FORTRAN program, developed by Alex Fogle in the Biosystems and Agricultural Engineering Department, was used to develop hyetographs (bin size= 3-minutes). A minimum duration of three hours of inactivity was used to separate rainfall into separate storm events (Warner et al., 2010). Storm events less than 5 mm (0.2 in) in depth were excluded. A total of 63 storm events were recorded during the monitoring period; however, in examining the hydrologic performance of the contour weep berms, only storm events that generated runoff were used in the analysis (Table 3.1). A total of eight storm events produced runoff to one or both contour weep berms. Of these runoff producing storm events, the maximum and minimum rainfall amounts used in the analysis were 49 mm and 11 mm, respectively with a mean of 29 mm. Rainfall durations varied from 2 to 16 hours with a mean of about 8 hours. Average intensities varied from about 1 to 11 mm hr⁻¹ with an average of about 6 mm hr⁻¹.

Rainfall normals from the National Climatic Data Center (2002) for Lexington, Kentucky were compared to total rainfall amounts for the project period. The total rainfall depth for the project period was 1,034 mm whereas the normal was 1,166 mm. As seen in

Figure 3.5, rainfall depths for the project period were below normal for all months with the exception of September, October and November of 2011 and May of 2012. For the months of September and November of 2011, rainfall depths were 150 mm and 70 mm, respectively, above normal. The fall months of 2011 were wetter than normal while the remainder of the year, particularly the spring and summer months of 2012, experienced a drought.

3.2.3.1.2 Cumulative Rainfall Frequency Analysis

Daily rainfall data from a 40-year period (January 1, 1971 to December 31, 2011) from the Lexington Kentucky Bluegrass Airport were used in the cumulative rainfall frequency analysis. Daily rainfall depths were multiplied by 1.13 to account for underestimation that occurs from storm events that span multiple daily periods (i.e. more than one calendar day) (Huff and Angel, 1992). Only adjusted daily rainfall depths greater

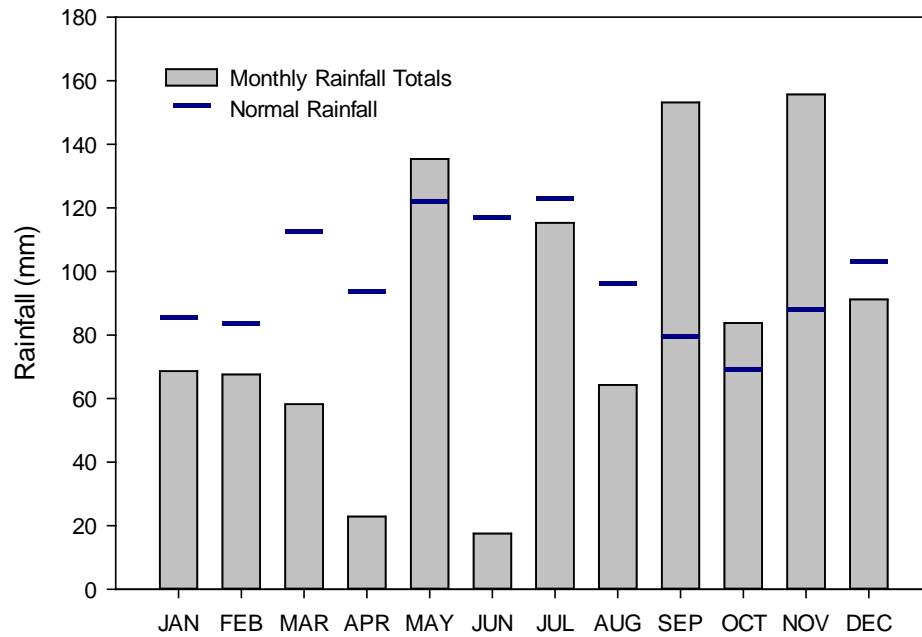


Figure 3.5: Rainfall Normals and Monthly Rainfall Totals for the Monitored Period (July 2011 to June 2012).

than 2.5 mm (0.1 in) were used in the analysis resulting in a total of 3,538 adjusted daily rainfall depths. A histogram of adjusted rainfall depths was then constructed using a bin size of 2.5 mm (0.1 in). Adjusted rainfall depths ranged from 2.5 mm (0.1 in) to 16 mm (6.3 in) resulting in a total of 64 bins.

Two methods used in the cumulative rainfall frequency analysis. The first method (Method I) examined the number of occurrences of a rainfall event within each bin size. For each bin, the total number of adjusted rainfall events of the depth specified by the respective bin was computed to arrive at a count value for each bin. Next, the incremental occurrence, IO , for each bin was computed, as seen in equation 3.1, by dividing the total number of adjusted rainfall events within the bin, C_i , by the total number of adjusted rainfall events for the 40-year period (i.e. 3,538 adjusted daily rainfall events equal to or greater than 2.5 mm or 0.1 in). In this analysis, a cutoff of 2.5 mm (0.1 in) was used as these are seldom runoff producing rain events (Iowa Stormwater Management Manual, 2008).

$$IO = \frac{C_i}{\sum_{i=0}^n C_i} \quad (\text{eqn. 3.1})$$

Finally, the cumulative occurrence was computed by summing the incremental occurrence for each bin with the incremental occurrence of its preceding bin, as shown in equation 3.2.

$$CO_i = IO_i + CO_{i-1} \quad (\text{eqn. 3.2})$$

The second method (Method II) converted the number of occurrences within each bin into a total rainfall depth for each bin. This step was done by multiplying the count value for the bin by the upper adjusted rainfall depth range for the bin. For example, if count for the bin of the adjusted rainfall depth range of 25.4 to 27.9 mm (1.0 to 1.1 in) was 77, then the total adjusted rainfall depth for the bin was computed as 2,148 mm (84.6 in). Next, incremental and cumulative values for each bin were computed, as in Method I, except total adjusted rainfall depths for the bins and the 40-year period were used. Lastly, the

normal annual rainfall depth for Lexington, KY of 1,166 mm (45.9 in) (NCDC, 2002) was multiplied by the cumulative adjusted rainfall depth values for each bin.

3.2.3.2 Runoff Volume

3.2.3.2.1 Contour Weep Berm

3.2.3.2.1.1 Water Level

Water level behind each contour weep berm was measured using a Level TROLL® 500 (5 psig) pressure transducer (In-Situ, Inc., Fort Collins, CO). Each pressure transducer was located at the point of maximum ponding depth behind the respective contour weep berms (Figure 3.6). Runoff ponding was identified when water level data exceeded the datum (i.e. no water present). As seen in Table 3.1, water level data were correlated with rainfall data to identify runoff producing storm events.

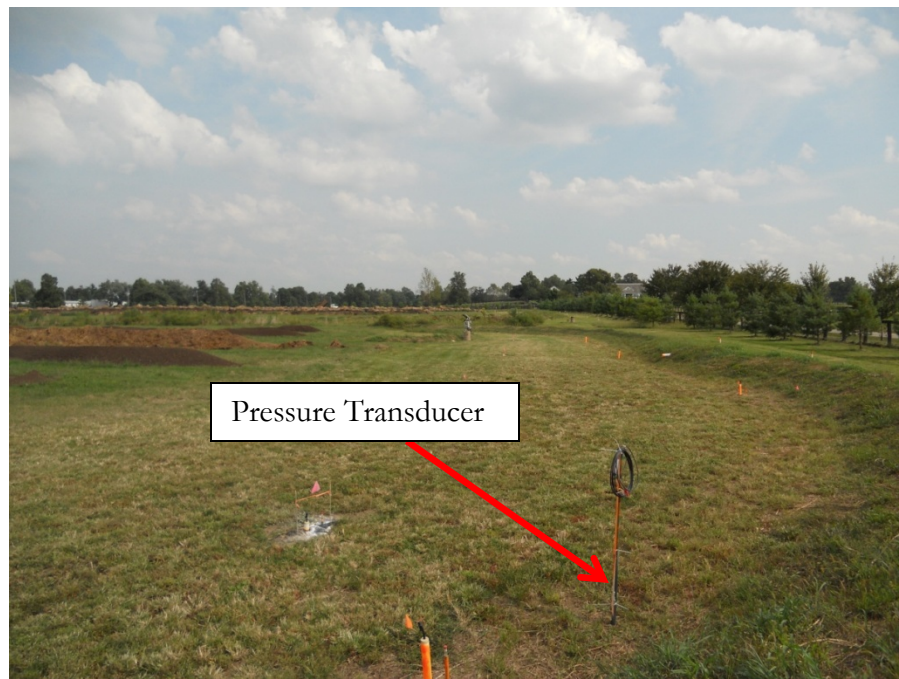


Figure 3.6: Location of Pressure Transducer for Water Level Monitoring Behind the Modified Contour Weep Berm.

3.2.3.2.1.2 Stage-Discharge Relationships

Stage-volume and stage-surface area relationships were developed for both the standard and modified contour weep berms. These relationships were used to compute infiltration rates (refer to Section 3.2.3.3). Topographic surveys were imported into ArcGIS and used to develop detailed maps of both contour weep berms (refer to Chapter 2). Using increments of 3 cm from 0 to 46 cm, both the surface area and storage volume potential were determined. Figures 3.7 and 3.8 show the stage-volume and stage-surface area relationships for the standard contour weep berm, respectively.

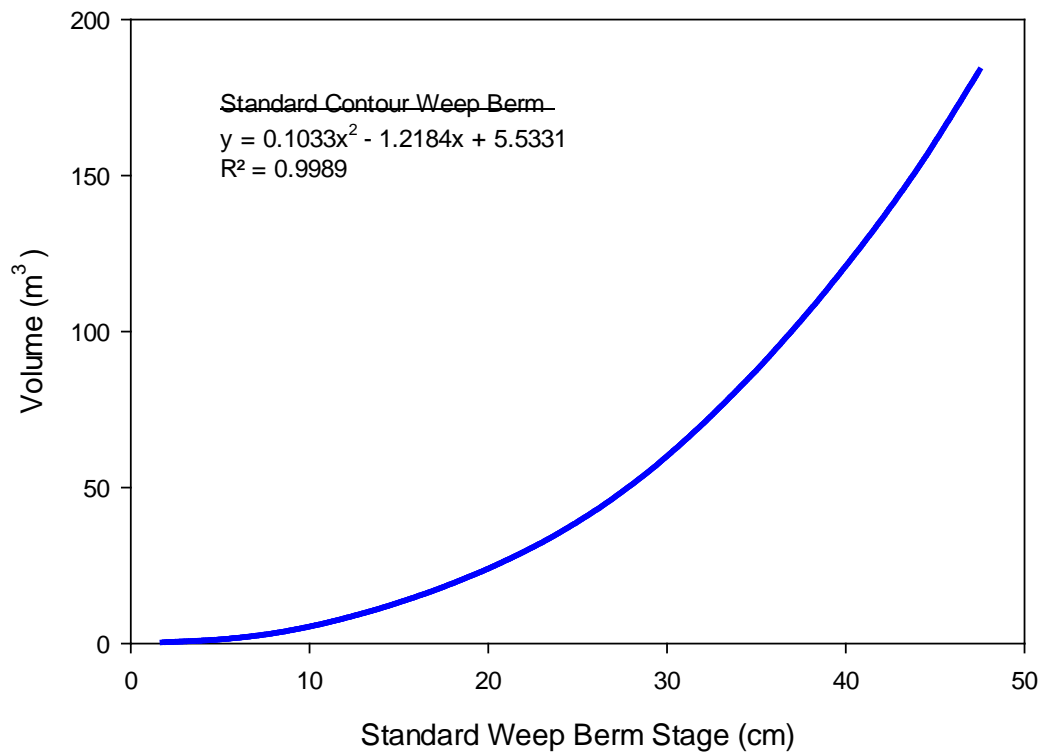


Figure 3.7: Stage-Volume Relationship for the Standard Contour Weep Berm.

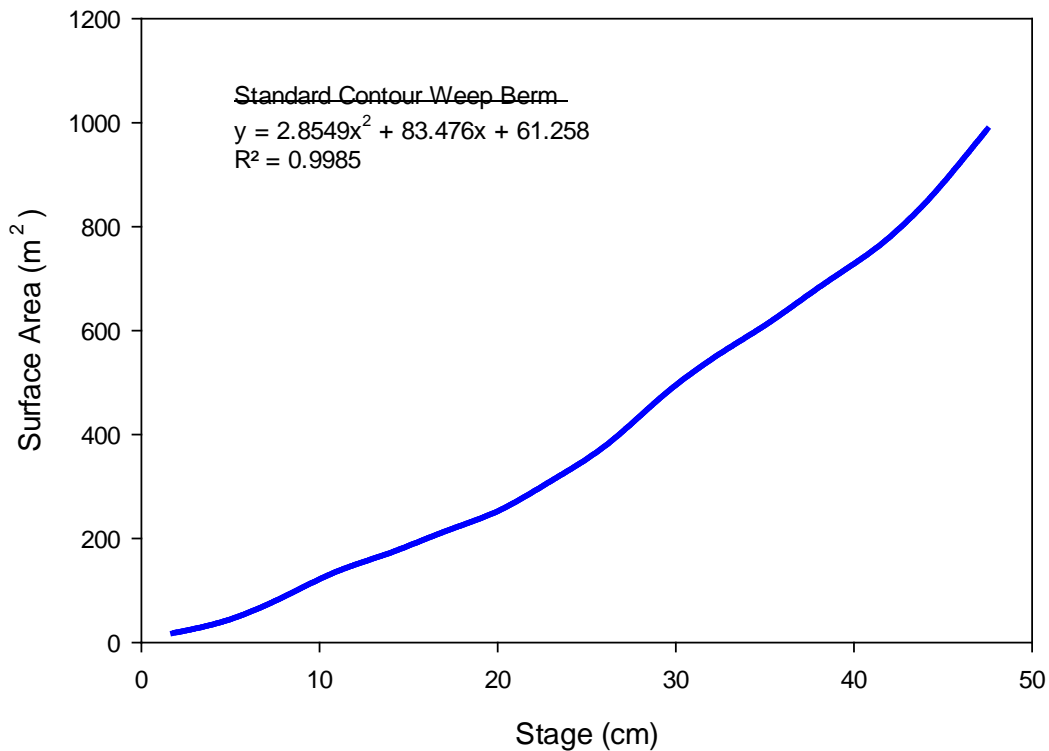


Figure 3.8: Stage-Surface Area Relationship for the Standard Contour Weep Berm.

For the modified contour weep berm, the stage-volume and stage-discharge relationships were developed in two parts: for the trench only and for the remaining upgradient portion excluding the trench. The reason for this is because infiltration properties for the trench and non-trench portion differ. As such, separate stage-volume and stage-surface area relationships are needed. In both scenarios, the surface area and volume were only considered from the datum (i.e. ground elevation at the pressure transducer) and upward. For simplification, storage within the trench itself was not considered. If completely full, assuming a void space of about 45 percent for the wood chips and neglecting storage in the 15 cm (6 in) of sand and 15 cm (6 in) topsoil, then the trench could potentially hold about 28 m³ (62 ft³) of water. The amount of storage in the trench is about 10 percent of the estimated maximum amount of water that could be stored behind the modified contour weep berm before runoff is discharged through the outlets. Figures 3.9

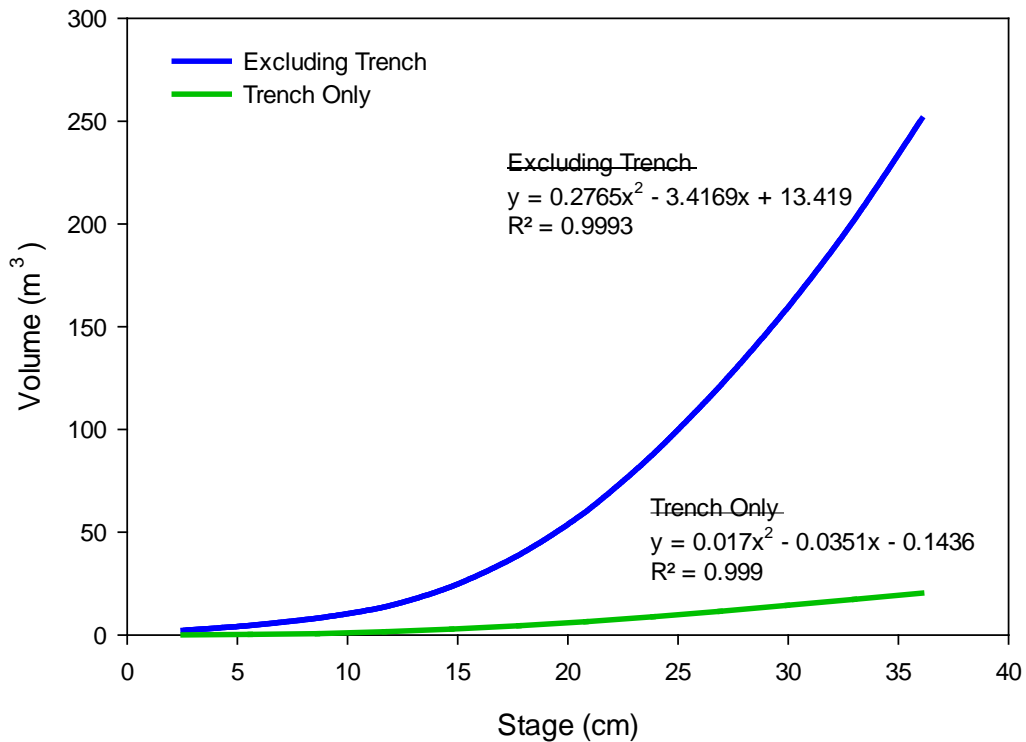


Figure 3.9: Stage-Volume Relationship for the Modified Contour Weep Berm.

and 3.10 show the stage-volume and stage-surface area relationships for the standard contour weep berm, respectively.

3.2.3.2.1 Vegetated Filter Strip (VFS)

3.2.3.2.1.1 Water Level

For the vegetated filter strip with both the standard and modified contour weep berms, a gutter system was developed to direct runoff to a central monitoring point (Figures 3.11 and 3.12). The guttering system consisted of roof guttering which was placed into a small trench at the down-gradient edge of each VFS. Silicone was used to join the gutter sections and create a watertight seal. At this lowest elevation point for each vegetated filter strip, water level was measured using a Level TROLL® 500 (5 psig) pressure transducer (In-Situ, Inc., Fort Collins, CO) which was inside a stilling well. Water exiting the gutter was

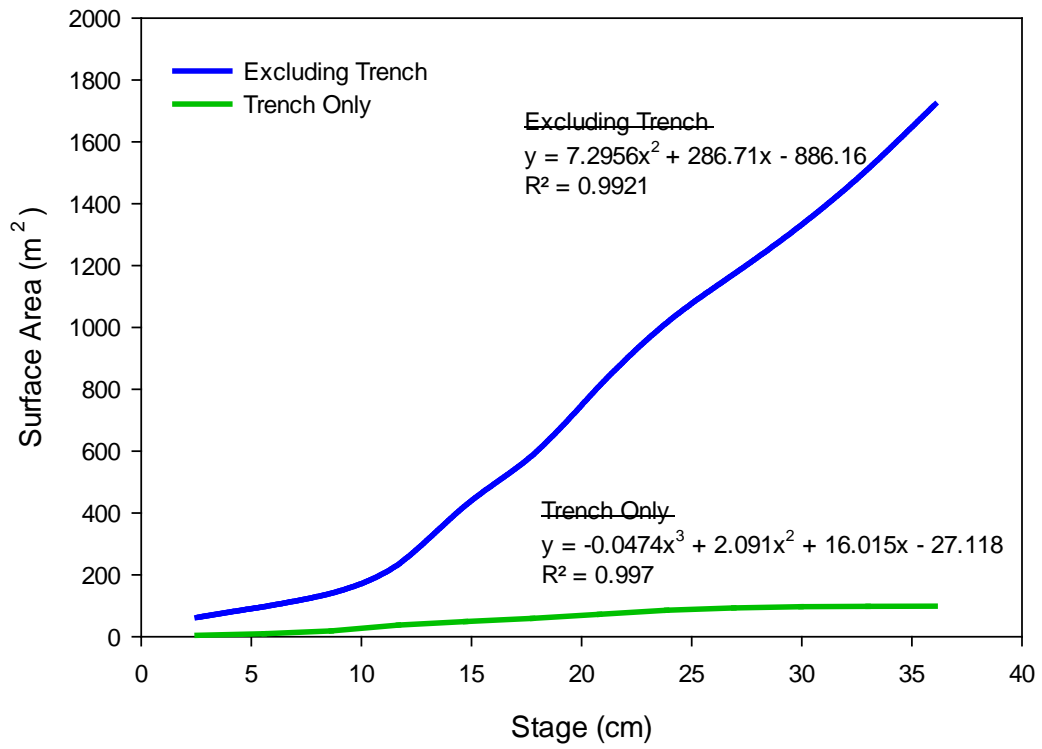


Figure 3.10: Stage-Surface Area Relationship for the Modified Contour Weep Berm.



Figure 3.11: Guttering System Used to Direct VFS Runoff to Central Monitoring Point.



Figure 3.12: Weir and Stilling Well Used in Monitoring VFS Runoff.

directed to a road channel (modified contour weep berm) or the ephemeral channel (standard weep berm) to minimize the formation of backwater conditions.

3.2.3.2.1.2 Stage-Discharge Relationships

A triangular V-notch weir (60°) was used to convert water level into discharge using equation 3.3 (Grant, 1992).

$$Q = 1.443H^{2.5} \quad (\text{eqn. 3.3})$$

The variable Q represents discharge (ft³ s⁻¹) and H represents head or water level (ft).

3.2.3.3 Infiltration

Contour weep berm infiltration rates and depths for both the standard and modified contour weep berms were calculated using the Green-Ampt Infiltration model as outline in equations 3.4 and 3.5 (Rawls et al., 1983). The Green-Ampt Infiltration model was used because it allows for the adjustment of infiltration rates and depths based upon surface ponding, which occurs with the contour weep berm, and coefficients for the equations have been developed based upon soil texture. Soil texture is an easily determined parameter, and the soil textures at the project site are known.

The first step in the Green-Ampt infiltration model is to solve for cumulative infiltration at time t as seen in equation 3.4.

$$F(t) = Kt + \psi n \ln \left(1 + \frac{F(t)}{\psi n} \right) \quad (\text{eqn. 3.4})$$

F(t)= cumulative infiltration at time t (cm)

K= hydraulic conductivity (cm hr⁻¹.)

t= time (hr)

ψ= wetting front capillary pressure with ponding depth (cm)

n= available porosity (cm³ cm⁻³)

Hydraulic conductivity, K , refers to the ability of a soil to transmit water; it is considered saturated, K_s , when subjected to a hydraulic gradient or ponded water (Klute and Dirksen, 1986; Soil Survey Staff, 1993). The wetting front refers to the interface between the wet and dry soil while the capillary pressure refers to the difference in pressure associated with the phases (air and liquid) (Hassanizadeh et. al., 2002). Available porosity is effective porosity minus the initial soil water content (Rawls et al., 1983). Rawls et al., (1983) define effective porosity as total porosity minus residual saturation.

Equation 3.4 cannot be solved explicitly, since the unknown variable $F(t)$ appears on both sides of the equation. Knowing values of K , n and ψ , a guess is made for the value of $F(t)$ on the right side of the equation. This process is repeated until the left and right sides of equation 3.4 converge. Refer to Section 3.2.3.3.1 for a discussion on the Green-Ampt coefficients used in the model.

After solving for $F(t)$, infiltration rates at time t were computed using equation 3.5 from Rawls et al. (1983).

$$f(t) = K \left[\frac{\psi n}{F(t)} + 1 \right] \quad (\text{eqn. 3.5})$$

$f(t)$ = infiltration rate (cm hr^{-1})

These values of $f(t)$, which are the predicted infiltration rates, were compared to infiltration rates measured in the field. Refer to section 3.2.3.3.1.1 for a discussion of field measured infiltration rates. Once $f(t)$ is known, it is multiplied by the surface area for time t and the time increment (i.e. 0.17 hours) to get the total volume infiltrated per increment. Finally, sum all incremental volumes to get the cumulative volume infiltrated. With the standard contour weep berm, this analysis is done once. But to determine the total volume infiltrated for the modified contour weep berm, three separate analyses are performed: 1) trench only – bottom, 2) trench only – side wall, and 3) excluding trench.

3.2.3.3.1 Green-Ampt Soil Coefficients

The parameters total porosity, residual saturation, wetting front capillary pressure, and effective porosity were based on soil texture as defined by Rawls et al. (1982) and Rawls

Table 3.2: Green-Ampt Coefficients for Both Standard and Modified Contour Weep Berms.

	Standard Contour Weep Berm		Modified Contour Weep Berm	
	<i>Mean</i>	<i>Range</i> ¹	<i>Mean</i>	<i>Range</i> ¹
Total Porosity (cm ³ cm ⁻³) ²	0.501	0.420-0.583	0.471	0.418-0.524
Effective Porosity (cm ³ cm ⁻³) ²	0.486	0.394-0.578	0.432	0.347-0.517
Residual Saturation (cm ³ cm ⁻³) ²	0.015	0.000-0.057	0.04	0.000-0.118
Wetted Front Capillary Pressure (cm) ³	16.68	2.62-95.39	27.3	6.67-131.50
Saturated Hydraulic Conductivity (cm hr ⁻¹) ²	0.68	--	0.15	--

¹ Range is based on one standard deviation

² Data from Rawls et al. (1982)

³ Data from Rawls et al. (1983)

et al. (1983), based on over 1,330 soils and 5,300 soil horizons, and shown in Table 3.2. The soil texture, as determined from the USDA Web Soil Survey, for the standard contour weep berm is silt loam while it is silty clay loam for the modified contour weep berm.

Available porosity was computed using equation 3.6.

$$n = (1 - S_e)\theta_e \quad (\text{eqn. 3.6})$$

S_e = effective saturation (unitless)

θ_e = effective porosity (cm³ cm⁻³)

Effective porosity was determined based on soil texture and Table 3.2. Effective saturation was computed using equation 3.7 (Brooks and Corey, 1964).

$$S_e = \frac{\theta - \theta_r}{\phi - \theta_r} \quad (\text{eqn. 3.7})$$

θ = soil water content (cm³ cm⁻³)

θ_r = residual saturation (cm³ cm⁻³)

ϕ = total porosity (cm³ cm⁻³)

Residual saturation refers to the water that remains in the soil pores even under high tension. Soil water content was computed using results from soils analyses (approximately seven samples per contour weep berm upgradient area), which were conducted the University of Kentucky Regulatory Service, for wilting point and field capacity. Average values of each parameter were used to determine soil water content. Changing soil water content in the Green Ampt model produced small changes in infiltration rates, thus the model is not sensitive to this parameter.

Starting values for the wetting front capillary pressure were selected from Table 3.2 to represent the condition of no ponding. For instances when ponding is present, the wetting front capillary pressure was adjusted based on changes in depth. The adjustment was made by adding the average ponding depth to the wetting front capillary pressure value from Table 3.2 (i.e. no ponding). Average ponding depth, \bar{d} , was determined using the respective stage-volume and stage-surface area relationships for the contour weep berms for each depth increment at the desired time interval, t. Table 3.3 displays the equations used to determine wetting front capillary pressure for all infiltration surfaces for both contour weep berms. Both trench only infiltration surfaces of the modified contour weep berm were adjusted by an additional head value based on elevation deviations from datum.

Table 3.3: Wetting Front Capillary Pressure Computations.

Contour Weep Berm	Wetting Front Capillary Pressure^{1,2}	Source
Standard	$\varphi_t = \varphi_0 + \bar{d}$	Figures 3.7 and 3.8
Modified – Excluding trench	$\varphi_t = \varphi_0 + \bar{d}$	Figures 3.9 and 3.10
Modified – Trench only, bottom	$\varphi_t = \varphi_0 + \bar{d} + 91$	Figures 3.9 and 3.10
Modified – Trench only, side wall	$\varphi_t = \varphi_0 + \bar{d} + 46$	Figures 3.9 and 3.10

¹ φ_0 =no ponding; from Table 3.2. t=time.

²Trench depth = 91 cm.

3.2.3.3.1.1 Saturated Hydraulic Conductivity

The Green-Ampt infiltration model is sensitive to the parameter hydraulic conductivity, K . Small changes in K can yield large changes in infiltration rates. Hydraulic conductivity is half of the saturated conductivity value ($K=0.5K_s$). In the Green-Ampt infiltration model, Bower (1969) recommended that K_s is divided by 2 to provide more representative results. Rawls et al. (1982) provides values for K_s for all 11 soil textural classes. Values of K_s range from 11.79 cm hr⁻¹ for sand to 0.03 cm hr⁻¹ for clay.

Due to the sensitivity of the Green-Ampt infiltration model to K , an average K was computed for each storm event using water level data. For the standard contour weep berm, six K values (storm events on November 27, 2011 and November 28, 2011 were combined; December 5, 2011 had insufficient data for K calculation) were computed while for the modified contour weep berm only three values were computed. Only five storm events produced runoff for the modified weep berm; however, one storm produced too little volume (July 22, 2011), one had insufficient data for K calculation (December 5, 2011), and one value was questionably high at over three times the value in Table 3.2 (November 27-28, 2011).

Values for K were determined using water level data collected after the point at which runoff ceased (i.e. past peak water level). The peak water level represented the maximum volume of stored water. At this peak level or prior, rainfall had ceased or decreased to a low level of intensity such that infiltration rates were greater than precipitation rates. This assessment is based in part of the small size of the contributing watershed meaning that runoff travels only a short time before reaching the contour weep berm.

Field based cumulative infiltration rates, $F(t)$, were computed by integrating the \bar{d} over 10 minute time increments for each runoff producing storm event. This process produces K values for each 10 minute period post-peak storage. For each storm event, the incremental K values were then averaged. The values of K were converted to K_s to compare to values provided by Rawls et al. (1982). With the modified contour weep berm, a weighted K_s was computed using the equations in Table 3.3. The weight was based upon the surface area influenced by the trench (bottom only), trench (side wall only) and non-trench area.

3.2.3.4 Curve Number

Curve numbers were calculated for each storm event for both the standard and modified contour weep berms. Curve numbers were computed using two different initial abstraction coefficients: 0.2 and 0.05 as described in Taylor et al. (2009). Results from the Green-Ampt infiltration analysis were used to determine runoff depth. The total volume of runoff infiltrated for each storm event at each contour weep berm was divided by the contributing drainage area.

3.2.4 Statistical Analysis

Using SigmaPlot version 12, t-tests were performed to check for differences ($\alpha=0.05$) between the standard contour weep berm and the modified contour weep berm with respect to the hydrologic parameters peak runoff volume, time to peak, total runoff volume, infiltration duration, and curve number.

3.3 RESULTS AND DISCUSSION

3.3.1 Cumulative Rainfall Frequency Analysis

Results from the cumulative rainfall frequency analyses showed that Method I produced greater values than Method II particularly for smaller adjusted rainfall depths (Table 3.4). For instance, if the designer wanted to capture a 90 percent storm event, then using Method I an adjusted rainfall depth of about 33 mm would be used whereas for Method II it would be 56 mm, a 41 percent difference.

Table 3.5 shows the cumulative rainfall frequencies computed using Methods I and II for a 24-hour storm event for return periods of 1, 2, 5, 10, and 25 years for Lexington, KY. For a 2 year 24 hour storm event in Lexington, KY with a rainfall depth of 76 mm, Method I predicts a cumulative rainfall frequency of 99.1 percent while it is 95 percent for Method II. Note that the error associated with the cumulative rainfall frequencies is expected to increase with increasing return period as the dataset used in the analysis only encompassed 40 years.

Table 3.4: Cumulative Rainfall Frequencies for Rainfall Depths Using Methods I and II.

Adjusted Rainfall Depth (mm) ¹	Cumulative Rainfall Frequency (%)	
	Method I	Method II
0	0.0	0.0
0-5	22.4	6.9
5-10	50.1	21.7
10-15	66.4	35.5
15-20	77.3	48.2
20-25	84.6	59.0
25-30	88.9	66.6
30-36	91.8	72.7
36-41	94.2	78.5
41-46	95.9	83.1
46-51	97.0	86.3
51-56	97.6	88.4
56-61	98.1	90.3
61-66	98.6	92.1
66-71	98.9	93.4
71-76	99.1	94.3
76-81	99.2	95.0
81-86	99.5	96.2
96-91	99.6	96.8
91-97	99.6	97.1
97-102	99.7	97.3
102-107	99.7	97.3
107-112	99.7	97.5

Table 3.4: Continued.

Adjusted Rainfall Depth (mm) ¹	Cumulative Rainfall Frequency (%)	
	Method I	Method II
112-117	99.7	97.7
117-122	99.8	98.3
122-127	99.9	99.0
127-132	99.9	99.0
152-157	100.0	99.7
157-163	100.0	100.0

¹Some rounding occurred due to conversion from Imperial to metric units

Table 3.5: Cumulative Rainfall Frequency Analysis Results for Lexington, KY.

24-hr Return Interval (yr)	Rainfall Depth (mm)	Cumulative Rainfall Frequency (%)	
		Method I	Method II
1	64	98.4	91.0
2	76	99.1	95.0
5	94	99.6	97.0
10	110	99.7	97.5
25	132	99.9	99.0

Cumulative frequencies for both Method I and II were determined for each storm event that generated runoff for either the standard and modified contour weep berm during the course of study period. The smallest storm event to produce runoff had a rainfall depth of 10.9 mm, which equates to a cumulate frequency of 52.7 and 23.7 for Method I and II, respectively (Table 3.6). The largest storm event to produce runoff had a cumulative frequency of 96.7 percent for Method I and 85.5 percent for Method II (Table 3.5).

Table 3.6: Cumulative Frequency of Runoff Producing Storm Events for Method I and II.

Date	Rainfall Depth (mm)	Method I	Method II
July 22, 2011	31.2	89.4	67.6
July 25, 2011	10.9	52.7	23.7
August 3, 2011	38.6	93.3	76.14
November 22, 2011	31.5	89.6	68.0
November 27, 2011 ¹	49.0	96.7	85.5
November 28, 2011 ^{1,2}	11.7	54.3	25.8
December 5, 2011 ¹	40.4	94.1	78.2
March 8, 2012	20.3	77.3	48.2

Method I and II have varying cumulative frequencies. Method I provides a cumulative frequency over 31 percent higher than Method II for a design storm ranging from 10-15 mm (Table 3.4). The variation in the cumulative frequency determined from Method I and II reduce after a design storm of 15 mm, until there is virtually no difference at a design storm of 120 mm (Figure 3.13). Overall, Method II provided a more conservative representation of storm event frequencies (Figure 3.13). Therefore, to provide a conservative representation of cumulative frequencies Method II was used throughout the thesis to represent frequencies associated with storm events.

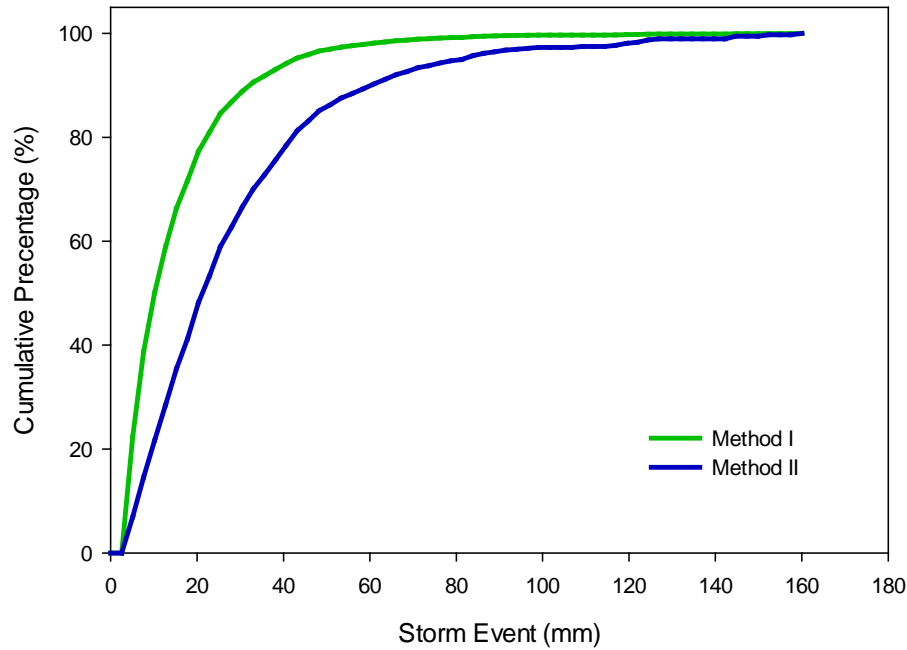


Figure 3.13: Comparison of Cumulative Percentage of Method I and II for Lexington, KY.

3.2.2 Saturated Hydraulic Conductivity

The highest saturated hydraulic conductivity for the standard contour weep berm was 0.68 cm hr^{-1} occurring on November 28, 2011, while the lowest saturated hydraulic conductivity of 0.24 cm hr^{-1} occurred on July 25, 2011 (Table 3.7) (Figures 3.14 and 3.15). The average saturated hydraulic conductivity for the standard contour weep berm was 0.43 cm hr^{-1} which is less than the 0.68 cm hr^{-1} value suggested by Rawls et al. (1982). The reason for the difference is not known; however, the change appears to be seasonal. During the summer months of the monitoring period, rainfall normal were below normal. It is possible that a thin crust formed on the soils during this drier period causing the reduction in saturated hydraulic conductivity (Morin et al., 1980).

The saturated hydraulic conductivity value calculated for the modified contour weep berm was 0.68 cm hr^{-1} . A saturated hydraulic conductivity value expected for the modified contour weep berm based on soil texture was 0.15 cm hr^{-1} (Rawls et a., 1982). Modified contour weep berm variation in saturated hydraulic conductivity was likely due to the influence of the trench. The trench has the capacity to store water in the void spaces. The

Table 3.7: Standard Contour Weep Berms Saturated Hydraulic Conductivity (K_s).

Date	Standard Contour Weep Berm
	K_s (cm hr ⁻¹) ¹
22-Jul-11 ²	0.27
25-Jul-11 ²	0.24
3-Aug-11 ²	0.35
22-Nov-11	0.44
28-Nov-11 ³	0.68
8-Mar-12 ²	0.45
Mean±Std. Dev.	0.43±0.16

¹ $K_s=2*K$

²Insufficient runoff measured for Modified Contour Weep Berm.

³Combined K_s value for November 27-28, 2011 storm events.

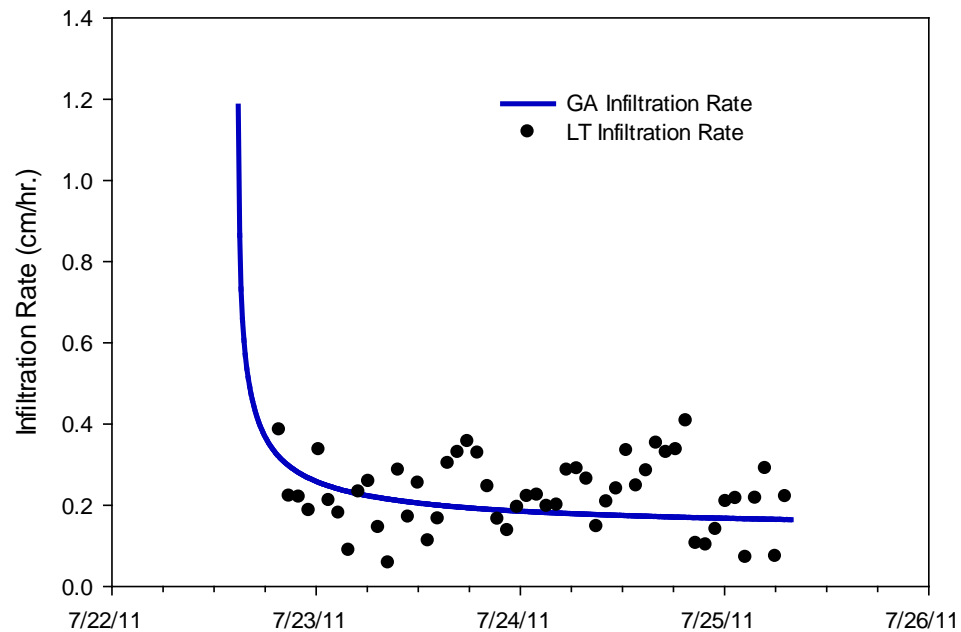


Figure 3.14: Standard Contour Weep Berm Infiltration Rate for July 22, 2011. GA indicates infiltration rates based on Green-Ampt model and LT indicates infiltration rates based on field measurements. *LT refers to Level Troll.*

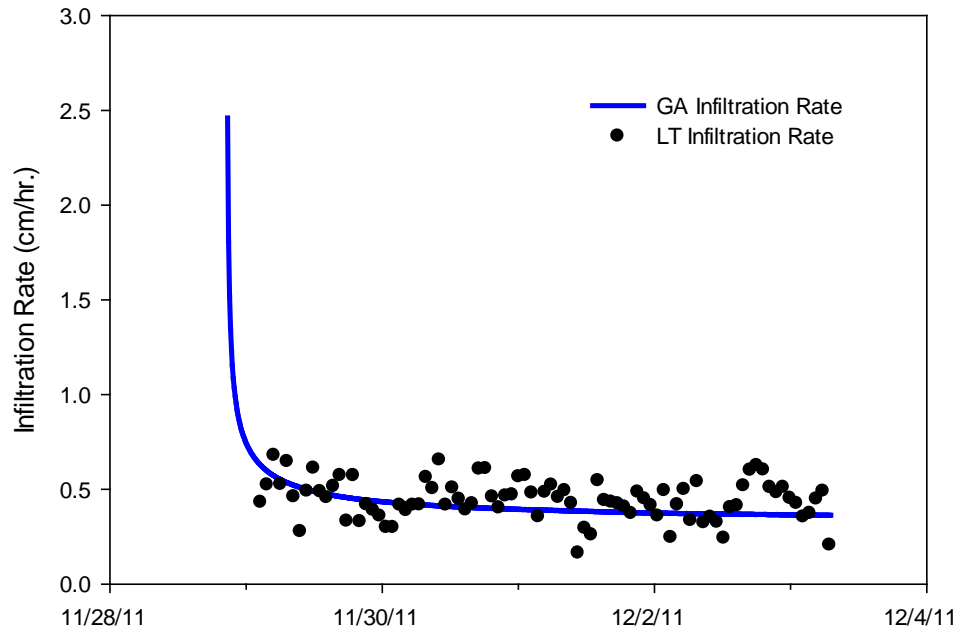


Figure 3.15: Standard Contour Weep Berm Infiltration Rate for November 28, 2011. *LT* refers to *Level Troll*.

amount of void space between the woodchips in the trench varied based on soil water content and antecedent moisture conditions but was estimated to be 28 m³ under wilting point conditions.

3.3.3 Hydrologic Performance

Standard contour weep berm had more storm events resulting in runoff than the modified contour weep berm system. There were a total of eight storm events resulting in runoff for the standard contour weep berm, while only five storm events resulted in runoff for the modified contour weep berm. The largest runoff volume for the standard contour weep berm system was 183.1 m³ from a 49 mm storm event occurring on November 27, 2011 while for the modified contour weep berm system had the largest runoff volume of 228.1 m³ from a storm event producing 40.4 mm of precipitation on December 5, 2011.

None of the peak volumes for either the standard or modified contour weep berm reached the outlet inverts meaning no runoff was discharge to the VFS during the study period. Work conducted by Atkinson (2010) indicated that evaporation is negligible with the

contour weep berm. Based upon the Lexington-Fayette Urban County Government (2009a), maximum evaporation occurs in July at a rate of 0.2 mm hr^{-1} which is much lower than the measured infiltration rates (Figure 3.16) (refer to Section 3.3.3). Thus, for the monitored period, both contour weep berm systems retained 100% of the runoff produced from the contributing watersheds for all storm events.

Table 3.8 revealed the modified contour weep berm had no runoff for three storm events that produced runoff for the standard contour weep berm (July 25, 2011; August 3, 2011; and March 8, 2012). If the peak runoff volume in the standard contour weep berm was less than 15 m^3 , runoff was not measured in the modified contour weep berm. The initial abstraction, largely due to surface depression storage, was greater in the modified contour weep berm. The greater amount of surface depression storage is due to past channel realignment. The ephemeral channel, which is located in the contributing watershed of the modified contour weep berm, was moved prior to the establishment of the composting operation. In the movement, the former stream alignment was not completely filled, or if it was, settling occurred.

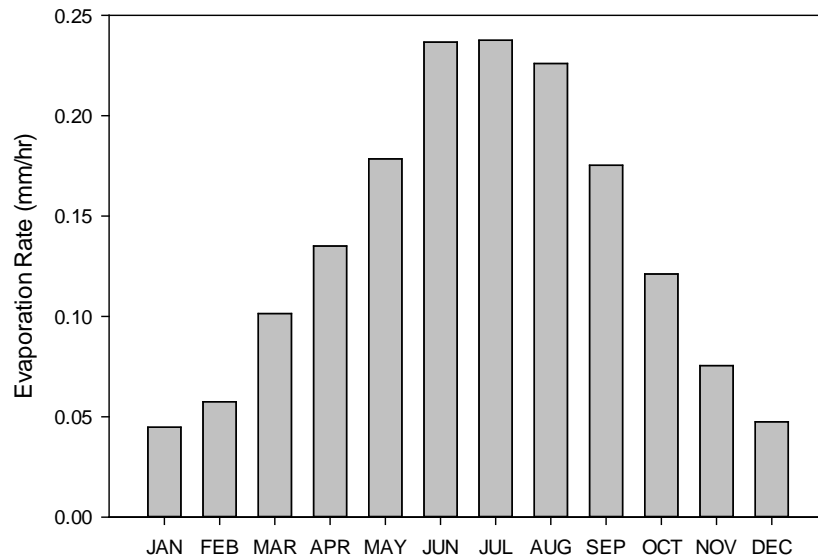


Figure 3.16: Monthly Normal Evaporation Rate per Hour for Lexington, KY.

Table 3.8: Hydrologic Results for the Standard Contour Weep Berm and the Modified Contour Weep Berm.

Date	Rainfall Depth (mm)	Peak Runoff Volume (m ³)		Time to Peak (hr)		Total Runoff Volume (m ³)		Infiltration Duration (hr)		CN ($\lambda=0.2$)		CN ($\lambda=0.05$)	
		Standard	Modified	Standard	Modified	Standard	Modified	Standard	Modified	Standard	Modified	Standard	Modified
July 22, 2011	31.2	15.9	0.4	4	0.7	17.8	0.6	65.2	1.2	71.3	63.9	48	33.2
November 22, 2011	31.5	16.9	55.6	16.3	13.7	21.9	96.5	70.5	36.2	72.1	83.5	49.8	74.3
November 27, 2011 ^{1,3}	49	144.2	106.3	30.5	5.3	183.1	188.5	133	92	77.1	79.3	66.3	70.1
November 28, 2011 ^{1,2,3}	11.7	28.6	10.4	5	3.2	63	30.4	10.5	8.7	95	92.5	92.4	87.1
December 5, 2011 ¹	40.4	118.6	164.5	26.2	9.5	154.1	228.1	-	-	80.6	86.9	70.9	82
Mean \pm Std. Dev.	32.8 \pm 13.9	64.8 \pm 61.6	67.4 \pm 68.6	16.4 \pm 12.0	6.5 \pm 5.2	88.0 \pm 76.4	108.8 \pm 98.2	69.8 \pm 50.1	34.5 \pm 41.2	79.2 \pm 9.6	81.2 \pm 10.8	65.5 \pm 18.1	69.3 \pm 21.3

¹Total volumes were extrapolated.

²Peak runoff volume extrapolated.

³Infiltration duration extrapolated.

Comparing hydrologic variables between the standard and contour weep berms is challenging in part due to differences in soils (HSG C with the standard contour weep berm and HSG D with the modified contour weep berm), the continually changing compost rows, and the limited number of storm events producing runoff. No significant differences were noted between the two types of contour weep berms with respect to peak runoff volume, time to peak, total runoff volume, infiltration duration, or curve number. However, the mean peak runoff volume and mean total runoff volume were greater for the modified contour weep berm compared to the standard contour weep berm while the mean time to peak was less (Figures 3.17 and 3.18). These results are likely attributable to differences in soil texture. The silt loam soil texture of the standard contour weep berm seems to result in a higher saturated hydraulic conductivity than silty clay loam of the modified contour weep berm. The lower saturated hydraulic conductivity equates to a slower infiltration rate for the modified contour weep berm.

Examination of mean infiltration durations indicated that on average, twice the length of time was required to infiltrate stored runoff volumes behind the standard contour weep berm as compared to the modified contour weep berm. The modified contour weep berm had a mean infiltration duration of 34.5 hr, while the standard contour weep berm had an mean infiltration duration of 62.4 hrs. This result is attributed to the addition of the trench in the modified contour weep berm. The modified contour weep berm was able to infiltrate a larger amount of water in a shorter period of time, on average. However, both contour weep berms exceeded the recommended maximum infiltration duration of 72 hr. Both contour weep berm occurrences of excess infiltration duration occurred in November. Therefore, potential problems associated with mosquito reproduction and biofilm formation were limited by temperature (American Mosquito Control Association, 2012; Jefferson County Mosquito Control Division, 2012).

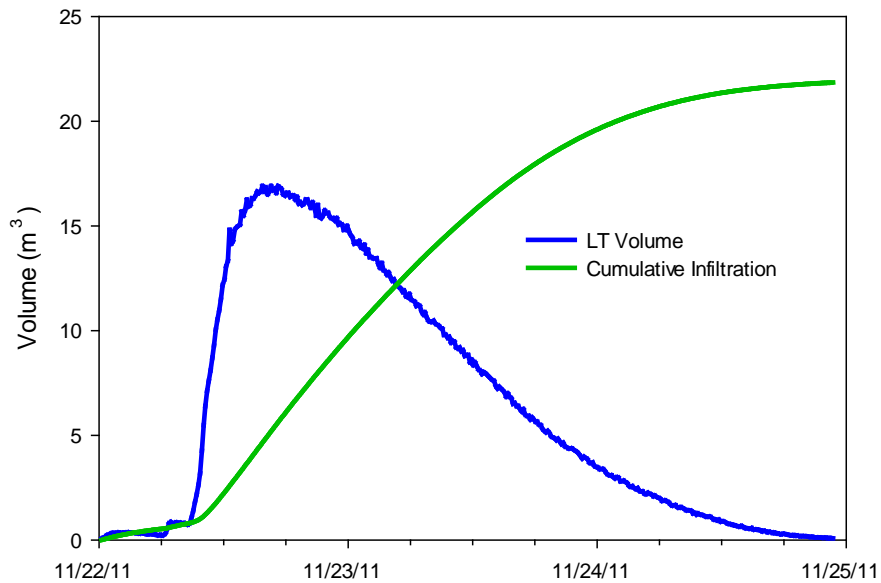


Figure 3.17: Standard Contour Weep Berm Hydrograph and Cumulative Infiltration for November 22, 2011.

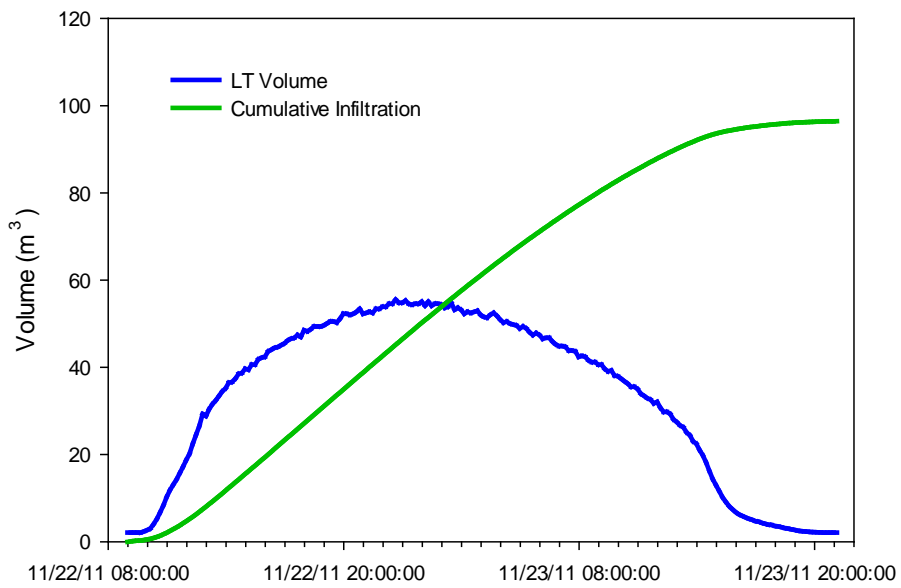


Figure 3.18: Modified Contour Weep Berm Hydrograph and Cumulative Infiltration for November 22, 2011.

CONCLUSIONS

Two contour weep berms were constructed at Victory Haven Training Center in Lexington, KY. A standard contour weep berm design and a modified contour weep berm design (i.e. standard contour weep berm design with a wood chip trench) were implemented to capture, detain, and infiltrated runoff coming from horse muck composting facility. During the study period, eight storm events produced runoff for the standard contour weep berm, while only five storm events resulted in runoff for the modified contour weep berm. The modified contour weep berm infiltrated a total runoff volume of 544 m³ compared to 452 m³ total runoff volume infiltrated by the standard contour weep berm for the total duration of the study. Both standard and modified contour weep berms did not release any runoff through the passive dewatering system during the study period. Consequently, there was complete containment of runoff from the standard and modified contour weep berms contributing watersheds. If the contour weep berms were not present, over 1,000 m³ (nearly 270,000 gal) of nutrient and pathogen laded runoff would have directly entered the stream. No clogging or fouling of the soils upgradient or down-gradient of the weep berm was observed during the study period.

Both contour weep berms were designed with the goal of complete infiltration within 72 hours and 60% within 24 hours to reduce mosquito breeding and biofilm formation. Results suggest that the outlet inverts need to be lower to accomplish this goal. The passive dewatering system was designed to completely capture 83% of storm events, but did not release any runoff through passive dewatering system during the study period. In areas with soils that have infiltration rates such as HSG of C and D, passive dewatering system invert needs to be lower to balance longer infiltration durations with treatment. Lowering the invert stage of passive dewatering system could be used if runoff has a long residence time. However, the lower the runoff withdrawal stage, the closer the discharge occurs where constituents are settling out.

Results showed that the addition of a woodchip trench increased infiltration rates and reduced infiltration durations for the modified contour weep berm compared to the standard contour weep berm. Increased infiltration rates obtained from the woodchip trench can allow for the reduction in berm sizing while maintaining infiltrated runoff volumes. In addition, higher infiltration rates obtained with the woodchip trench reduce the

concern of potential mosquito and biofilm formation. However, issues with water quality treatment may be potentially concerning due to decreases in residence time.

Both contour weep berms were able to infiltrate all runoff in approximately five days or less in soils with a HSG of either C or D, demonstrating contour weep berms effectiveness at infiltrating runoff in areas with less than desirable soils. Unlike contour weep berms, typical low impact development techniques for infiltration do not recommend use in HSG of C and D. However, soils normally located in riparian areas are predominately of the HSG C and D. Contour weep berms have the potential to be used to protect streams from water quantity issues (i.e. increase volume and peak) and water quality. Water quality improvements were achieved by reducing suspended sediments and sediment bound particles, but whether or not these reductions were significant enough to alter stream water quality is unknown. Also unknown is the fate of dissolved constituents such as nitrates. Further work is needed in this area.

CHAPTER 4: FUTURE WORK

Water quality data was acquired during the course of this study and needs to be evaluated to understand the potential benefits associated with both the standard contour weep berm system and a modified contour weep system. Comparisons between the standard and modified contour weep berms can provide further insight into potential benefits of the woodchip trench. In addition, nutrient variations associated with the trench could be examined to determine if nutrient transformations are chemically or biologic related.

Future work could be conducted on contour weep berm hydrology. Further studies in a controlled environment need to be performed to better determine hydrologic benefits associated with a woodchip trench. Long term studies should also be considered to examine changes in infiltration rates of contour weep berms over longer durations. Contour weep berms may have increased infiltration rates over extend periods from the development of mature vegetation, and reduced formation of soil crusting. However, contour weep berms may have decreased infiltration rates over time associated with suspended sediment deposition and biofilm formation.

Future work could also be performed to determine the effects different types of vegetation have on contour weep berm hydrology and water quality. Native wildflowers could be beneficial at reducing maintenance cost associated with mowing and trimming. In addition, wildflowers or other diverse vegetation could be more advantageous in accumulating various nutrients and promoting higher infiltration rates through mature root systems.

APPENDICES

APPENDIX A: STAGE RELATIONSHIPS

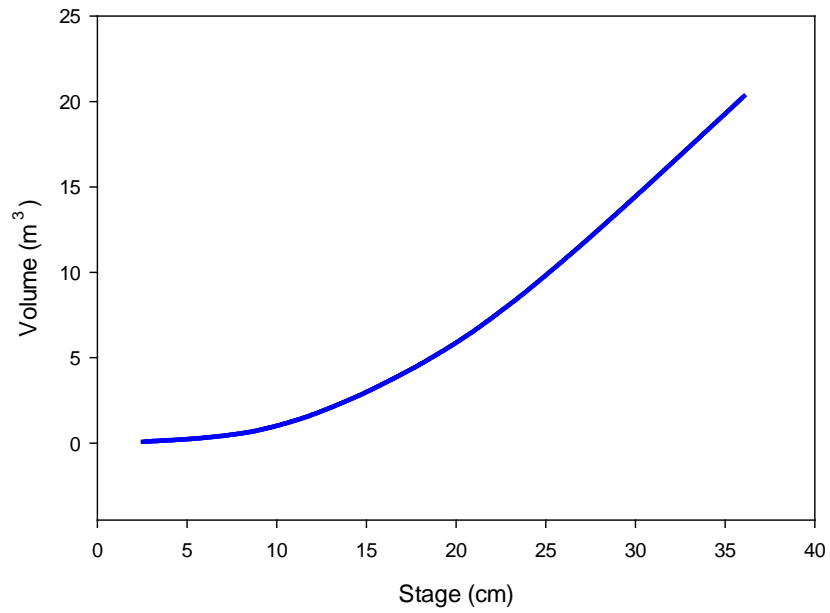


Figure A.1: Stage-Volume Relationship for Modified Contour Weep Berm Trench Only.

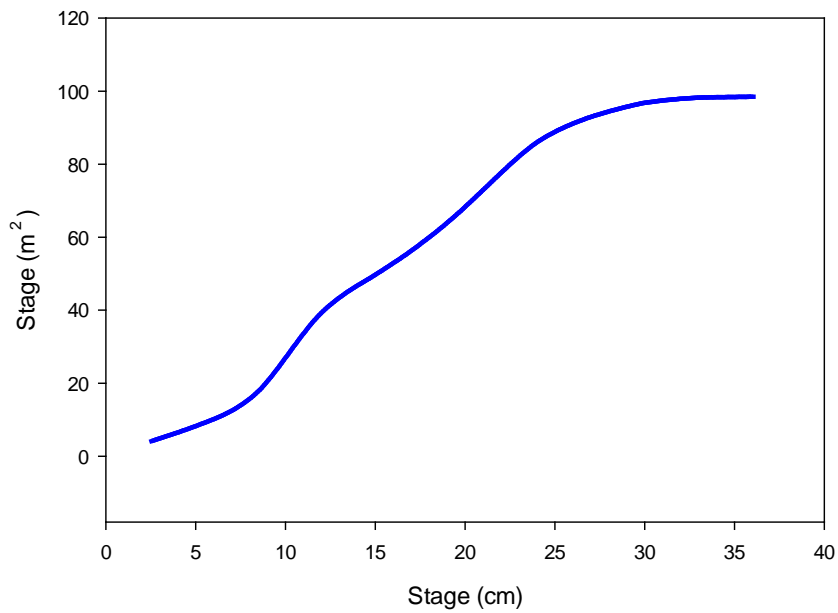


Figure A.2: Stage-Surface Area Relationship for Modified Contour Weep Berm Trench Only.

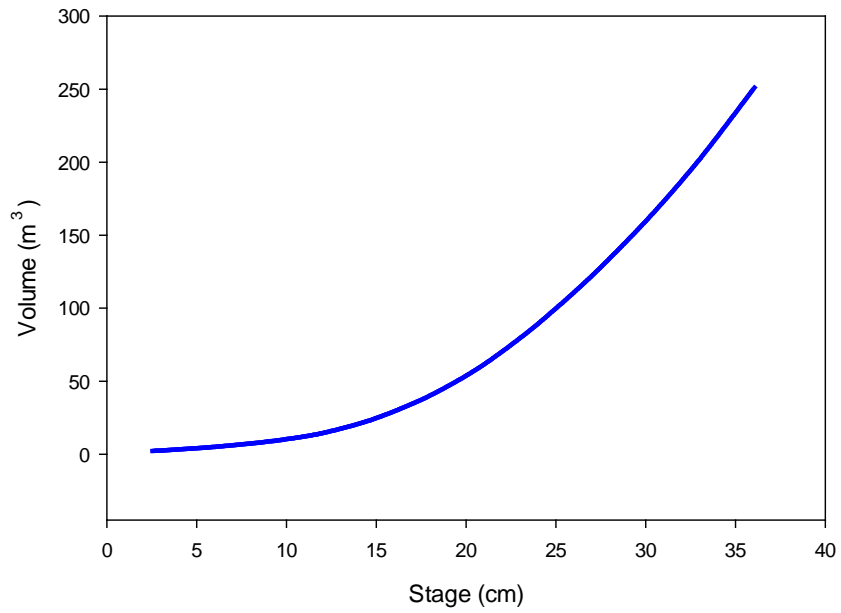


Figure A.3: Stage-Volume Relationship for Modified Contour Weep Berm Excluding Trench.

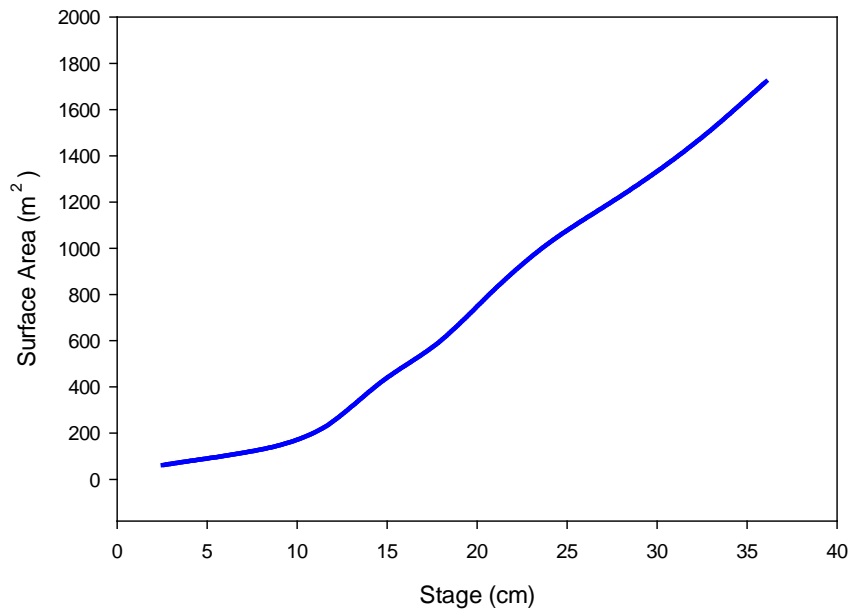


Figure A.4: Stage-Surface Area Relationship for Modified Contour Weep Berm Excluding Trench.

APPENDIX B: RUNOFF PRODUCING STORM EVENTS

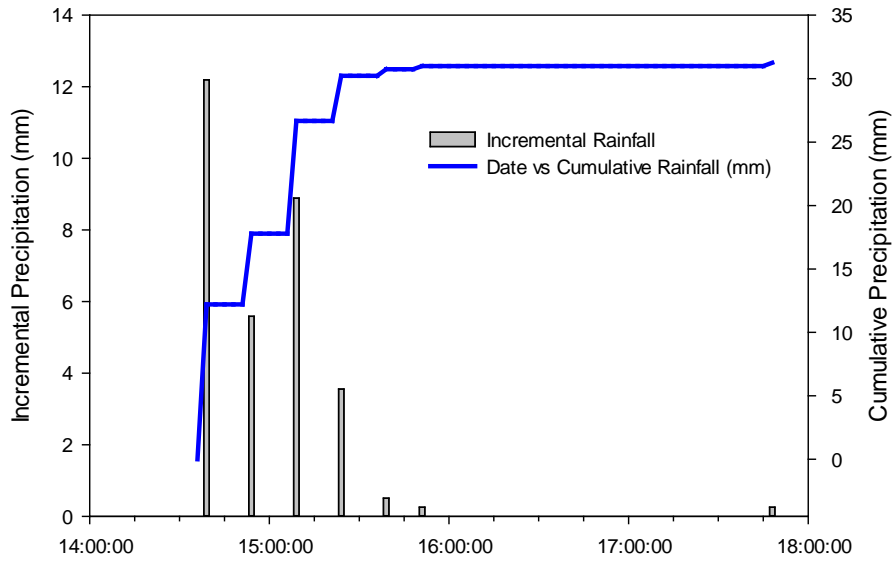


Figure B.11: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 7/22/11.

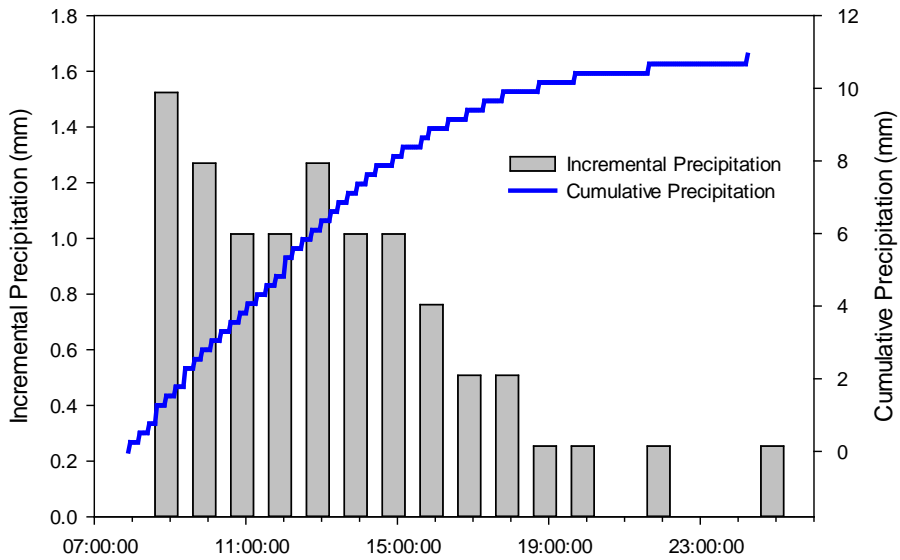


Figure B.2: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 7/25/11.

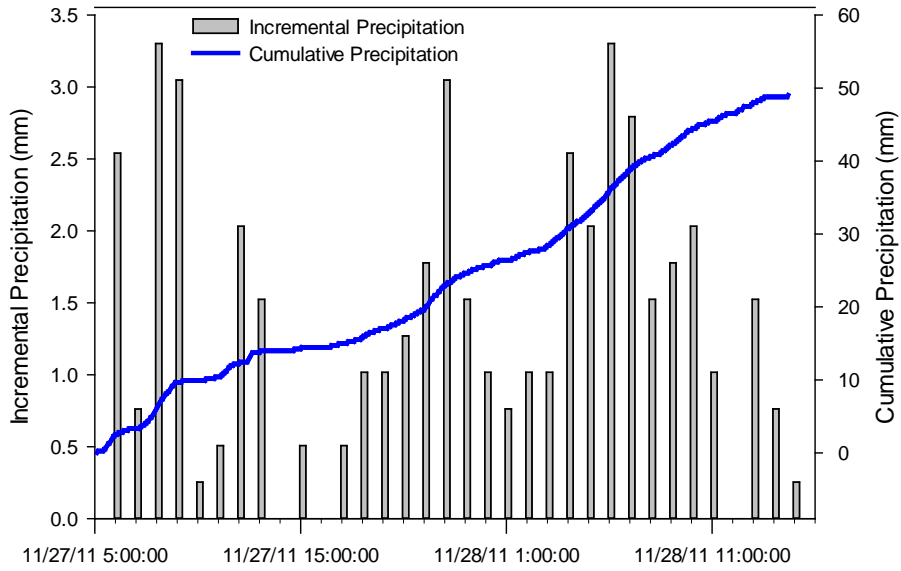


Figure B.3: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 11/27/11.

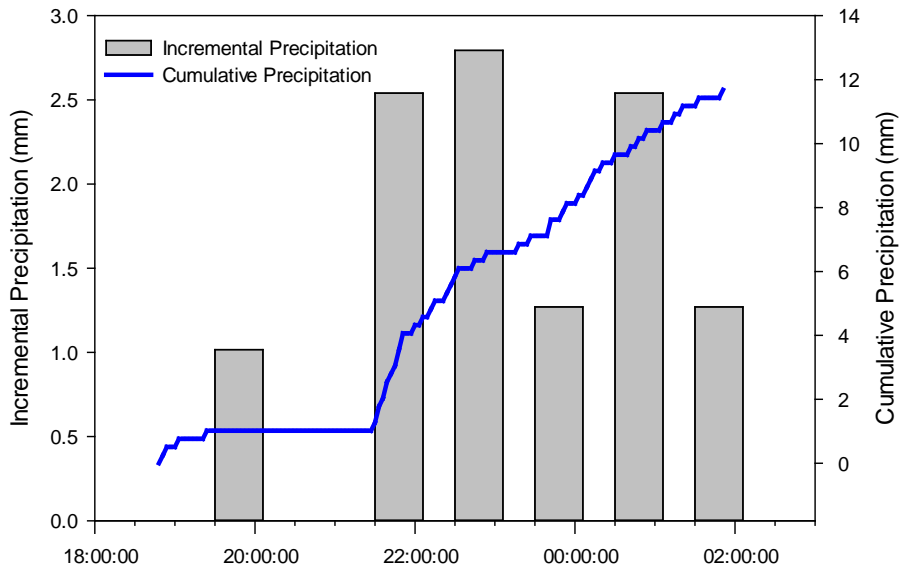


Figure B.4: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 11/28/11.

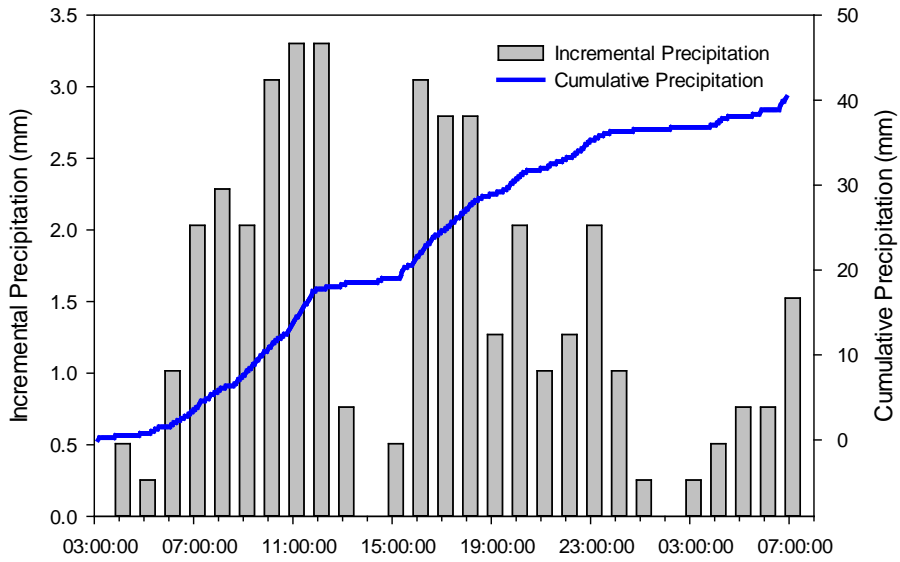


Figure B.5: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 12/5/11.

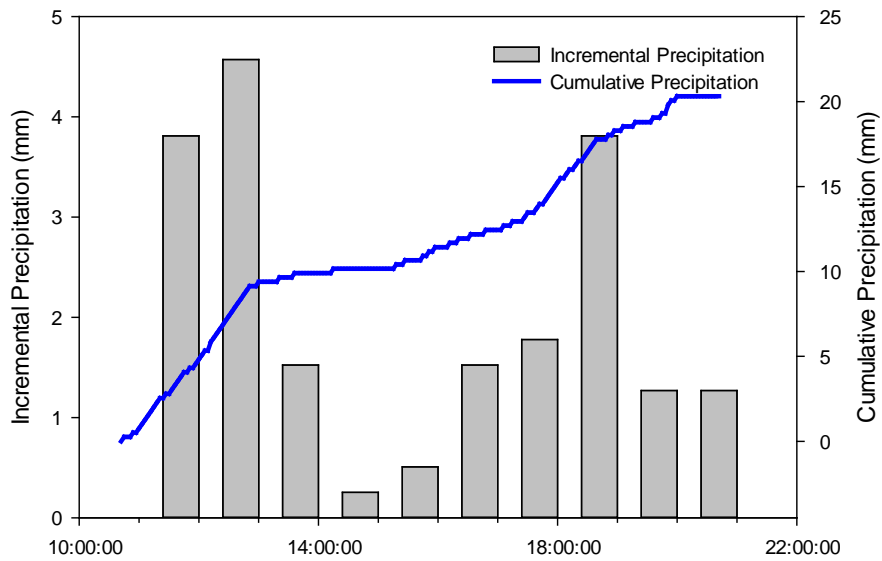


Figure B.6: Incremental Precipitation and Cumulative Precipitation of Victory Haven Training Center for Storm Event on 3/8/12.

**APPENDIX C: STANDARD CONTOUR WEEP BERM GREEN AMPT
INFILTRATION RATES**

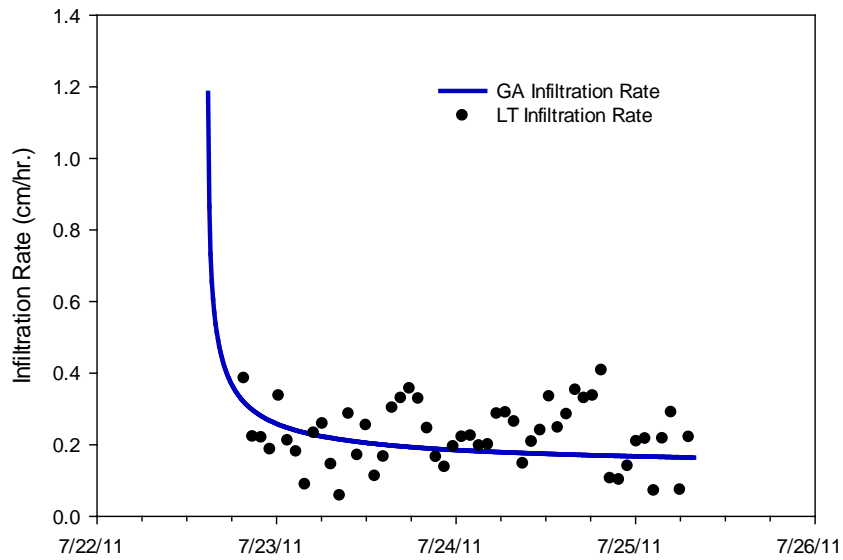


Figure C.1: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 7/22/11. *LT indicates Level Troll.*

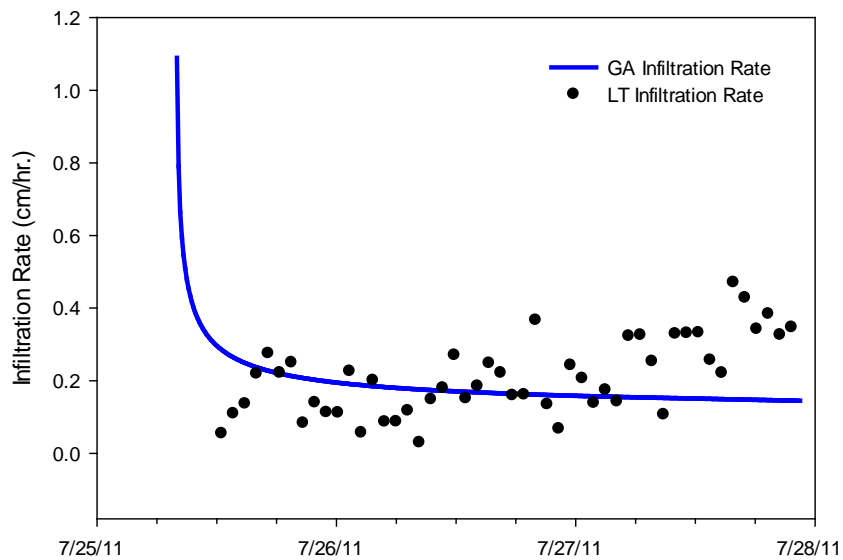


Figure C.2: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 7/25/11. *LT indicates Level Troll.*

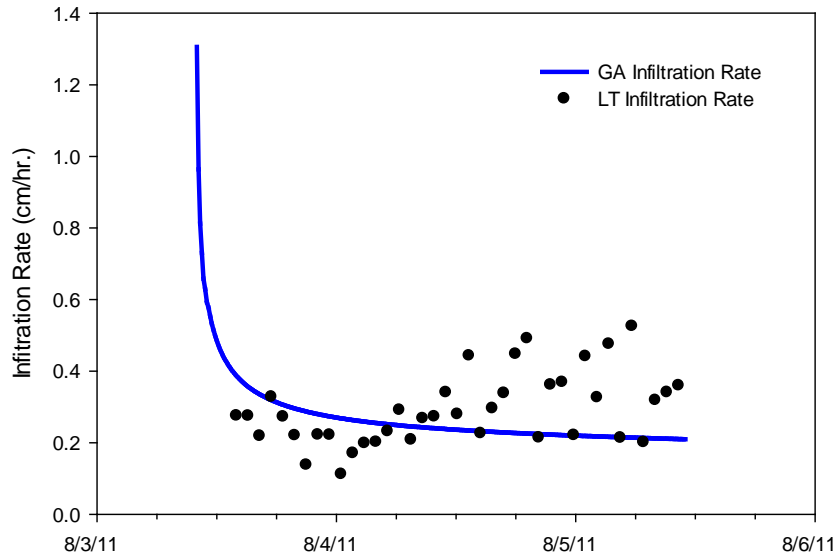


Figure C.3: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 8/3/11. *LT indicates Level Troll.*

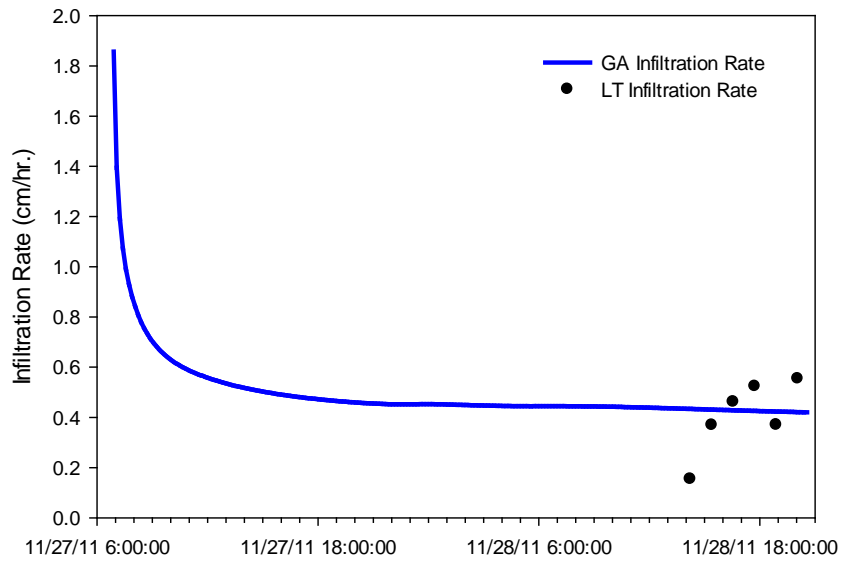


Figure C.4: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 11/27/11. *LT indicates Level Troll.*

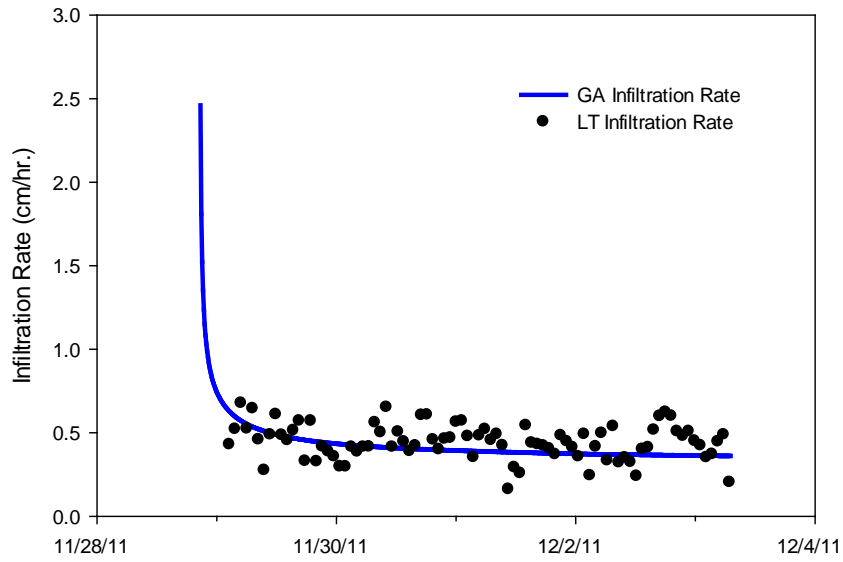


Figure C.5: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 11/28/11. *LT indicates Level Troll.*

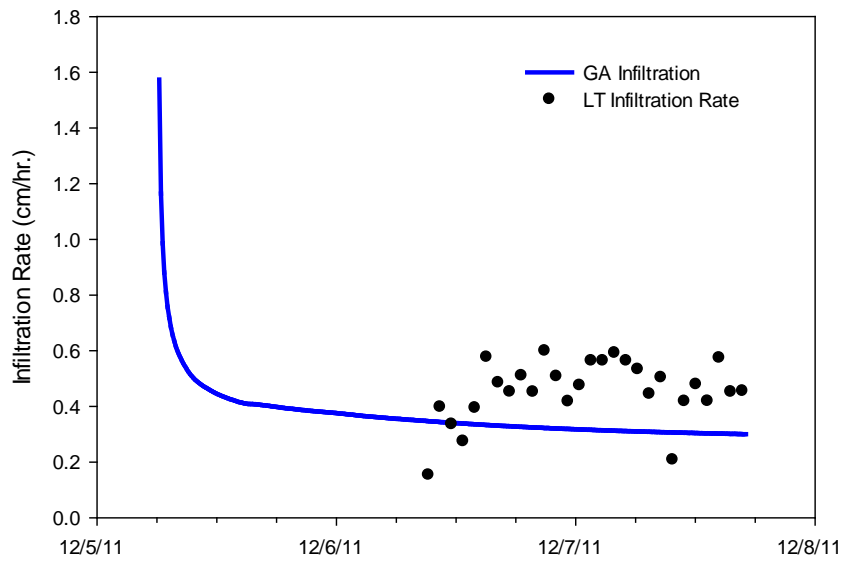


Figure C.6: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 12/5/11. *LT indicates Level Troll.*

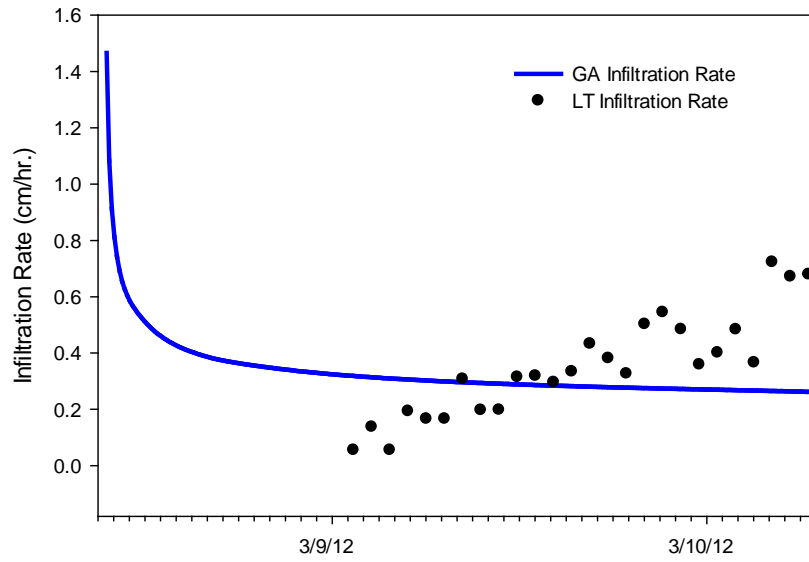


Figure C.7: Standard Weep Berm Infiltration Rate based on Green-Ampt Infiltration Model and Level Troll Infiltration Rate for 3/8/12. *LT indicates Level Troll.*

**APPENDIX D: STANDARD CONTOUR WEEP BERM HORTON MODEL
INFILTRATION RATES AND CUMULATIVE INFILTRATED VOLUMES**

The Horton equation is used to model infiltration rates for surfaces assuming no ponding and a rainfall intensity that is greater than infiltration capacity (Akan, 1993).

$$f = f_c + (f_0 - f_c)e^{-kt} \quad (\text{eqn. D.1})$$

f = infiltration rate (cm hr⁻¹)

f_c = final steady-state infiltration (cm hr⁻¹)

f_0 = initial infiltration rate (cm hr⁻¹)

k = constant for a given soil and initial condition (hr⁻¹)

Table D.1: Horton Coefficients and Cumulative Infiltrate Volumes for Standard Modified Contour Weep Berm.

Date	Final Steady-State Infiltration (cm hr ⁻¹)	Initial Infiltration Rate (cm hr ⁻¹)	Constant (hr ⁻¹)	Cumulative Infiltrated Volume (m ³)
July 22, 2011	0.19	7.6	4.14	15.2
July 25, 2011	0.19	2.5	4.14	8.6
August 3, 2011	0.19	7.6	4.14	7.2
November 22, 2011	0.25	7.6	4.14	19.0
November 27, 2011 ¹	0.25	7.6	4.14	128.5
December 5, 2011 ²	0.25	2.5	4.14	-
March 8, 2012	0.25	7.6	4.14	9.0

¹Combined infiltration of both storm events on Nov 27-28, 2011.

² Sensor pulled, unknown infiltration duration.

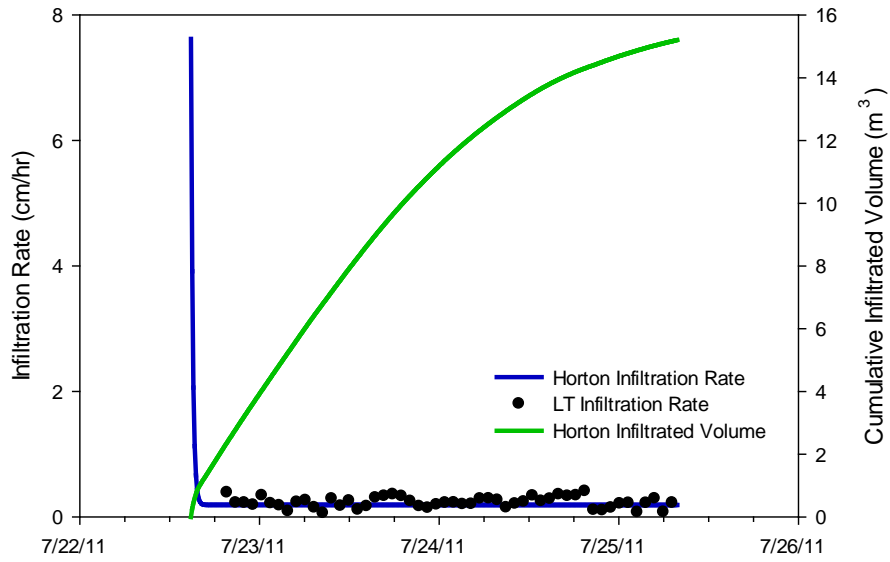


Figure D.1: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 7/22/11. *LT indicates Level Troll.*

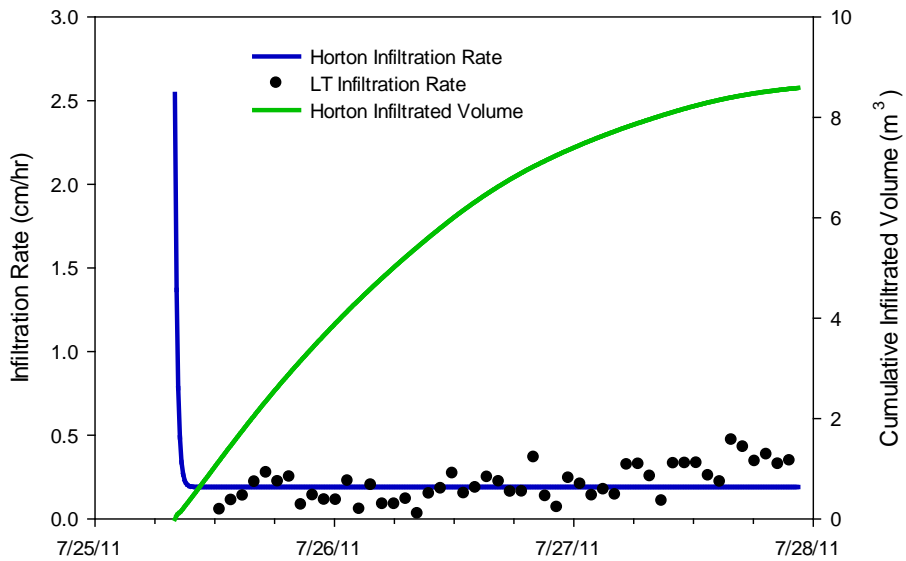


Figure D.2: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 7/25/11. *LT indicates Level Troll.*

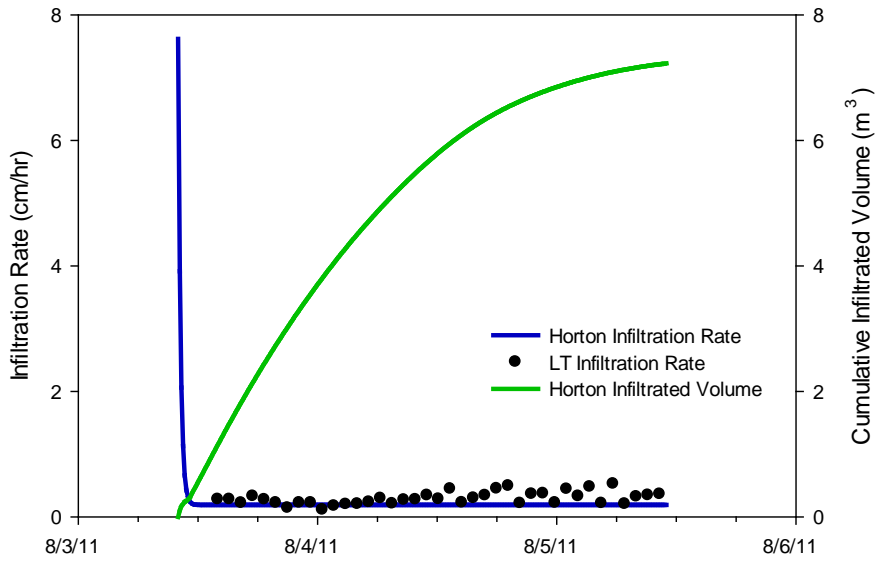


Figure D.3: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 8/3/11. *LT indicates Level Troll.*

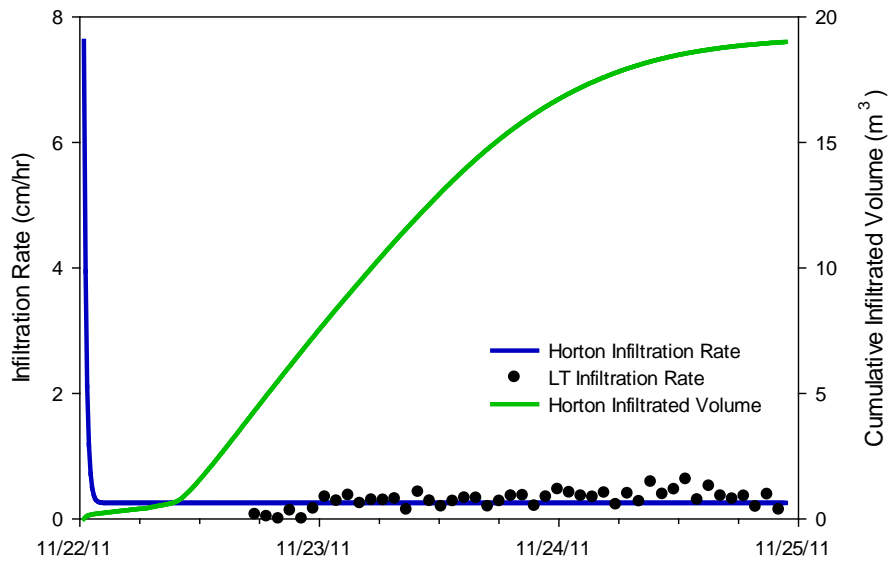


Figure D.4: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 11/22/11. *LT indicates Level Troll.*

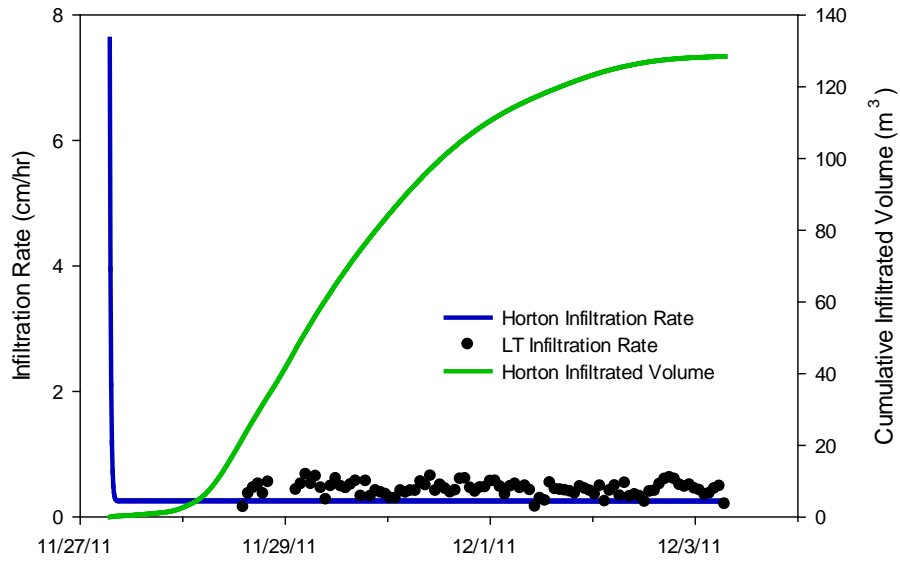


Figure D.5: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 11/27/11 and 11/28/11. *LT indicates Level Troll.*

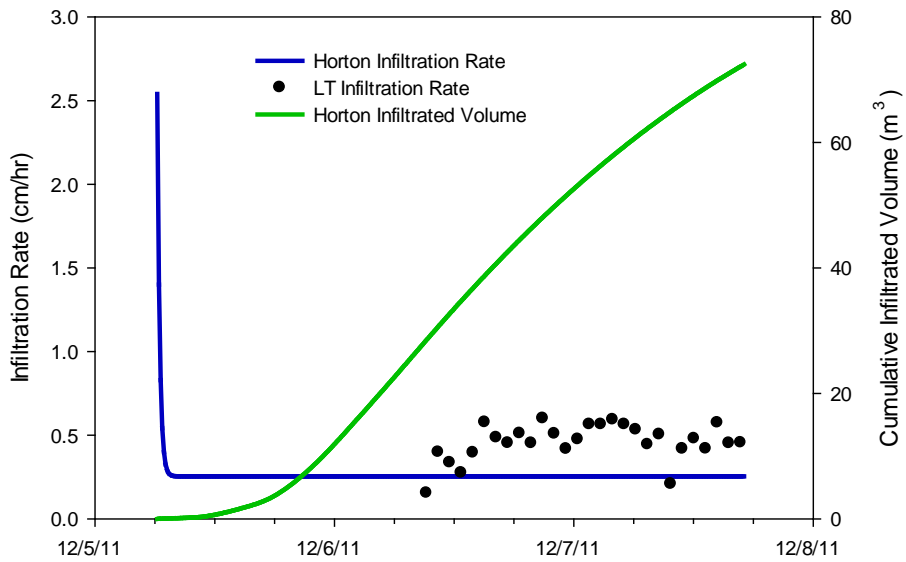


Figure D.6: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 12/5/11. *LT indicates Level Troll.*

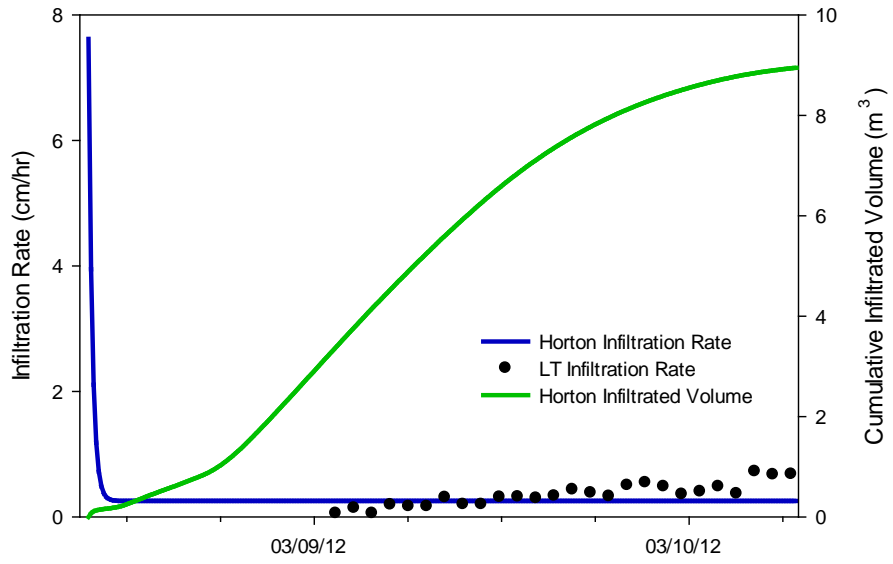


Figure D.7: Standard Weep Berm Infiltration Rate and Cumulative Infiltrated Volume based on Horton Infiltration Model and Level Troll Infiltration Rate for 3/8/12. *LT indicates Level Troll.*

APPENDIX E: CUMULATIVE FREQUENCY

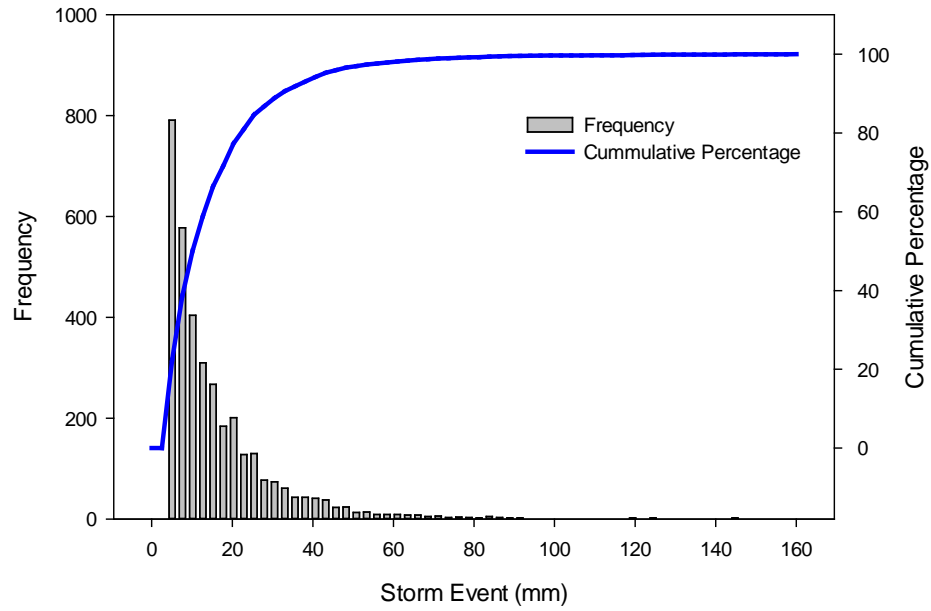


Figure E.1: Method I for 30 years of Historical Data for Lexington, KY Based on Precipitation Levels for 24-hr Storm Events.

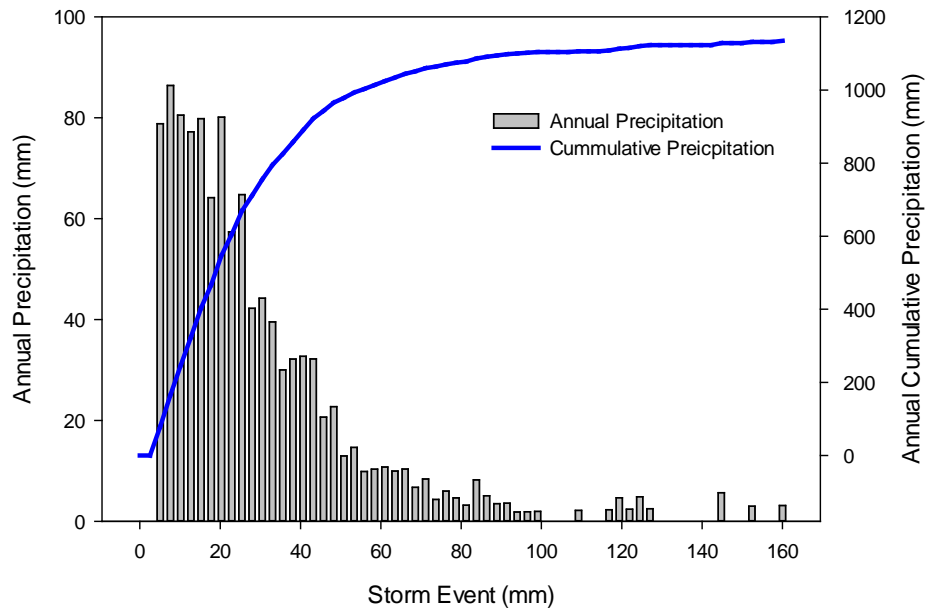


Figure E.2: Method II for 30 years of Historical Data for Lexington, KY Based on Precipitation Levels for 24-hr Storm Events.

REFERENCES

Akan, A. O.. 1993. Urban Stormwater Hydrology: A Guide to Engineering Calculations. Technomic Publishing Co., Lancaster, PA.

American Mosquito Control Association. 2012. Control. Available at: <http://www.mosquito.org/control>. Accessed October 2012.

Atkinson, T.S.. 2010. Hydrologic and Water Quality Performance of a Weep Berm-grass Filter System for Runoff from Stockpiled Horse Muck: A Preliminary Study. M.S. Thesis, University of Kentucky, Lexington, KY.

Barnett, J.R., R.C. Warner, C.T. Agouridis, and D.R. Edwards. 2010. Ability of a Weep Berm to Enhance Grass Filter Performance in a Simulated Grazed System: Preliminary Results. Natural and Environmental Sciences 1: 12-20.

Bonnin, G. M.; D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley. 2006. "Precipitation-Frequency Atlas of the United States," NOAA Atlas 14, Volume 3, Version 3, Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia, 2006. Available at: <http://hdsc.nws.noaa.gov/hdsc/pfds/>. Accessed June 2012.

Bower, H.. 1969. Rapid Field Measurement of Air Entry Value and Hydraulic Conductivity of Soil as Significant Parameters in Flow System Analysis. Water Resources Research 2: 729-738.

Brooks, R.H. and A.T. Corey. 1964. Some Methods for Calculating Unsaturated Permeability. Transactions of ASAE 10: 400-404.

Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements- A review. Journal of Environment Quality 23: 878-882.

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian areas as filters for agricultural sediment. *Soil Science Society of America Journal* 51: 416-420.

Coyne, M.S., R.A. Gilfillen, R.W. Rhodes, and R.L. Blevins. 1995. Soil and fecal coliform trapping by grass filter strips during simulated rain. *Journal of Soil and Water Conservation* 50: 405-408.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. *Soil Science Society of America Journal* 60: 246-251.

Davies, P.E., and M. Nelson. 1994. Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. *Australian Journal of Marine and Freshwater Resources* 45: 1289-1305.

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

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative Filters Strips for Agricultural Nonpoint Source Pollution Control. *Transactions of the ASAE* 32: 513-519.

Exmark Lawn Equipment. 2012. Zero-Turn Riding Mower Safety Tips. Available at: http://www.exmark.com/safety/pdfs/Exmark_Zero_Turn_Safety_Tips.pdf. Accessed July 2010.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keenley, and G.J. Stensland. 1999. Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin. Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. NOAA, Washington DC.

Goolsby, D.A., and W.A. Battaglin. 2000. Nitrogen in the Mississippi Basin-Estimating Sources and Predicting Flux to the Gulf of Mexico. Published: United States Department of Interior, United States Geological Survey. USGS Fact Sheet 135-00.

Grant, DM. 1992. ISCO Open Channel Flow Measurement Handbook. 3rd Edition. ISCO Environmental Division, Lincoln, Nebraska.

Hassanizadeh, S., M. Celia, and H. Dahle. 2002. Dynamic Effects in the Capillary Pressure-saturation Relationship and its Impacts on Unsaturated Flow. *Vadose Zone Journal* 1: 38-57.

Hawkins, R.H., D.E. Woodward, and R. Jiang. 2002. Investigation of the runoff curve number abstraction ratio. USDA-NRCS Hydraulic Engineering Workshop, Las Vegas, NV.

Henley, W.F., M.A. Patterson, R.J. Neves, and A.D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. *Fisheries Science* 8:125-139.

Hershfield, D. M., 1961. Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Technical Paper No. 40, Weather Bureau, U.S. Dept. of Commerce, Washington, D.C..

Higgins, S., S.R. Workman, V.N. Gallagher, D.J. Stamper, and R. Coleman. 2008. ID-168 Composting Horse Muck. University of Kentucky Cooperate Extension Service Lexington, KY.

Hubbard, R.K. 1997. Riparian buffer systems for managing animal waste. Proceedings of the Southeastern Sustainable Animal Waste Workshop. Athens, GA: University of Georgia.

Huff, F.A., and J.R. Angel. 1992. Rainfall Frequency Atlas of the Midwest. Bull. 71. Illinois State Water Survey, Champaign, IL.

Jefferson County Mosquito Control Division. 2012. What Can I do to Have Less Mosquitoes at My House. Available at: <http://www.co.jefferson.tx.us/jcmcd/summary.htm>. Accessed June 2012.

Iowa. 2008. Stormwater Management Manual. 2C-2 Rainfall and Runoff Analysis. Available at: <http://www.intrans.iastate.edu/publications/posts/?publication=stormwater-management-manual>. Accessed June 2012.

Kentucky Division of Water [KDOW]. 2010. Final 2010 Integrated Report to Congress on the Condition of Water Resources in Kentucky. Volume II. 303(d) List of Surface Waters. Available at: <http://water.ky.gov/waterquality/Integrated%20Reports/2010%20IR%20Volume%202-%20Final.pdf>. Accessed March 2012.

Klute, A., C. Dirksen. 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. In: Methods of Soil Analysis, (Ed. A. Klute) Part 1. Agronomy Monograph No. 9: ASA and Soil Science Society of America, Madison, Wisconsin, USA. pp. 687-734.

Lexington-Fayette Urban County Government [LFUCG]. 2009a. Stormwater Manual. Chapter 10: Stormwater Best Management Practices for Water Quantity and Water Quality Control. Available at: <http://www.lexingtonky.gov/Modules/ShowDocument.aspx?documentid=1981>. Accessed July 2012.

Lexington-Fayette Urban County Government [LFUCG]. 2009b. Stormwater Manual. Chapter 11: Erosion and Sediment Control. Available at: <http://www.lexingtonky.gov/Modules/ShowDocument.aspx?documentid=17568>. Accessed July 2012.

Lowrance, R., J.K. Sharpe, and J.M. Sheridan. 1986. Long-term sediment deposition in the riparian zone of a Coastal Plain watershed. *Journal of Soil and Water Conservation* 41: 266-271.

Lowrance, R., L.S. Altier, R.G. Williams, S.P. Imadar, D.D. Bosch, J.M. Sheridan, D.L. Thomas, and R.K. Hubbard. 1998. The Riparian Ecosystem Management Model: Simulator for ecological processes in riparian zones. *Proceedings of the First Federal Interagency Hydrologic Modeling Conference*.

Madison, C.E., R.L. Blevins, W.W. Frye, and B.J. Bartfield. 1992. Tillage and grass filter strip effects upon sediment and chemical losses. In *Agronomy abstracts* pp. 331. ASA, Madison, WI.

Magette, W.L., R.B. Brinsfield, R.E. Palmer, and J.D. Wood. 1989. Nutrient and sediment removal by vegetated filter strips. *Transactions of the ASAE* 32: 663-667.

McCaleb, M.M., and R.A. McLaughlin. 2008. Sediment Tapping by Five Different Sediment Detention Devices on Construction Sites. *Transactions of the ASABE*. 51: 1613-1621.

Moorman, T.B., T.B. Parkin, T.C. Kaspar, and D.B. Jaynes. 2010. Denitrification activity, wood loss, and N₂O emissions over nine years from a wood chip bioreactor. *Ecological Engineering* 36: 1567-1574.

National Climatic Data Center [NCDC] and National Oceanic and Atmospheric Administration. 2002. *Climatology of the United States No. 81. Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1971-2000*, Kentucky 15.

Powers, S.E.. 2007. Nutrient Loads to Surface Water from Row Crop Production. *International Journal of Life Cycle Assessment* 12: 399-407.

- Rawls, W.J., D.L. Brakensiek, and K.E. Saxton. 1982. Estimation of Soil Water Properties. *Transactions of the ASABE*. 25: 1316-1320.
- Rawls, W.J., D.L. Brakensiek, and N. Miller. 1983. Green-Amp Infiltration Parameters from Soils Data. *Journal of Hydraulic Engineering* 109:62-70.
- Robertson, W.D., L.C. Merkley. 2009. In-stream bioreactor for agricultural nitrate treatment. *Journal of Environmental Quality* 38: 230-237.
- Santamaria, P. 2006. Nitrate in vegetables: toxicity, content, intake and EC regulation. *Journal of the Science of Food and Agriculture* 86: 10-17.
- Scarlet, A.J., J.N. Reed, and D.A. Semple. 2006. Operator rollover protection on small vehicles (HSE Research Report 432). Bedford, U.K.: Health and Safety Executive.
- Schipper, L.A., W.D. Robertson, A.J. Gold, D.B. Jaynes, and S.C. Cameron. 2010. Denitrifying bioreactors-An approach for reducing nitrate loads to receiving waters. *Ecological Engineering* 36:1532-1543.
- Schneider, L.E., and R.H. McCuen. 2005. Statistical guidelines for curve number generation, *Journal of Irrigation Drainage Engineering* 131: 282–290.
- Schueler, T. R., and J. Lugbill. 1990. Performance of current sediment control methods at Maryland construction sites. Washington, D.C.: Metropolitan Washington Council of Governments, Department of Environmental Programs.
- Schultz, R.C., J.P. Colletti, T.M. Isenhardt, W.W. Simpkins, C.W. Mize, and M.L. Thompson. 1995. Design and placement of a multi-species riparian buffer strip system. *Agroforestry Systems* 29: 201-226.

Soil Conservation Service (SCS). 1972. National Engineering Handbook, Section 4, Hydrology, U.S. Department of Agriculture, Washington, D.C..

Soil Conservation Service (SCS). 1986. Technical Release 55: Urban Hydrology for Small Watersheds. U.S. Department of Agriculture, Washington, D.C..

Soil Conservation Service (SCS). 1993. National Soil Survey Handbook, Title 430-VI. United States Department of Agriculture, Washington, D.C..

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available at: websoilsurvey.nrcs.usda.gov. Accessed June 2010.

Sturm, T. W., R.C. Warner, S. Torrealba, and F. Hamade. 2007. Demonstration of a Performance Based System of Storm Water and Erosion Controls on Small Residential/Commercial Sites in the Georgia Piedmont, Final Report, EPA, Region 4, Atlanta, GA.

Sutherland, A.B., J.M. Culp, and G.A. Benoy. 2012. Evaluation of Deposited Sediment and Macroinvertebrate Metrics Used to Quantify Biological Response to Excessive Sedimentation in Agricultural Streams. *Environmental Management* 50:50-63.

Taylor, T.J., C.T. Agouridis, R.C. Warner, and C.D. Barton. 2009. Runoff curve numbers for loose-dumped spoil in the Cumberland Plateau of eastern Kentucky, *International Journal of Mining, Reclamation and Environment* 23: 103-120.

Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, New York, New York, USA.

Tollner, E.W. and K.C. Das. 2004. Predicting Runoff from a Yard Waste Windrow Composting Pad. *Transactions of ASABE* 67: 1953-1961.

Toy, T.J., G.R. Foster, and K.G. Renard. 2002. Soil Erosion: Processes, Prediction, Measurement and Control. John Wiley and Sons, Inc., New York. pp. 281-287.

Turner, R. E., N. N. Rabalais, and D. Justic. 2008. Gulf of Mexico Hypoxia: Alternate States and a Legacy. *Environmental Science & Technology* 42: 2323-2327.

U.S. Department of Agriculture [USDA], National Agriculture Statistics Service. 2009. 2009 Agricultural Statistics Annual. Chapter XV Miscellaneous Agricultural Statistics.

U.S. Department of Agriculture, Natural Resource Conservation Service [NRCS].2003. Water and Sediment Control Basin. Conservation Practice Standard, Code 638. Alabama NRCS. Auburn, Alabama.

U.S. Department of Agriculture, Natural Resource Conservation Service [NRCS]. 2004. National Engineering Handbook, Part 630 Hydrology. Accessed May 2012.

U.S. Department of Agriculture, Natural Resource Conservation Service [NRCS].2005. Dike. Conservation Practice Standard, Code 356. Alabama NRCS. Auburn, Alabama.

U.S. Department of Agriculture, Natural Resource Conservation Service [NRCS].2008. Vegetative Treatment Area. Conservation Practice Standard, Code 635. Iowa NRCS. Des Moines, Iowa.

U.S. Department of Agriculture, Natural Resource Conservation Service [NRCS].2010. Filter Strip. Conservation Practice Standard, Code 393. Iowa NRCS. Des Moines, Iowa.

U.S. Department of Commerce, National Weather Service [NWS]. 1961. Technical paper of #40 of the National Weather Service. Available at:
<http://www.erh.noaa.gov/er/hq/Tp40s.htm> . Accessed October 2011.

U.S. Environmental Protection Agency [USEPA]. 1996. Nonpoint Source Pollution: The Nations' Largest Water Quality Problem. Pointer No. 1, EPA841-F-96-004A. Available at: <http://water.epa.gov/polwaste/nps/outreach/point1.cfm>. Accessed May 2011.

U.S. Environmental Protection Agency [USEPA]. 2011. Fact Sheet: Silt Fences. Available at: <http://www.epa.gov/npdes/pubs/siltfences.pdf>. Accessed January 2012.

U.S. Environmental Protection Agency [USEPA]. 2012. Water Quality Assessment and Total Maximum Daily Loads Information, National Summary of State Information.

Available at:

http://iaspub.epa.gov/waters10/attains_nation_cy.control#STREAM/CREEK/RIVER.

Accessed September 2012.

Warner, R.C., T.W. Sturm, and S. Torrealba. 2007. Seep Berm Design Manual. Georgia EPD and U.S. Environmental Protection Agency, Atlanta, GA.

Warner, R.C., C.T. Agouridis, and R.L. Guffey. 2012. Using Weep Berms to Improve Water Quality. AEN-114. Available at:

http://dept.ca.uky.edu/agc/pub_prefix.asp?Prefix01=AEN. Accessed November 2012.

Waters, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7, Bethesda, MD. pp. 249.

Webber, D.F., S.K. Mickelson, B.D. Whitman, T.L. Richard, and H.K. Ahn. 2011. Livestock Manure Windrow Composting Runoff and Infiltration Characteristics from Laboratory Rainfall Simulations. Compost Science and Utilization 19: 6-14.

Wenger, S.. 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens, GA.

Wood, P.J. and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21:203-217.

Young, R.A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. *Journal of Environmental Quality* 9: 483-487.

Zech, W.C., J. McDonald, and T.P. Clement. 2009. Field Evaluation of Silt Fence Tieback Systems at a Highway Construction Site. *Practice Periodical on Structural Design and Construction* 14:105-112.

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