EVALUATION OF CHECK DAMS FOR SEDIMENT CONTROL ON DISTURBED LAND SURFACES

BY

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THESIS

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ABSTRACT

An erosion and sedimentation study was conducted and the University of Illinois at Urbana-Champaign to evaluate the suitability of using check dams as an erosion control practice on military bases. Military readiness and effectiveness is enhanced by constant training and use of their lands; this training leaves the landscape disturbed and more susceptible to erosion. Check dams are an ideal management practice to study because of their small size versus their relative impact. Five types of check dams were investigated: compost filter berm, compost sock, foam and geotextile berm, plastic dam with a compost blanket, and a riprap berm. The check dams were evaluated in two studies, one on the University of Illinois South Farms and one under a rainfall simulator. Many climactic and soil factors were measured, although the main focus was on runoff and sediment removal. The investigation revealed that all structures effectively reduced the amount of sediment lost; all except the compost sock reduced it by over 50%. Some variability was observed and all products were statistically similar with high confidence. Compost berms were the least expensive form of check dam and would likely be the best all around option for the military to use.

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CHAPTER 1: INTRODUCTION

Soil erosion and the resulting sedimentation is an inevitable facet of nature. Geophysical and climactic processes act on the surface of the earth and inevitably move soil around. Despite this, the concern over this natural movement and translocation of soil particles and what they carry are of utmost concern to us as humans. Our activities routinely exaggerate and expedite erosion and sedimentation.

Common causes of accelerated erosion are agricultural practices, construction work, and land development. These disturbances facilitate heightened levels of erosion for a variety of reasons and much of the research about erosion and its control has been based around one of these areas; however, an often overlooked but just as important aspect is erosion caused by the military, namely that on its training grounds.

Erosion and sedimentation training grounds is a dangerous and debilitating problem for the United Stated Armed Forces. Not only are military lands vital to the training and functioning of the military forces but they are also subject to the same environmental standards as every other piece of land. Wildlife habitat, stream and receiving water quality, and a sustainable environment are all greatly affected by erosion on military lands.

Erosion on military training grounds is often due to the direct disturbance of the soil and the ground cover, mainly vegetation. This disturbance can be from foot traffic, vehicular traffic, or ordnance impact. The resulting bare soil is subject to accelerated erosion due to the direct exposure to the elements. The United States Department of Defense (DoD) is charged with being stewards of these lands and is looking for inexpensive and effective means of mitigating this erosion on their lands.

A traditional and common erosion and sediment control practice for this kind of situation is the use of a check dam or series of check dams. A check dam is a small structure that is placed in the flow path of water, normally sheet or channel flow that is designed to slow, or check, the water so that it loses kinetic energy and gives any suspended sediment time to settle out of the flow. Check dams are useful because they can be used to contain a problem area by controlling sediment without having to cover the entire location with an erosion control practice like an erosion control blanket, thus saving time, effort, and hopefully money.

In recent years compost, recycled yard trimmings, or wood waste has been used as an erosion control method. This material is inexpensive and abundant; research has shown it does exceedingly well at controlling erosion when spread as a compost blanket. Compost is gaining in popularity as an erosion control alternative and other ways of using it for sediment control are being studied. Compost can be used as a berm or in a tube or wattle which are very similar to a check dam.

Using the benefits of compost and combining them with the proven effectiveness of a check dam would be an ideal solution for erosion prone areas. This is of great interest and importance to the DoD. Therefore, this comparative study of check dams and compost alternatives was begun.

This study begins by detailing the past research in the area of erosion control and compost and then delves into the performance of compost and check dams in controlling both runoff and sediment removal from two sites: a field study at the University of Illinois South Farms and a controlled rainfall simulator experiment.

CHAPTER 2: REVIEW OF LITERATURE

2.1 MILITARY LANDS

The United States DoD manages 12.1 million hectares with the United States Department of Army managing over 6.2 million hectares that are in active use (OUSD, 2008). These areas vary in size from 1 million hectares to under 0.2 hectares and are used for operations, training, research, development, and testing. Ayers et al. (2000) report that 10 million hectares of these lands are in the United States while 6 million are available for the various military training activities. These lands provide the resources for the United States Military to safeguard itself and its interests from any threat. These grounds are routinely subject to foot traffic, vehicular traffic, military equipment, and ordnance impact as well as natural and geophysical processes.

2.2 EROSION ON MILITARY LANDS

The DoD's training areas are subject to heavy use of all types. Whitecotton et al. (2000) and Wang et al. (2007) both note that military training lands are subject to erosion due to the high level of human activities and presence including foot and off-road vehicle traffic; both disturb the ground and vegetative cover. These disturbances leave the grounds vulnerable to erosion processes. Each year an estimated 2.7 tonnes of soil per acre are lost from military lands (Mitasova, 1999) accounting for billions of dollars of lost time, money, and resources. Nationwide that number is estimated at 1.8 billion tonnes of soil (USEPA, 1997). Sustainable erosion and sediment control practices would help to mitigate this loss.

Damage to the landscape and terrain make it very difficult for the required training to take place in an efficient fashion. The sustainability of the military's training ranges is part of the mission of the Army Corp of Engineers. One of its most severe problems dealing with said sustainability is exposed soil from ordnance impact, steep slopes, and heavy traffic. To keep these training facilities open, a sustainable equilibrium must be reached with soil erosion, land degradation, and land use. Vachta and Hutchinson (1990) state the loss of training land utility to soil erosion at many installations clearly indicates that military training lands are limited resources and thus require careful management.

The military does have set policies dealing with of solving erosion and sediment control issues but follows several guides on a case-by-case basis. The Land Condition Trend Analysis (LCTA) technical reference manual, although out of date by 10 years, states that effective management of training lands requires information regarding initial resource conditions and knowledge of various types of training practices. Military training has both short and long term effects on physical soil properties, vegetative cover and density, and soil erosion (LCTA, 1999).

Erosion control issues often fall under the Integrated Training Area Management (ITAM) and the Sustainable Range Program (SRP). The SRP exists to assist military range managers in complying with environmental regulations, resolving encroachment issues as well as extending training capabilities. Vachta and Hutchinson (1990) suggested the implementation of an erosion control management plan, after investigating several pilot studies based at various military posts across the Untied States. The implementation of an erosion control management plan is imperative to achieve optimal land rehabilitation and maintenance. Determining the effectiveness of erosion control and sediment control practices and the minimizing of costs is crucial to optimize range sustainability and benefit military operations.

Normal avenues of erosion control approach are to manufacture stable slope grades, recondition damaged soils, establish permanent vegetative cover, and stabilize soil slopes (USAF, 2008). Many common management practices used in the real world, such as terracing or change in land use would not be suitable for a military site. Other methods must be implemented for a realistic and efficient training environment that will lessen erosion and sedimentation. Erosion control structures were studied by Svendsen et al. (2005) in temperate climate conditions at several military ranges; they recommend the use of standardized erosion control techniques for all military structures and a comprehensive erosion control plan for the rest of the military lands.

2.3 EROSION BACKGROUND

Erosion is the translocation or removal of soil particles and aggregates via water, wind, frost, ice and/or extreme sun/heat action (Gray and Sotir, 1996). Primary factors affecting erosion are the climate, topography, soil texture, land cover and the past and present land use (Gray and Sotir, 1996; Schwab et al., 1993). Water erosion is generally caused by raindrop impact and the associated surface runoff. Energy for particle detachment and associated transport of the particles is derived from raindrops striking the soil surface and from the runoff across the soil surface (Agassi, 1996). When raindrops strike the soil, energy is transferred for the detachment and transport of soil particles. The particles are then transported across the land surface via runoff and overland flow.

There are two types of water erosion: natural and accelerated. Natural erosion is unstoppable, caused by the natural, environmental, and geologic forces acting on the soil. The natural erosion rate is determined to be that of the undisturbed environmental condition (Toy et al., 2002). Accelerated erosion results from disturbances within the natural system: change of vegetation or cover, exposing of soil, changes in slope. Humans and their influences generally cause such changes.

Accelerated erosion can be subdivided into three categories — sheet, rill, and gully. These terms all pertain to overland flow and are based on the premise of progressing severity. Sheet flow is assumed to be a uniform flow across the surface and thus a uniform removal of soil in thin layers. As erosion progresses rills and then small channels develop. A rule of thumb is that rill erosion begins when sheet erosion reaches approximately 15 metric tons per hectare (Toy et al., 2002). In reality, minute rilling takes place almost simultaneously with the first detachment of particles (Schwab et al., 1993). If rill erosion continues unchecked it progresses into gully erosion; this is where the rills grow into gullies. Common definitions differentiate rills from gullies by the ability to be removed by tillage (Schwab et al., 1993): rills can be removed, gullies cannot.

2.4 EROSION AND SEDIMENT CONTROL STUDIES

2.4.1 Compost and Ground Covers

Erosion control and sediment control are often used interchangeably; the approach of these methods is quite different. Erosion control practices, strategies consist of working with the source of the sediment, while sediment control strategies focus on the recovery and treating the effects once the damage is done (Theissen, 1993). For best results it is important to employ erosion and sediment control practices cooperatively and not depend on one method to the exclusion of the other.

Soil cover has long been known to provide protection against rainfall and preserve beneficial soil properties: namely by reducing erosion. Plant cover is the most natural form of soil cover and has been known for centuries to influence soil properties. Lal (1994) relates that the main reason for early erosion and sedimentation research was to give a means of quantifying soil losses on land treated with conservation practices in comparison with untreated land.

Numerous studies have been done on various types of soil covers and their effects on runoff and erosion. Mannering and Meyer (1963) were some of the first to note that mulches have been effective in controlling erosion; little information is available on the relative effectiveness of various mulching rates, types, or depths. They concluded that mulch rates of 225 to 450 kilograms per acre were suitable in effectively decreasing soil content in runoff.

The Mannering and Meyer (1963) study was conducted with wheat straw mulch, while different researchers studied other types of cover. Corn stover, and soybean residue (Kidder et al., 1943) were studied as well as straw (Kramer and Meyer, 1969). Meyer, and others, conducted many studies on mulches used as an erosion control device and discovered that the mulching rate increased as the erosion hazard increased (Meyer et al., 1970) and the effectiveness of various mulches changed on steeper slopes even if suitable on lesser slopes (Meyer et al., 1971). During this same time research was being conducted that showed that the length of straw mulches also influenced erosion rates and that longer fiber straw mulches were much more efficient at preventing erosion (Kill and Foote, 1971).

Soon after this research, studies delved into a wider comparison of ground covers such as straw, stone, gravel, woodchips, and cement powder (Meyer et al., 1972), at various application rates. They noted that many of these treatments were cheaper than the conventional sodding of slopes. The also noted that stone, gravel, and woodchips perform better than straw. The data from Meyer et al. is displayed in Figure 2.1.

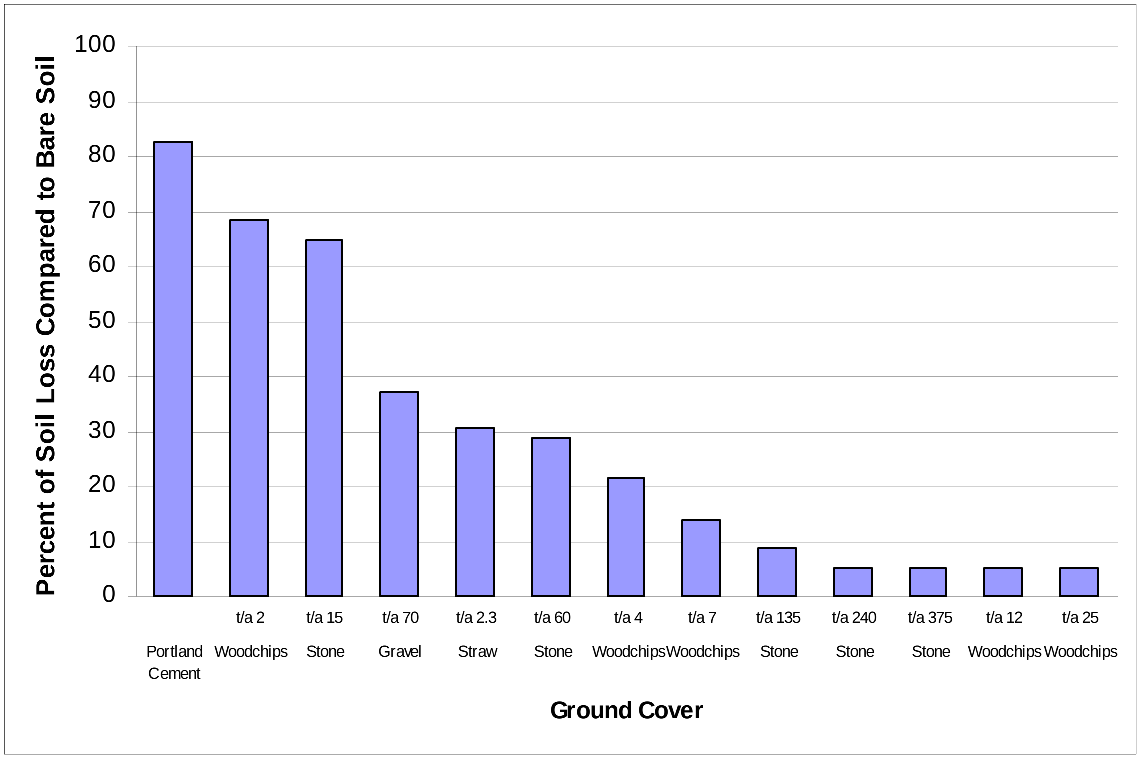

Figure 2.1. Ground coverings used as erosion control (Meyer et al., 1972).

Continuing studies have been done over the realm of variables encountered with compost and erosion research. Codner (2003) compared topsoil and seeded topsoil to bio-industrial byproduct compost, municipal solid compost, and unscreened compost and determined that unscreened compost was the most effective at runoff control and erosion control. The USEPA (1997) determined that mature yard trimming compost was the best erosion control practice, out of hydromulch with fertilizer and similar compost with fertilizer, at controlling both runoff and erosion. Tyler (2001) used various screenings of a yard trimming based compost and resolved that they were all statistically similar. Risse (Risse and Faucette, 2003) compared 11 different compost blankets to a bare soil; only aged poultry litter performed worse than their control. Figure 2.2 details more of their results.

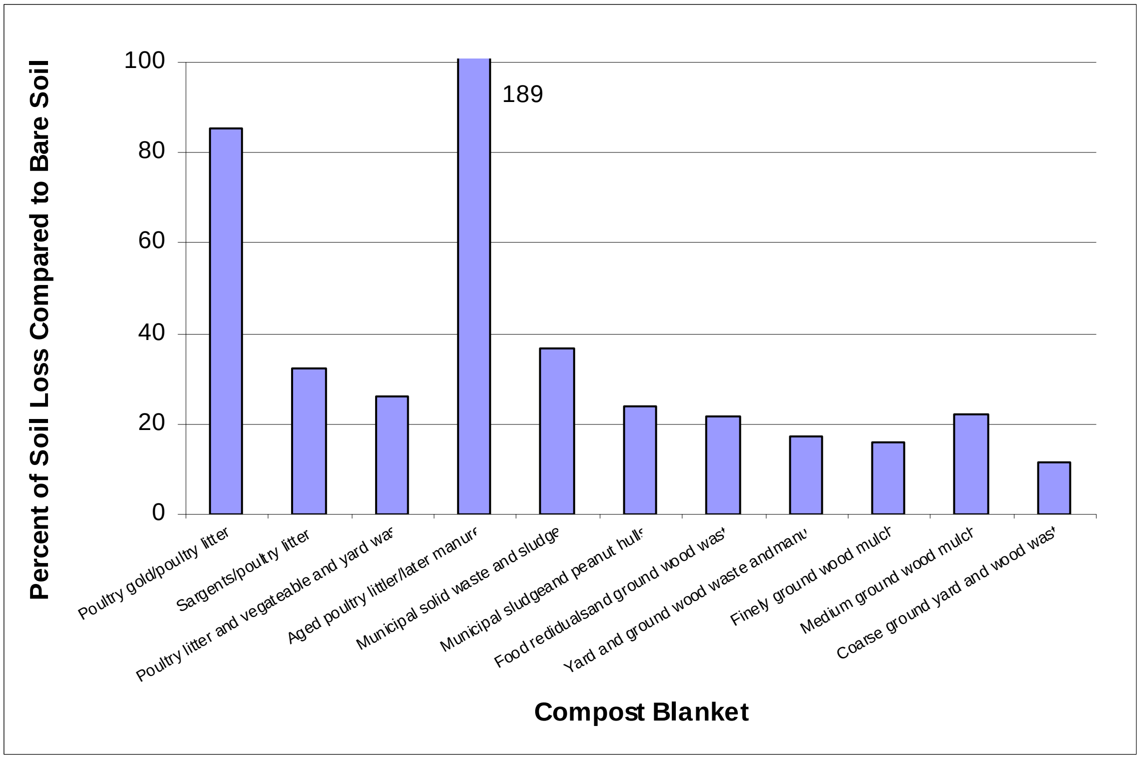

Figure 2.2. Compost blankets used for erosion control (Risse and Faucette, 2003; Faucette, 2004).

Faucette et al. (2007) compared bare soil with straw to several blends of woodchips and compost. They discovered that the greater the percent of compost used in the blanket, the lower was the total runoff, the greater was the percent of rainfall absorption, and the slower was the runoff rate. Conversely, the greater the percent of wood mulch used in the erosion control blanket, the lower was the sediment and suspended sediment load. These results indicate that particle size distribution, not necessarily wood mulch or compost specifically, is likely the main characteristic influencing runoff and/or sediment loss. Buchannan (2002) studied sizes of woodchips and found that a mixture of large and small chips was most effective at preventing erosion and reduced it by 86%.

Curtis et al. (2007) determined that a mixture of soil and 24% municipal yard waste was able to reduce erosion by 50% on steep road cuts on the mountainside. Persyn et al. (2002) and Persyn et al. (2004) compared 3 types of compost to topsoil and compacted subsoil on vegetated and un-vegetated plots. They discovered compost was effective at reducing both runoff and erosion under both cases. Demar (1998) showed mulching reduced erosion by over 90%. The

USEPA (1998) reported that commercial municipal solid waste was one quarter the runoff as bare soil.

2.4.2 Composts Affects on Soil Properties

Detailed studies of mulches and compost as soil amendments have also been conducted. Fairbourn and Gardner (1974) revealed that vertical mulching helped to trap soil moisture and lower soil moisture evaporative losses; this could help increase yields in semi arid regions, but also could lead to higher runoff rates. Municipal sludge was determined to also increase soil moisture content (Epstein et al., 1976). Pagliai (1981) showed the increase in porosity of compost amended soils. These studies were further supported by the Kreft (1987) study that composts increase the water holding capacity of soils and even further bolstered by the United States Composting Council (1996) showing that composts can help improve draught resistance.

The ability of compost to absorb water is not its only beneficial influence on soil. The EPA even listed the benefits of using compost (USEPA, 1997); they stated that compost adds organic bulk and humus to regenerate poor soils, helps suppress plant disease and pests, increases soil nutrient content and water retention, and restores soil structure after reduction by chemical fertilizer. Glanville et al. (2001) and Glanville et al. (2003) displayed plots treated with yard waste or bio-industrial waste composts. Runoff from these plots was statistically lower than plots treated with topsoil and that topsoil treated plots had higher erosion rates.

The addition of compost improves soil structure by reducing the bulk density, increasing the permeability, and increasing aggregate stability according to Kreft (1987) and Tester (1990). The benefits of compost use for erosion control include increasing water infiltration into the soil surface, increasing plant growth and soil cover, increasing water holding capacity of soil (which in turn reduces runoff), buffering soil pH which can increase vegetation establishment and growth, and alleviates soil compaction by increasing soil structure reducing runoff. It also reduces soil particle transport in runoff and reduces soil particle dislodging (Risse and Faucette, 2001). These improvements all help reduce erosion as compost alters the physical properties of the soil, shield from raindrop impact, and help to decrease runoff velocity.

Compost for erosion control is best placed on the surface in a blanket and is roughly three times better than compost incorporated into the soil at preventing soil loss (Agassi et al., 1998). Wischmeier and Mannering (1969) found that the permeability of the surface decreased as organic matter content, percent sand, aggregation index, or bulk density decreased and as silt, clay ratio, suspension percentage, moisture equivalent, or pH increased. Curtin and Mullin (2007) discovered that the addition of mushroom compost increases the organic content but high application rates could decrease aggregate stability. In general the addition of compost decreases soil erodibility.

Faucette is a leading researcher in compost. Faucette et al. (2002; 2004) and Risse and Faucette (2003) compared 11 compost blankets to a bare soil, and noted compost treatments produced more vegetative biomass and cover than the mulch treatments. Muhktar et al. (2004) stated that an erosion control blanket made of 50% dairy manure compost and 50% woodchips had smaller total runoff mass than other treatments and significantly lower total solids and total suspended solids compared to commercial treatments. Foltz and Copeland (2009) indicated that wood shreds reduced runoff and soil loss from both soil types. Erosion mitigation ranged from 60 % to nearly 100% depending on the soil type and amount of concentrated flow and wood shred cover.

2.4.3 Comparison to Conventional Erosion and Sediment Control Practices

The effectiveness of compost continues to remain questionable, as more technologies are developed to fill the same erosion and sediment control niche. Conventional treatments for exposed slopes include silt fencing, straw mulch, sodding, or hydroseeding. These practices are fast and fairly easy to set up but have come under fire from studies supporting the use of composts and other treatments and products as more effective or environmentally friendly.

Ettlin and Stewart (1993) showed that compost blankets easily can out perform silt fencing in term of soil loss and in most cases perform better than wood mulch hydroseeding. They also discovered that compost reduced the amount of heavy metal run off. In 1997, the USEPA released a report stating that an investigation with the use of composted yard trimmings for controlling erosion on highway embankments and the revegetation of those embankments showed that compost outperformed hydromulch (USEPA, 1997). By 1997, 19 different states' highway departments had standards for using compost and 34 states reported use of compost in roadside applications, at least experimentaly (Mitchell, 1997).

Facuette et al. (2005) studied compost over time and found after 3 months compost generated five times less runoff than hydroseed, with silt fence, and after one year generated 24 percent less runoff. However, most of this compost is used as a compost or erosion control blanket; there are other alternatives to using compost blankets.

2.4.4 Compost Filter Berms

Recently, the use of compost and similar products, as well as knowledge of their benefits, has expanded. Compost has also been commonly used as filter berms to filter out not only sediment, but also heavy metals and other pollutants from the water. Faucette has determined that compost filled filter socks or tubes are an effective means to filter pollutants commonly found in urban runoff , particularly, coliform bacteria, metals (with the exception of Chromium), and petroleum hydrocarbons (Faucette et al., 2009). In previous studies, they determined that compost reduced Nitrogen and Phosphorous concentration after several rainfall events compared to hydroseeding (Faucette et al., 2005).

The EPA even recognizes compost as an inexpensive and technologically straight-forward solution for managing hazardous waste streams and for remediating soil contaminated with toxic organic compounds (USEPA, 1998). The USEPA (1997) also found that compost absorbs odors, degrades organic compounds, binds heavy metals and prevents them from migrating or being absorbed, and degrades wood preservatives, petroleum products, pesticides, as well as chlorinated and nonchlorinated hydrocarbons. Compost has achieved the Leadership in Energy and Environmental Design certification as a green building credit for restoring habitat, decreasing storm water, and helping to decrease urban heat islands and water use. It also uses recycled and locally manufactured materials.

Compost filter berms, or compost berms, have also been used to control sediment and runoff. Another report by the USEPA stated, on steep slopes, berms of compost can help prevent erosion by slowing the velocity of water and thus protect receiving bodies of water (USEPA, 1997). Berms can also be placed at the base of slopes and are very effective for sediment control according to Alexander (1999). Demars and Long (1998) found the use of compost berms to be a viable alternative to silt fencing and they can reduce sediment lost rates by an order of magnitude. Later, Demars et al. (2004) studied a paper mill wood waste sediment control filter berm and showed it was more effective than either hay bales or geosynthetic silt fences at controlling sediment from the soil.

Field reports from Richmond, Virginia, Sun City, South Carolina, and two from Columbus, Ohio (Tyler, 2001) reported that compost filter berms and blankets are cheaper and more effective than conventional erosion and sediment control procedures such as hydromulching or silt fencing. Tyler went on to elaborate on the comparison between filter berms and silt fencing. Compost amends native soil assisting in vegetation establishment, is easily reincorporated into the soil, less expensive and more effective at removing sediment and pollutants, and is a renewable resources; silt fencing is ineffective in removing either sediment or chemicals from runoff, hard to maintain during activities, must be picked up at the end of activities, is non-recyclable.

Faucette and Risse compared 12 types of compost blankets or berms and found all but one to be markedly better than bare soil (Risse and Faucette, 2003). The following year the 4 best were compared to conventional practices of hydroseeding and silt fencing and all were found to be much better noting over 3 times the erosion occurred on conventional treatment plots during the first storm and 16 times more on the second. Figure 2.3 shows their data.

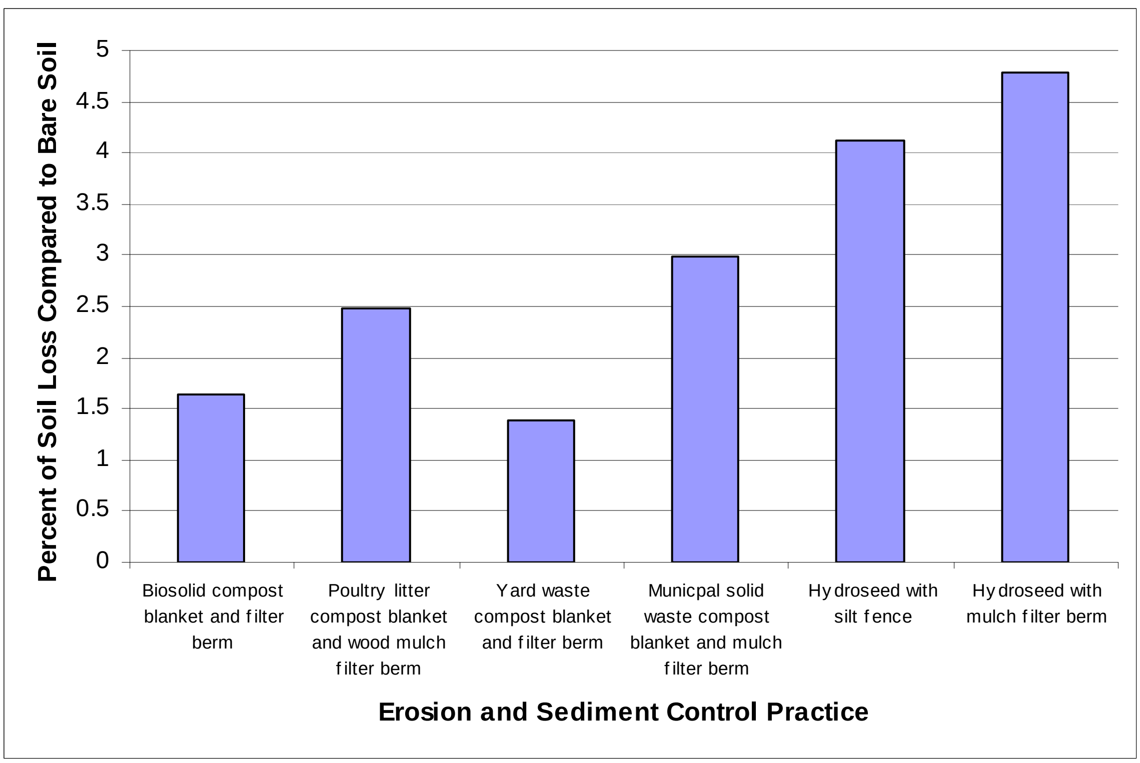

Figure 2.3. Soil loss for compost and conventional practices for erosion control (Risse and Faucette, 2003).

2.4.5 Compost Socks

Compost can also be placed in a fiber tube and placed similarly to a berm; such application is commonly referred to as a compost sock or a silt sock. Research by Keener et al. (2006) provides details of how such socks are comparable to silt fence and actually more durable and less likely to over flow even at half the height. They noted suspended solid removal was not statistically different between the two treatments. Kelsey (2007) showed that tubular sediment control practices are effective tools for reducing soil loss and sediment concentration through cumulative storms; and that excelsior fiber logs reduced soil loss better than straw wattles. Her data is graphed in Figure 2.4. Kelsey also noted that buffer strips are even more effective than silt sock or tubular devices.

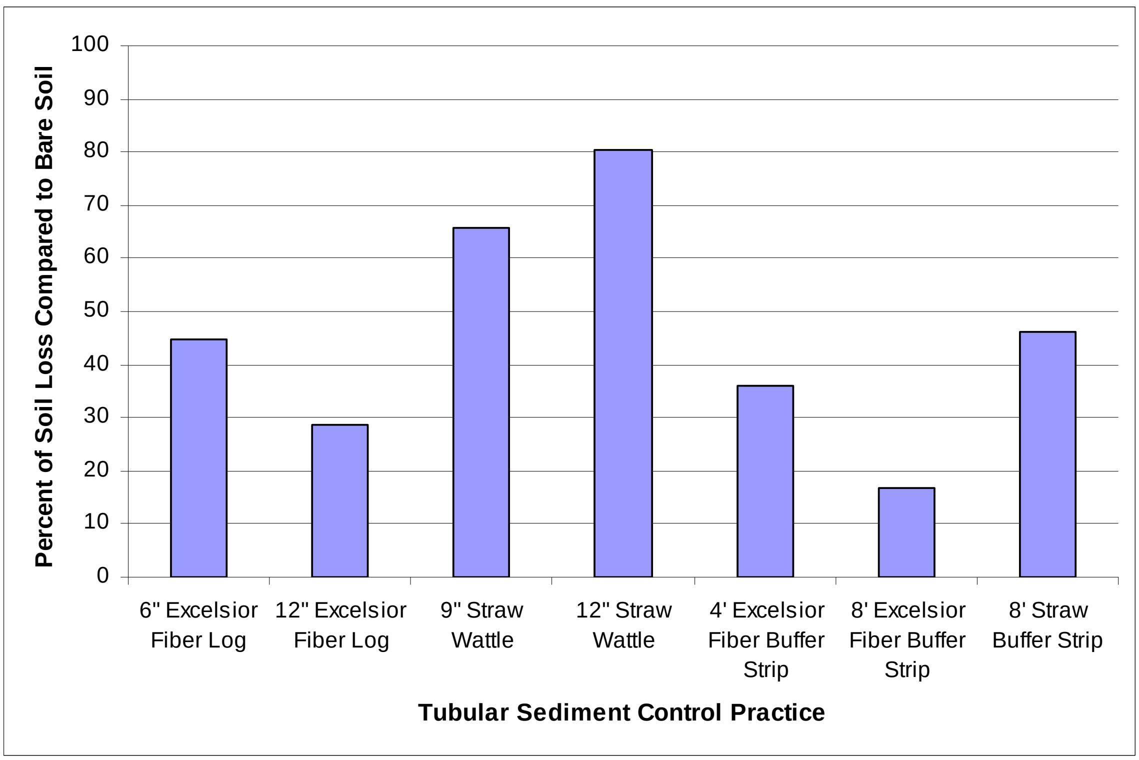

Figure 2.4. Sediment loss for tubular sediment control practices (Kelsey, 2007).

Faucette et al. (2009) studied compost socks and revealed straw bales, mulch filter berms, compost filter socks, and compost filter socks with polymer all discharged significantly lower total suspended solids than the bare soil, and that all compost sock treatments were significantly lower than the mulch filter berm and straw bale.

2.4.6 Other Erosion and Sediment Control Check Dams

Check dams are structures placed in the flow path that impede/check the flow of runoff, reduce flow velocity, and allow for sedimentation. Check dams are common in sheet or channel flow scenarios were flow paths are predictable. Check dams can be used in series or as an individual dam. Their intended use has a considerable impact on their application and installation.

In series they are in effect an erosion control practice. They creating a series of obstacles that break up the flow path, shorten the slope length, dissipate the energy of the flow, and alter the land grade via sedimentation. This is all in an effort to prevent the detachment of soil. In this installation the peak of one dam is no lower than the base of the upstream dam so that in maximum flooded conditions ponding would create terraces of water.

A solitary check dam is often placed toward the end of a slope and is a sediment control method. It is designed to impede the flow so that sediment will come out of suspension and be deposited before the flow continues on. Placing it toward the end of the slope leaves little area left for the effluent water to erode more sediment. This difference in intended purpose is important to know as it impacts there use.

The difference between erosion and sediment control is also important in comparing between control practices and research studies. Silt fence does not prevent erosion, but is designed for sediment control. Most ground covers are designed to prevent erosion while, hydroseeding or compost blankets can be used for both. Just because a product can be used for controlling sediment does not make it applicable for erosion control, and vice versa.

In 2004 (Leib et al., 2004) check dam systems were compared versus other common practices such as drains, surge irrigation, and grass lined ditches for suspended sediments in the water. Check dams were out preformed by the grass ditches in removing sediment, but were comparable to grass in infiltration and stopping bed load transport. A case study by Hassanli et al. (2009) revealed that placement of the dam determines the amount and type of sediment caught by the structure and the farther downstream the dam is placed the more fine sediment it traps.

In China (Xu et al., 2005) an analysis of a check dam system in place on a loess plateau revealed that the check dam system had retained the most sediment out of all erosion control measures used. Research and modeling by Boix-Fayos et al. (2008) indicated that check dams are effective measures for decreasing sediment yield in catchments; check-dams are very effective in the short term, but may potentially increase erosion downstream. This increase is caused by the check dam's slowing of water and allowing sediment to settle out of suspension, the resulting flow from the check dam would have more potential for erosion as it is not carrying as much sediment as before.

Check dam structures can be composed of many materials that have varied properties; they must be durable to withstand the force of the moving water, porous so water will flow through not over, around, or pond behind, and stable so that they do not move or get washed away. Common materials include straw/hay bales, wood chips, compost, organic fibers, foam, riprap, silt fences, and plastic dykes. Industrial products are commonly composed out of various plastics, foams, fibers, and organics.

Over the years many more studies have been done to compare various types of compost or products and their erosion or sediment controlling potential. However, the vast array of variables makes the plethora of information invaluable. A list of study results mentioned is tabulated in Appendix A.

CHAPTER 3: OBJECTIVES

The overall objective of this study was to observe the soil erosion and analyze the sediment lost and surface runoff amounts associated with various check dam practices on near bare soil, and to provide recommendation for their use to prevent soil loss. The specific objectives are:

- Monitor field soil loss and runoff from check dam plots on a Dana silt loam soil
- Analyze erosion and runoff data from rainfall simulator with check dams
- Assess the affects of check dams and their usefulness on bare soil conditions
- Suggest beneficial check dam practices to eliminate problems due to erosion

CHAPTER 4: METHODS AND MATERIALS

4.1 CHECK DAMS STUDIED

Five types of check dam structures were considered in the studies: riprap berm, compost berm, plastic grid dam, foam dike, and compost sock. Each check dam system has very specific standards to meet and specifications to follow. These specifications were met as closely as possible and modified to fit the study criteria and setup. Check dam systems are designed to be used in series such that the foot of the upstream structure is no higher than the peak of the downstream structure. Thus, all structures used were close to the same height and, therefore, met similar spacing requirements. This was 5.8 m and was used in the field plots. Table 4.1 summarizes the important details of each structure.

Table 4.1. The height and type of check dams studied.

Check Dam	Product	Height [m]
Compost Berm	Compost	0.30
Compost Sock	Ditch Chexx[1]	0.30
Foam Dike	Triangular Silt Dike[1]	0.25
Plastic Dam	GeoRidge[1]	0.28
Riprap Berm	Riprap	0.30

[1]: Reference to any specific companies, commercial products, process, or service by name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by any of the entities or individuals involved.

4.1.1 Riprap Berm

There are many standards and specifications for riprap and riprap berms. The check dams were established according to specifications from Indiana Department of Transportation (IN DOT, 2006) and the Metro Council (Barr Engineering, 2001). Such specifications were chosen due to their clarity and the regional similarity to the area of this study. The stone used for the dams consisted of crushed quarry rock and was sized according to the standards: ASTM D 6092-97 and ASTM D 4992-07.

The dams were lined with GeoTex 102F (Propex, 2008) a woven geotextile designed for such use. It was keyed into the soil to a depth of 2-3 inches. To simulate field conditions, check dams were placed flush against wooden side structures. This was done to mock the keying in of the check dams' sides found in natural or man made ditches. The rock was dumped in place by hand as recommended in the standards to form a natural pile. The berm was trapezoidal shaped with a base width of 1.5 m and a maximum height of around 0.3 m. The berm had a maximum side slope of 2 to 1, horizontal to vertical. A photograph of a riprap berm used in the study is shown in Figure 4.1.

Figure 4.1. Riprap berm at field study site.

4.1.2 Compost Berm

There were minimal available resources on the installation of a compost berm but a plentiful amount of standards regarding the amount and type of compost. The AASHTO standard MP-9 (AASHTO, 2003) and USCC, (2001) were the standards used for the compost filer berms. The compost used had to meet the rigorous criteria set out in the standards; nine different types of compost were gathered from the Urbana Landscape and Recycling Center and tested according to TMECC (USCC, 2004) to meet the standards, most specifically the standard for particle size distribution. It was determined that premium shredded mulch (ULRC, 2008) would be the most economical of the mixes available that met the standards. The compost size standard and compost size used are shown in Figure 4.2.

A trapezoidal berm, with a base of 1.5m wide, was created roughly 0.3 m tall, with side slopes of 2 to 1. The compost berm was also placed flush up against the side borders. The compost was placed by hand in order to get accurate dimensions and then allowed to vegetate naturally. A photograph of a constructed berm is shown in Figure 4.3.

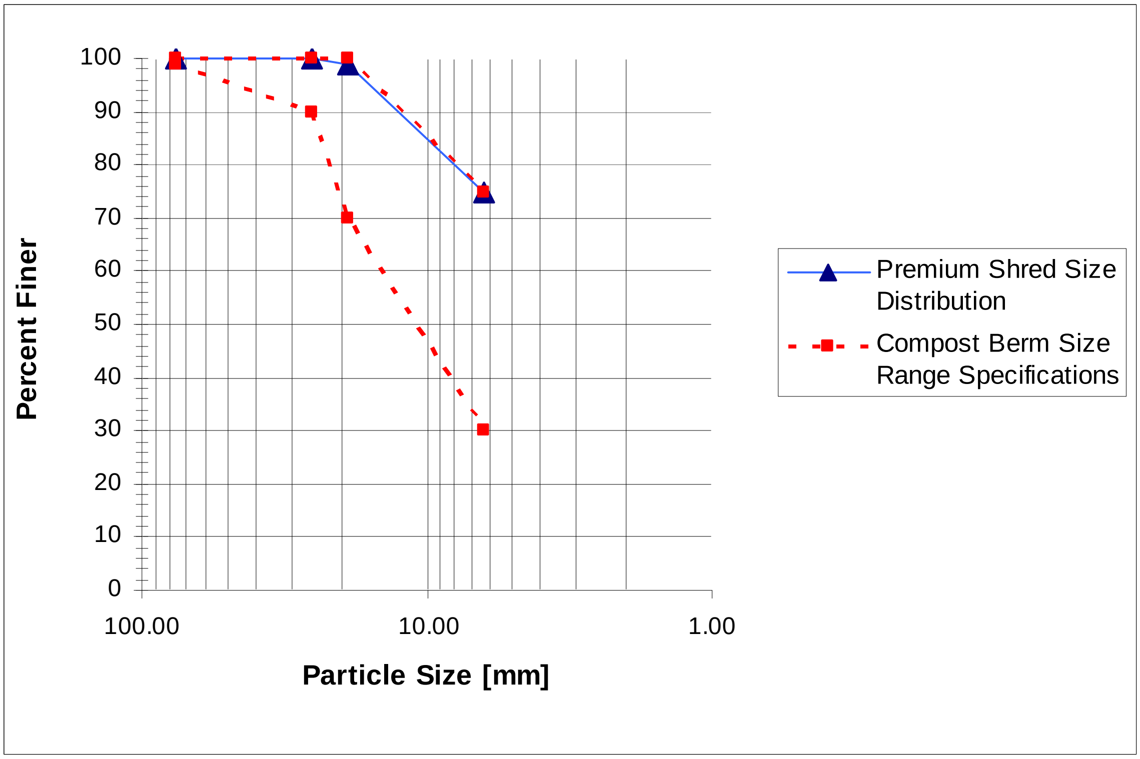

Figure 4.2. Particle size standard for compost berm compared to premium shredded compost.

Figure 4.3. Compost filter berm at field study site.

4.1.3 Compost Sock

Commercially produced products had their own set of guides and specifications to follow. One of these products was Ditch Chexx; it also utilized compost. Ditch Chexx is a fiber mesh bag filled with a specific standard of compost. Such check dams are commonly referred to generically as compost socks or silt socks. The compost came with different requirements (Filtrexx, 2005) than the compost for berms. The compost and fiber tube socks were therefore purchased pre-filled from an authorized dealer.

These check dams were installed on the site following the provided methods of application and installation from Filtrexx (Filtrexx, 2008); the socks were installed in a C-shape curved with the direction of flow. The side of the tube were placed as flush to the borders as possible to minimize gaps that would allow the water through unchecked. The minimum of three stakes were anchored through the compost sock as specified, one through the middle and one at each end. These plots were inspected and maintained according to their guide. A photograph of the plot setup of a compost sock can be seen in Figure 4.4.

Figure 4.4. Compost sock at field site.

4.1.4 Plastic Dam and Compost Blanket

Another product tested in the study was a GeoRidge check dam. Manufactured by Nilex Inc. GeoRidge is a triangular plastic grid dam frame. The structure could have been installed as is, according to the installation manual (Nilex Inc., 2008); however, the manual recommended that an erosion control blanket (ECB) be used under it. For the purposes of testing compost in this experiment, a compost blanket was used in place of a traditional ECB. Two inches of compost were hand placed on the ground, to insure accuracy of depth and the two panels of the grid were staked into the ground with 5 stakes each so that there was at least 6 inches of overlap between the panels.

This compost blanket was determined from the AASHTO guide MP-10 (AASHTO, 2003) and the best available compost was determined to be the Economy Chipped Mulch, Eco Chip, from the Urbana Landscape and Recycling Center (ULRC, 2008) using TMECC standards (USCC, 2004). Figure 4.5 shows the compost blanket size standard and the selected compost size. The finished setup of this structure can be seen in the photograph in Figure 4.6.

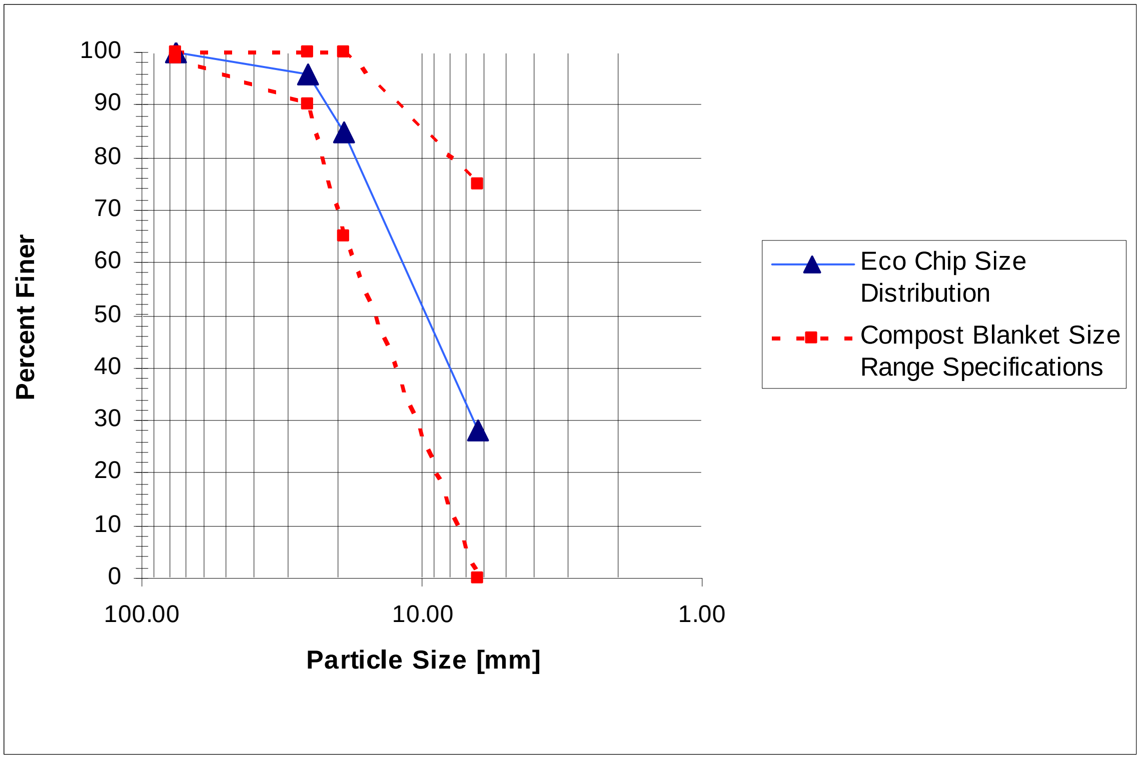

Figure 4.5. Particle size standard for compost blanket compared to eco chip compost.

Figure 4.6. Plastic dam and compost blanket and field site.

4.1.5 Foam Dike

The final product studied was the Triangular Silt Dike. Triangular Silt Dike is a triangular polyurethane log wrapped in geotextile. The foam dams came pre-wrapped in geotextile which already met erosion control specifications (TSD, 2005). The entire foam dike came with its own set of specifications (ACF, 2005) and was installed accordingly. The geotextile was wrapped around the foam core and then extended on the sides to create an apron that covered a total length of 1.6 m, including the 0.5 m foam core. The geotextile was then keyed into the soil a depth of 2-3 inches. The structure is shown in Figure 4.7.

Figure 4.7. Foam dike at field site.

4.2 FIELD SITE

The field experiments were conducted at the University of Illinois at Urbana-Champaign (UIUC) South Farms. Experiments were run during a period from 2008-2009. Sixteen field plots were established on Dana Silt Loam 56B (USDA, 2008) on a 0.6 hectare plot with an average slope of 24:1, or 2.4 degrees. They are located at 40°03’24.30”N and 88°11’27.40” W. This site was surveyed with a Topcon GTS 312 total station. The map in Figure 4.8 was generated that shows the experiment site.

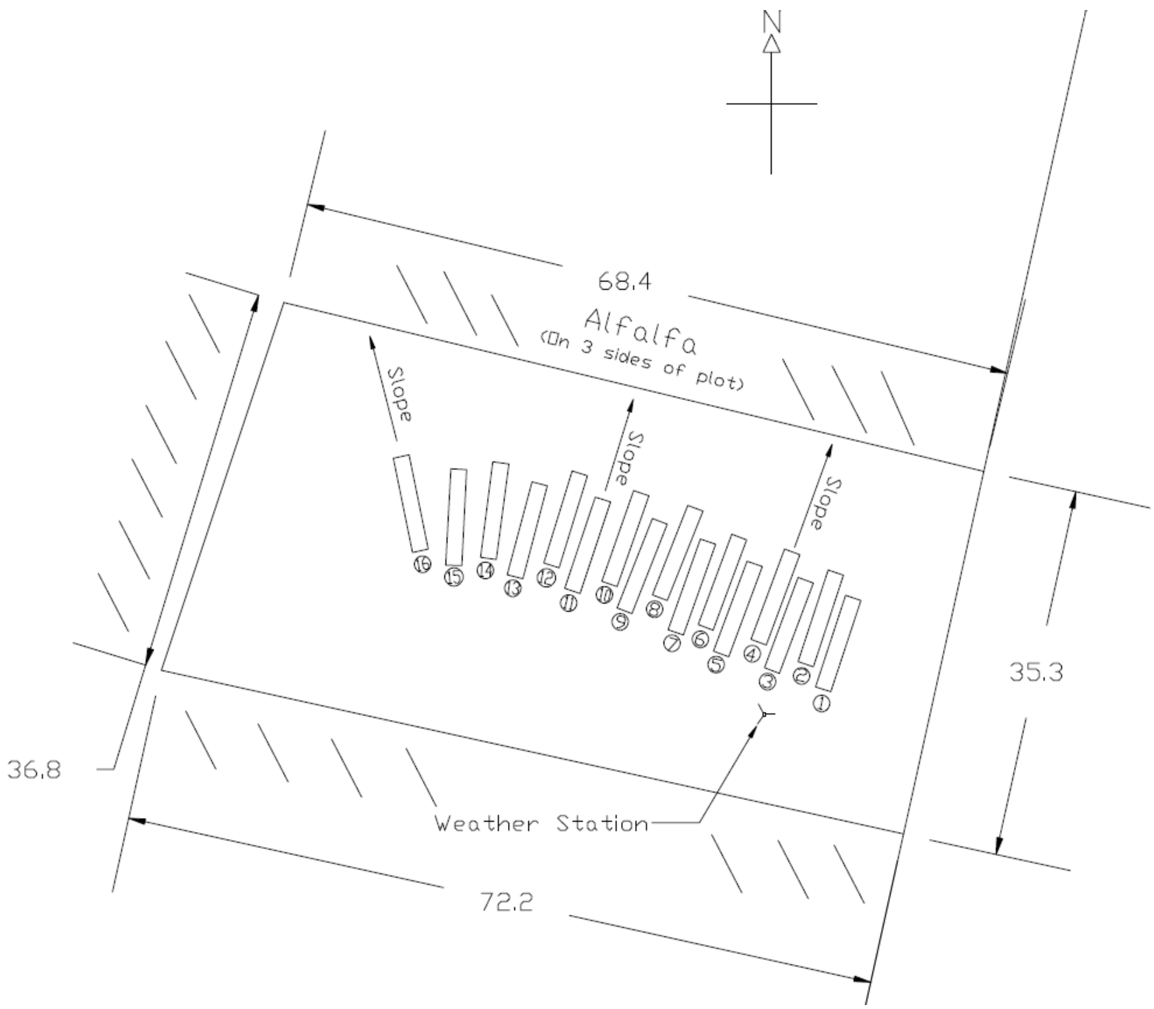

Figure 4.8. Map of field study site at the UIUC-South Farms, dimensions are in meters.

4.2.1 Weather Station

An Onset HOBO Weather Station equipped with an array of environmental sensors was installed on the field site according to provided specifications from Onset Computer Corporation. The weather station had many sensors that were installed on it: soil moisture smart sensor, barometric pressure smart sensor, silicon pyranometer smart sensor, tipping bucket rain gauge, photosynthetically active radiation sensor, temperature/relative humidity smart sensor, and wind speed and direction sensor. A more specific description of sensors is included in Appendix B. The logger was configured with BoxCar Pro 4.3 software and set to record every 15 minutes over the duration of the experiment. Data collection was sufficient for the study because the small immediate changes in weather are not as crucial as the larger changes, however short term changes in rainfall intensity are important. The logger was set and maintained from July 15, 2008 to May 20, 2009.

4.2.2 Field Soil and Plot Details

Dana silt loam soil typically has a pH from 5.6-7.3, organic matter percent of 3.0-5.0, clay percent from 18-27, and has a moderate fine granular structure (USDA, 2008). Soil samples taken from each plot were sent to a soil lab to be analyzed. The complete results are in Appendix C. Soil lab results concurred well within all these given ranges except for an organic matter. It ranged from 2.5-3.1 percent, likely due to the active farming done on the site before use in this study.

The 16 plots were established using a modified Mutchler's setup for USLE style plots (Mutchler et al., 1994). The plots had shortened plot length due to limited slope lengths in the research area. Full size USLE plots could not be used because the length of slope on the hill would not allow for it without major topographic changes. Limitations in area along the slope also restricted the number of plots; thus, there was only one control plot and three replications of each check dam plot.

Plot dimensions were 1.5 m by 8.9 m. The plots had 7.5 m^2 of exposed soil, followed by a check dam structure, 0-2 m in plot length, and the rest of the plot was left bare until it terminated 8.9 m from the start of the plot. The check dams were not placed at the end of the plot so some soil loss was expected; this allowed for the check dams affect on the runoff and flow to be taken into consideration. Plots were lined with 15 cm metal borders with 45 cm wooden borders around check dams to allow for stability of berms and containment of ponded water. The metal borders were sealed with a water repellant foam sealant as shown in the photograph in Figure 4.9.

Figure 4.9. Plot borders with foam sealant.

The soil was sprayed with a glyphosate herbicide to eliminate plant growth and keep the plots mostly bare throughout the study period. The glyphosate herbicide was reapplied twice during the study period when weeds infiltrated the erosion plots and provided unwanted soil cover. Treatments, utilizing compost, were not sprayed and were allowed to vegetate naturally.

All plots converged to a flow control structure, either a chute flume or a 90 degree V-notch weir. The structures were placed so that the same area of soil surface was exposed, albeit not the same shape. The weir was added so that given a substantially large rainfall event time rates of flow from the plots could be recorded; no such event occurred during a time that was suitable to observe. The entire runoff was collected in a series of buckets. The buckets were covered with lids to keep out animals and avoid error due to evaporation and direct rainfall collection. Figure 4.10 shows the basic layout of the plot.

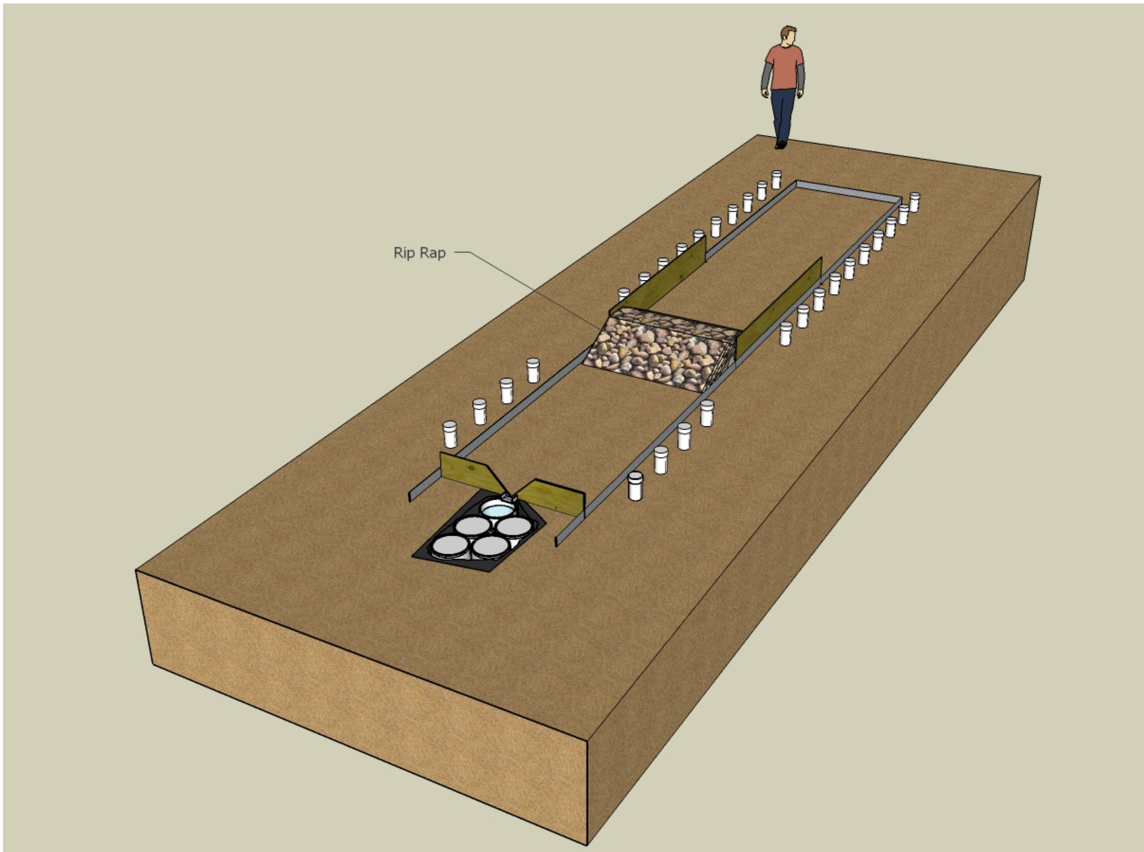

Figure 4.10. Diagram of field study erosion control plots.

4.3 Rainfall Simulator Study

The rainfall simulator study used two soil wagons. Two tilting soil beds were mounted on these wagons, the same as used by Trask et al. (2004). The soil used was gathered from the field study area and is the same Dana silt loam as in the plots. Soil was scraped off by layer and then placed into the wagon to create a similar field profile. Each wagon had dimensions of 3.6 m by 1.5 m. The bottom one third of the wagons had holes in the bottom allowing for natural infiltration and percolation to occur; this subsurface water movement was not monitored in this study.

The rainfall simulator used for this study was designed by Hirschi et al. (1990). It is located at the University of Illinois Urbana-Champaign campus in the Department of Agricultural and Biological Engineering. The simulator equipment was consistent with Trask's experiment (Trask et al., 2004): two modules, 1.3 m apart, each containing five Spraying Systems Veejet 80100 nozzles that operate at 41 kPa. The rainfall simulator assembly is shown in Figure 4.11.

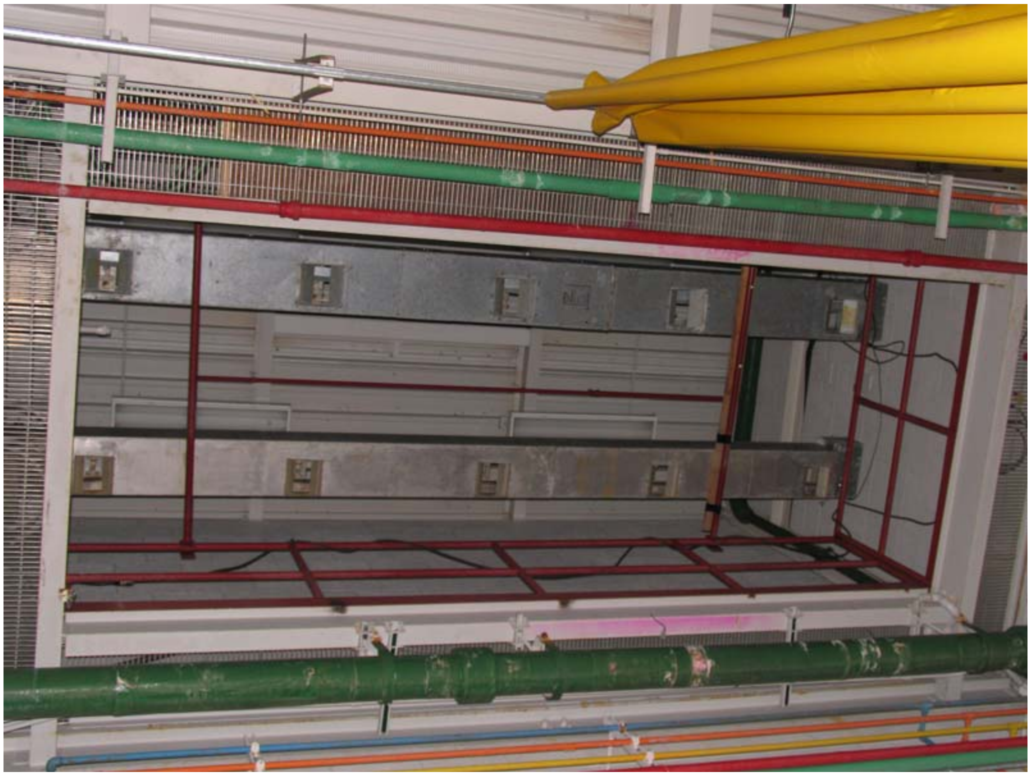

Figure 4.11. Indoor rainfall simulator housed at University of Illinois Urbana Champaign.

The soil surface area was divided into two plots each 0.75 m wide while check dam treatments were installed on each side with 1.5 m of bare soil upslope. The soil beds converged to a piece a sheet metal with twelve 9.5 mm holes sending runoff to two metal troughs each connected to a funnel and piping that led the runoff to separate collection jars. The total soil depth in the wagons was about 32 cm. The wagons were tamped down and put under the rainfall simulator to simulate natural compaction. Figure 4.12 shows the slanted soil beds.

Figure 4.12. Tilting bed soil wagons used under rainfall simulator.

Three different slopes were chosen to study. Slopes of 6:1, 9:1, and 12:1 were used to measure the performance of the check dam systems. These slopes were obtained using the hydraulic jacks on the wagons and then surveying the plots with a level and surveying rod.

The rainfall event used to test the structures for this study was a 10 year 30 minute rainfall at constant intensity for Champaign, Illinois. This equates to a total volume 2.2 cm of rain at the constant intensity of 4.4 cm per hour. The rainfall regime was chosen because of its fairly common return period but extreme enough to stress the check dams. A very extreme storm on the magnitude of a 25-50 year return period would be rare for structures that are intended to be temporary, and failure of the any of structures would not provide useful comparison for this scope of study.

Moisture content was measured for the soil beds before each run using a soil moisture probe with 12 cm rods. The soil bed was sampled 9 times to produce an average reading for the bed while minimally affecting the soil. Readings from the moisture probe are included in Tables H-1 through H-6 in Appendix H.

After each experiment the beds were reset. The check dams were removed and the beds were raked to simulate the natural soil condition found in the field after disturbances. Additional topsoil was added to account for soil lost and to bring the soil surface up to the holes in the wagon. The surface was tamped to simulate compaction and let settle for at least 2 days prior to any experiment.

4.4 Data Collection and Methods

4.4.1 Runoff and Sediment Collection

The same sampling procedure was followed for the field study and the rainfall simulator study. Following a rainfall event, the amount of runoff was calculated from the collection vessels by volume calibration on the buckets or jars. The collections jars were then emptied into secondary buckets for ease of sampling and then sampled identically to the field study. Samples were taken from each bucket and analyzed according to ASTM D 3977. The water collected in the buckets was stirred for 2 minutes to achieve sediment suspension. Figure 4.13 shows a disturbed and undisturbed bucket . From each bucket a half-liter sample was collected in a glass sampling jar completely submerged in the bucket. After sampling the buckets were power washed.

Figure 4.13. Sampling buckets used for field study.

The sample jars were then taken to the lab for measurements. Only the total solids was measured, thus, the entire sample was set in a forced air universal oven set at 98 degrees Celsuis for up to 24 hours to evaporate most of the supernatant water. Once the majority of the water was evaporated the oven was set at 105 degrees Celsius and left for up to another 24 hours to completely dry the sediment, also according to ASTM D 3977. The resulting weight of dry sediment and jar was measured.

Following the weighing of sediments, the samples were then rewetted with a known volume of water to determine the volume of sediment and the ratio of water volume to sediment volume. A thorough cleaning process was used on the jars; the jars were hand washed and then placed in a chemical and biological lab ware dishwasher and acid washed. Following the drying a tare weight of each jar was taken.

4.4.2 Statistical Analysis

There can be a high degree of variability in soil studies, especially in dealing with erosion and sediment control. A statistical test of the data was desired to ascertain a degree of confidence in the check dams' comparative performance. A Welch's T-test (Welch, 1947) was ideal; it assumes that the samples are drawn from independent populations and have different inherent variances.

A Welch's T-Test was performed on paired samples of the data to gauge the certainty of whether the two check dams results could be drawn from the same population, in other words whether the treatments perform the same. The initial test was run with a significance level of 0.10, however the results were inconclusive. Therefore further testing reported just the p-value of the comparisons and not any significance value associated with them.

4.4.3 Pin Frame Records

A profile rill meter or pin frame was used to give precise elevation profiles of the soils surface, to test the suitability and accuracy for the benefit further studies. Sequential profiles were rendered together to generate a surface model, successive surfaces over time were then compared to give an estimate of not only total erosion but also the development of topographical features, such as rills.

At three times throughout the study period, pin frame records were taken. Erosion and deposition surfaces were calculated using a 201-pin frame. The pin frame was 2 m x 1.7 m with 60 cm long 0.3 cm aluminum pins spaced 1 cm apart on center. The design was adapted from the triangular frame used by McCool in studies in the Pacific Northwest (McCool, 1981). One end of the frame had 1.5 m long poles that would hold a signboard with calibrations for measuring height. The cross bar on the other end had a camera mount in the middle; it was situated so that when a Canon PowerShot Pro 1 camera was placed on the frame the camera would have a view of the entire sign board. One end of the pins was wrapped in black electrical tape to prevent them from sliding all the way through the holes and to provide contrast against the white signboard for pictures. The legs of the pin frame were 2.5 cm round metal pipes that could be inserted into the holding pipes. A picture of the assembled pin frame is in Figure 4.14.

Figure 4.14. Pin frame, sans camera, assembled.

Holding pipes were 7.6 cm diameter PVC pipes 46 cm long. These pipes were hammered into the soil on each side of every plot at 0.5 m horizontal intervals on the exposed soil. They provided a consistent measuring point for the pin frame for measurement repetition. The pipes were covered with PVC caps to keep water and debris out.

In the rainfall simulator study, before and after each run readings were taken every 50 cm on bare soil with the pin frame. Pictures were taken using the pin frame with the same principles as the field. In the lab movable stands were used to hold the pin frame and lined up with reference points on the wagons for repeated accuracy of location. The wagon itself served as the benchmark due to the movable stands.

When measurements and pictures were taken the frame was placed in the holding pipes allowing the pins to rest on the ground. The surface profile was then transferred via the pins onto the backdrop of the signboard. The signboard had calibration marks every millimeter placed on it. Once the photo was taken it was analyzed via Adobe Photoshop CS3 Extended software from Adobe Systems Incorporated, to read out the pin measurements. Given a point of known elevation and scale the software allowed for the measuring of other points. This data was then exported to a spreadsheet where it was combined with the other pictures of the plot and converted into a surface map of each plot. Subsequent repetitions allowed for the change in profile to be determined as well as the volume change of the plots relating to soil movement.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 RESULTS AND IMPLICATIONS OF FIELD STUDY

Soil samples of each plot were taken and analyzed in the lab to determine chemical properties. Important properties known to affect erosion rates, organic matter and pH, are shown in Table 5.1. The complete results are in Appendix C.

Table 5.1. Slope and important chemical properties, organic matter and pH, of field study site plots.

Plot #	Mean Slope [L:H]	Treatment	Organic Matter [Percent]	Soil pH
1	24:1	Plastic Dam	2.6	5.8
2	22:1	Foam Berm	2.9	5.8
3	24:1	Compost Berm	3.0	6.2
4	22:1	Foam Berm	2.6	6.0
5	24:1	Riprap Berm	2.7	6.2
6	23:1	Compost Sock	2.8	6.9
7	26:1	Riprap Berm	2.5	6.3
8	25:1	Control	2.8	6.2
9	27:1	Plastic Dam	2.7	6.5
10	25:1	Compost Berm	2.8	6.2
11	28:1	Foam Berm	2.6	6.3
12	24:1	Compost Sock	2.7	6.5
13	32:1	Plastic Dam	2.6	6.0
14	26:1	Compost Berm	2.3	6.4
15	28:1	Compost Sock	2.4	6.2
16	29:1	Riprap Berm	3.1	6.2

The percentage of organic matter ranged from 2.5 to 3.1 and the soil pH ranged from 6.0 to 6.9. No plot had consistently different values than the others; the ranges were fairly close. Therefore, each plot is similar to the others without extreme soil conditions.

5.1.1 Results from the Field Study

The field study results yielded 6 significant rainfall events of which only 4 were of suitable intensity to provide sufficient data. The individual rainfall hydrographs of the 4 study storms are included in Appendix D. All of the rainfall events were common storms with predicted return periods of less than one year; only a few contained periods of a more significant rainfall event. Each storm or rainfall event is identified by the date in which its data was gathered and not necessarily the date on which the event started. Other weather data gathered from the weather station is presented in Appendix E.

The rainfall events that did not produce more than 2 cm of rainfall often had insignificant runoff from the plots to draw any conclusions from. Figure 5.1 through 5.4 show totals for both runoff volume and mass of sediment removed during the study period. Figure 5.1 and 5.2 show the check dam averages per rainfall event. Figures 5.3 and 5.4 show the check dam averages for the entire study period, with the minimum and maximum values included. Units are in kilograms per hectare and millimeters so they are independent from plot size.

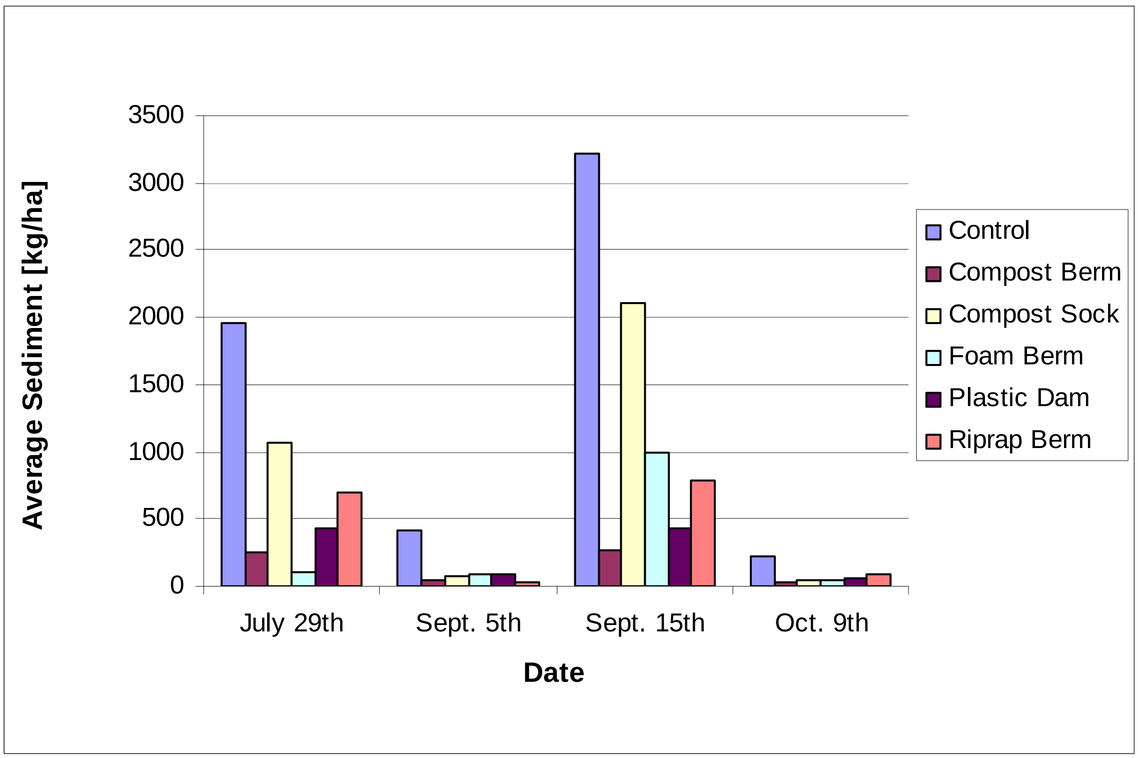

Figure 5.1. Average soil loss from plots with check dams per storm in the field study.

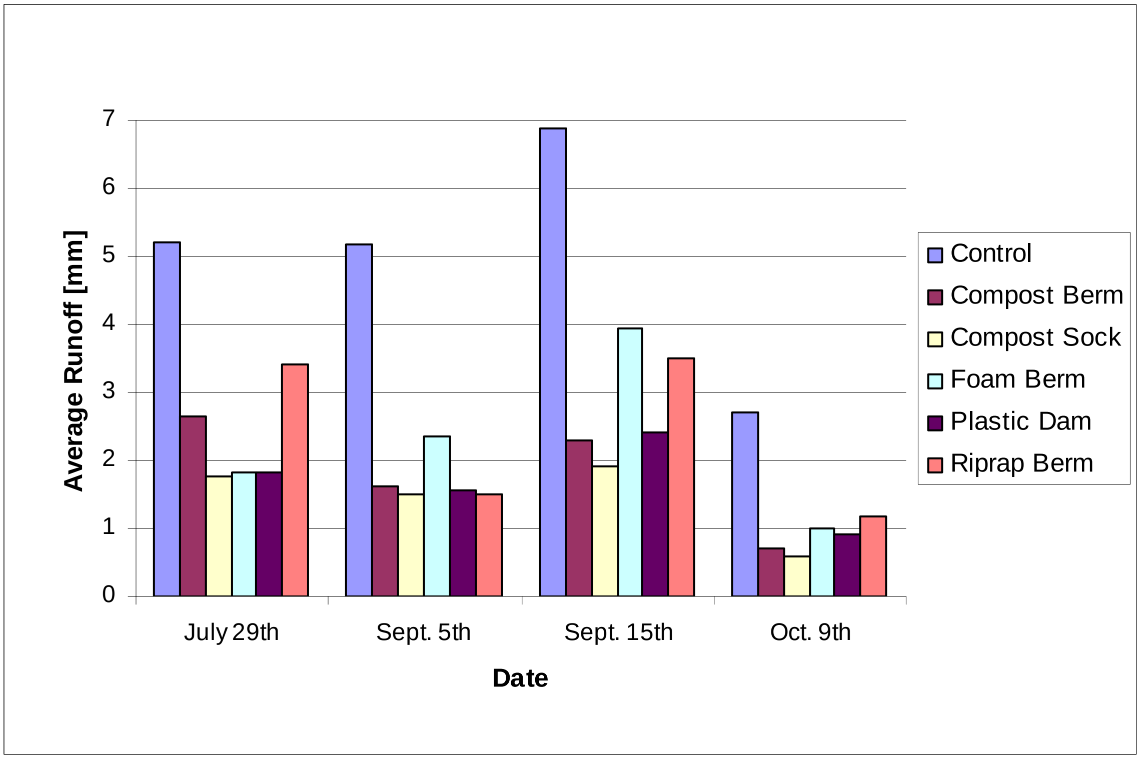

Figure 5.2. Average runoff from plots with check dams per storm in the field study.

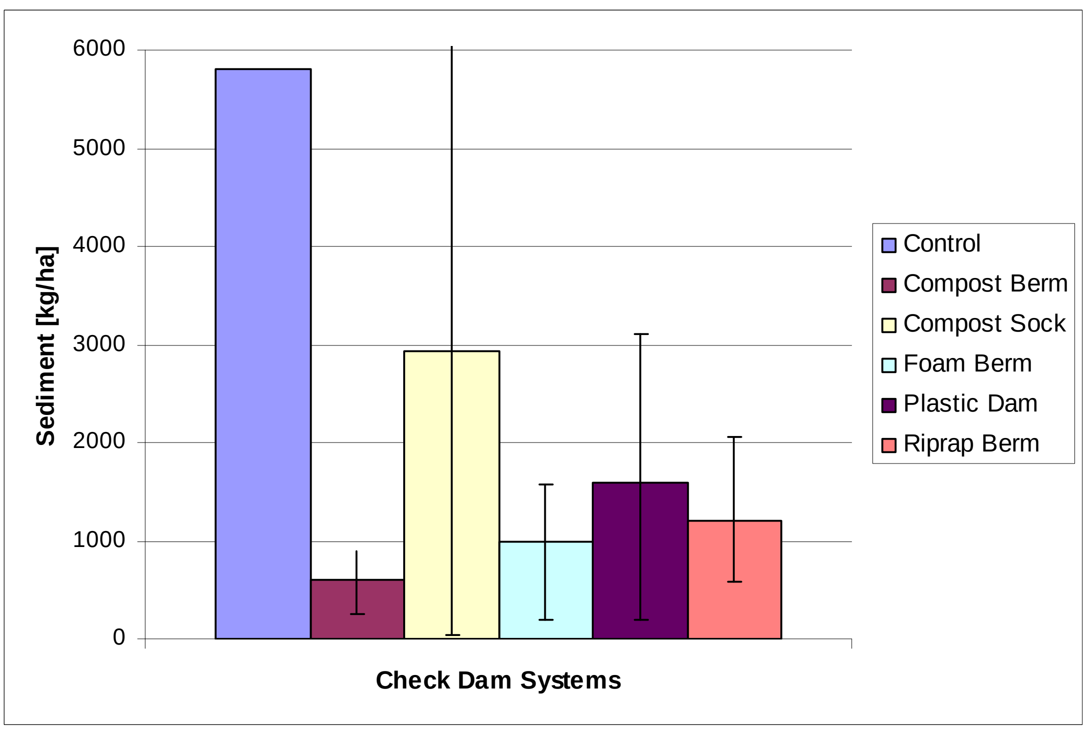

Figure 5.3. Average soil loss from the check dam plots for the entire field study period, with minimums and maximums.

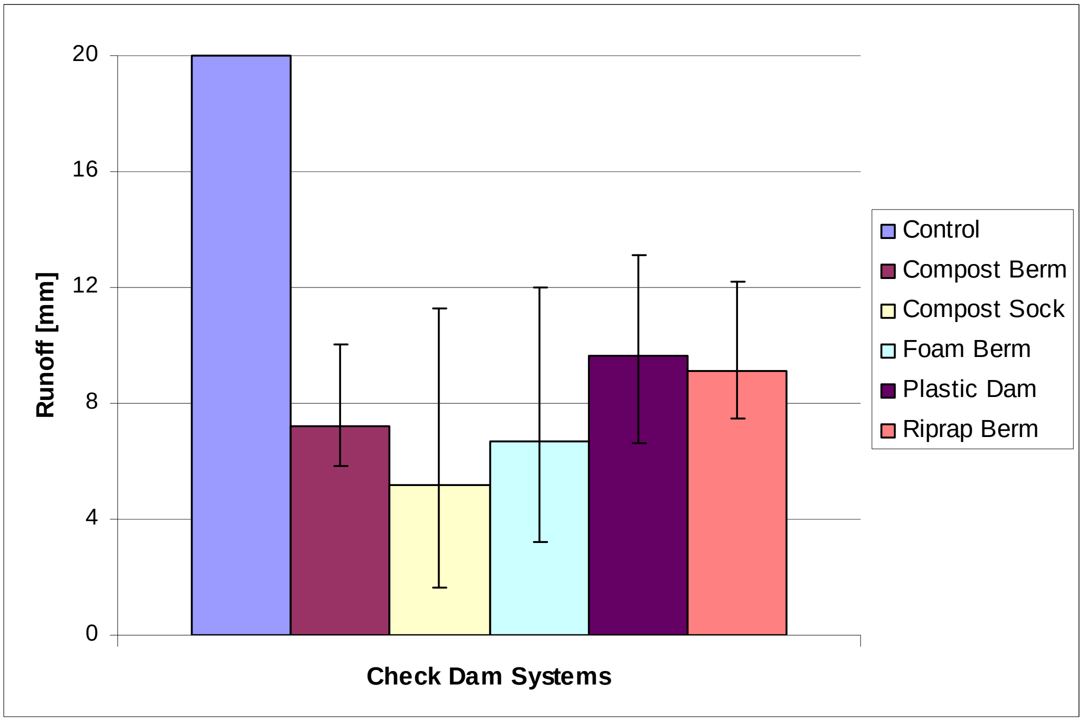

Figure 5.4. Average runoff from the check dam plots for the entire field study period, with minimums and maximums.

The erosion and runoff graphs for the individual plots during storm events are included in Appendix F.

The field study provided much useful in comparing runs, because it has many measured variables from the weather station and the soil chemistry. Every treatment in the field was used under the exact same climactic conditions; while, in the lab conditions do not account for natural changes in the rainfall, soil, or weather that occur in real world use. The field data is more valuable for making general comparisons.

5.1.2 Statistical Analysis of Field Data

The data appears to show some trends in runoff volume and sediment removed but the high degree of variability makes accurate analysis difficult. The check dams' averages and comparison are tabulated in Tables 5.2 and 5.3. Table 5.2 shows the runoff from each treatment; Table 5.3 provides the soil loss. Tables 5.4 and 5.5 show matrices of p-values for the entire study period; Table 5.4 shows runoff and Table 5.5 shows soil loss. Appendix G contains matrices for the individual rainfall events, confidence interval tables, and standard deviation data displayed graphically. A 90% confidence test was inconclusive due to the large variability in the field study, and thus larger statistical variances.

Table 5.2. Comparison of runoff, in millimeters, at the field study site.

Date Rainfall	July 29th 3.1 cm	Sept. 5th 4.6 cm	Sept. 15th 7.6 cm	Oct. 9th 2.3 cm	Yearly Plot Average 17.8 cm
Control	$5.2^{a.b}$	5.2	6.9	2.7	$20.0^{k,l}$
Compost Berm	$2.6^{c,d,e,f}$	$1.6^{a,b,c,d}$	$2.3^{a,b,c,d}$	$0.7^{a,b,c,d}$	$7.2^{a,b,c,d}$
Compost Sock	$1.8^{a,c,g,h.i}$	$1.5^{a,e,f,g}$	$1.9^{a,e,f,g}$	$0.6^{a,e,f,g}$	$5.2^{a,e,f,g}$
Foam Berm	$1.8^{d,g,j,k}$	$1.6^{b,e,h,i}$	$2.4^{b,e,h,i}$	$0.9^{b,e,h,i}$	$6.7^{b,e,h,i}$
Plastic Dam	$3.4^{b,e,h,j,l}$	$1.5^{c,f,h,j}$	$3.5^{c,f,h,j}$	$1.2^{c,f,h,j}$	$9.6^{c,f,h,j}$
Riprap Berm	$1.8^{f,i,,k,l}$	$2.3^{d,g,i,j}$	$3.9^{d,g,i,j}$	$1.0^{d,g,i,j}$	$9.1^{d,g,i,j}$

Table 5.3. Comparison of soil loss, in kilograms per hectare, at the field study site.

Date Rainfall	July 29th 3.1 cm	Sept. 5th 4.6 cm	Sept. 15th 7.6 cm	Oct. 9th 2.3 cm	Yearly Plot Average 17.8 cm
Control	1961^{a}	417	3224^{a}	230	5801^{a}
Compost Berm	$248^{b,c,d}$	$45^{a,b,c,d}$	$261^{b,c,d,e}$	$23^{a,b,c,d}$	$597^{b,c,d,e}$
Compost Sock	$1064^{a,b,e,f,g}$	$71^{a,e,f,g}$	$2110^{a,b,f,g,h,}$	$44^{a,e,f,g}$	$2929^{a,b,f,g,h}$
Foam Berm	$430^{c,e,h,i}$	$95^{b,e,h,i}$	$429^{c,f,i,j}$	$66^{b,e,h,i}$	$990^{c,f,i,j}$
Plastic Dam	$703^{d,f,h,j}$	$27^{c,f,h,j}$	$779^{d,g,i,k}$	$86^{c,f,h,j}$	$1590^{d,g,i,k}$
Riprap Berm	$103^{g,i,j}$	$88^{d,g,i,j}$	$989^{e,h,j,k}$	$43^{d,g,i,j}$	$1208^{e,h,j,k}$

*In each column treatments with the same superscripts denote that those check dams are within the 90% confidence interval of each other.

Table 5.4. P-values for runoff from the comparison of pairs to treatment during the entire study period at the field study site.

	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.006	0.020	0.020	0.016	0.010
Compost Berm	0.006		0.303	0.437	0.193	0.219
Compost Sock	0.020	0.303		0.369	0.154	0.187
Foam Berm	0.020	0.437	0.369		0.221	0.249
Plastic Dam	0.016	0.193	0.154	0.221		0.423
Riprap Berm	0.010	0.219	0.187	0.249	0.423	

Table 5.5. P-values for soil loss from the comparison of pairs to treatment during the entire study period at the field study site.

	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.001	0.179	0.003	0.015	0.004
Compost Berm	0.001		0.250	0.237	0.184	0.164
Compost Sock	0.179	0.250		0.285	0.348	0.306
Foam Berm	0.003	0.237	0.285		0.281	0.344
Plastic Dam	0.015	0.184	0.348	0.281		0.357
Riprap Berm	0.004	0.164	0.306	0.344	0.357	

The tables and graphs indicated that any check dam system is better than no treatment in the mitigation of runoff and the retaining of sediment. Comparison between systems was not very precise and although general trends could be inferred, statistically they were very similar with little realistic confidence in their differences. Because each rainfall event had different characteristics each event is a unique occurrence, and the confidence between rainfall events is not directly comparable.

5.2 RESULTS AND IMPLICATIONS OF RAINFALL SIMULATOR STUDY

5.2.1 Results of the Rainfall Simulator Study

The rainfall simulator studies measured the same check dams but provided extra control over the slope and the rainfall events. A constant intensity rainfall event dropped a total of 2.2 cm of rain onto the wagons over a 30-minute period. Three repetitions of each treatment were done at each slope: these individual graphs are shown in Appendix H. The averages of runoff and soil lost from all treatments are compared in the graphs of Figure 5.5-5.6.

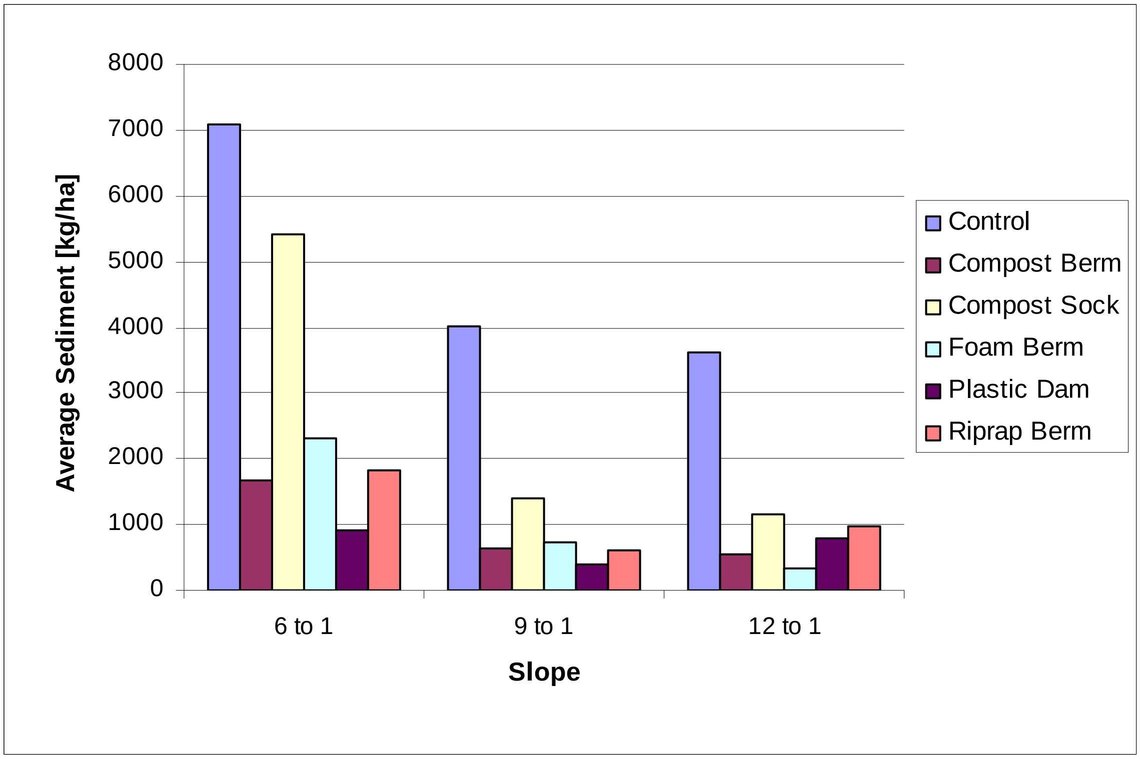

Figure 5.5. Average soil loss from the rainfall simulator plots for all slopes.

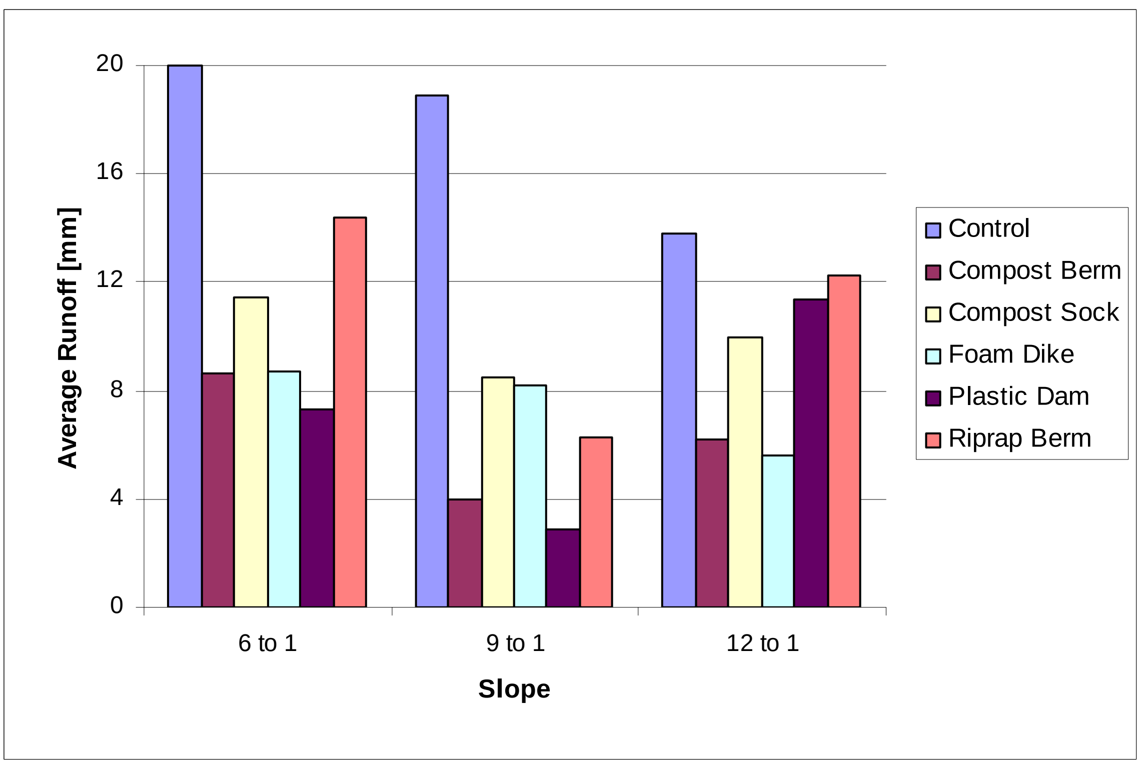

Figure 5.6. Average runoff from the rainfall simulator plots for all slopes.

These graphs are more precise than the field study due to more control over variables; however, the precision may not mean accuracy due to the lack of realistic environmental factors and conditions.

5.2.2 Statistical Analysis of Rainfall Simulator Data

The data appeared to show some trends in runoff volume and sediment retained, but the high degree of variability made accurate analysis difficult. A Welch's T-Test was performed on paired samples of the data to gauge the certainty of whether the two check dams' results are drawn from the same population, whether the treatments perform the same. The average and comparisons are provided in Table 5.6 for runoff and Table 5.7 for soil loss.

Table 5.6. Comparison of runoff, in millimeters, from the rainfall simulator study.

Slope	6 to 1	9 to 1	12 to 1
Control	20.0	18.9	13.8
Compost Berm	$8.6^{a,b,c}$	$4.0^{a,b,c,d}$	$6.2^{a,b,c}$
Compost Sock	$11.4^{a,d,e,f}$	$8.5^{a,e,f}$	$9.9^{a,d,e,f}$
Foam Berm	$8.7^{c,f,g,h}$	$8.2^{d,f,h,i}$	$5.6^{c,f,h}$
Plastic Dam	$7.3^{b,d,g}$	$2.9^{b,g,h}$	$11.3^{b,d,g,h}$
Riprap Berm	$14.4^{e,h}$	$6.3^{c,e,g,i}$	$12.2^{e,g}$

Table 5.7. Comparison of soil loss, in kilograms per hectare, from the rainfall simulator study.

Slope	6 to 1	9 to 1	12 to 1
Control	7074	4012	3634
Compost Berm	$1684^{a,b,c}$	$633^{a,b,c,d}$	$539^{a,b}$
Compost Sock	5412^{d}	$1390^{a,e,d,g}$	$1142^{c,d}$
Foam Berm	$2310^{c,d,e,f}$	$719^{d,g,i,,j}$	348^{b}
Plastic Dam	$908^{a,e}$	$407^{b,e,h,i}$	$1142^{a,c,e}$
Riprap Berm	$1840^{b,f}$	$610^{c,f,h,j}$	$963^{d,e}$

*In each column treatments with the same superscripts denote that those check dams are within the 90% confidence interval of each other.

The entire confidence interval data is included in Appendix I as well as standard deviation graphs. The tighter control over variables in the lab experiment affected the confidence significantly and, therefore, the 90% confidence tables are more descriptive than the field study but still very inconclusive.

P-values were also tabulated in matrices for the rainfall simulator study. Table 5.8 shows the values for runoff and Table 5.9 shows the values for sediment loss. The tables reveal that compost berm and the plastic dam were regularly the best performers, or close to it, at all slopes measured. Meanwhile, the compost sock routinely performed poorly, but all products were much more efficient than no treatment.

Table 5.8. P-values for runoff from the comparison of pairs to treatment from the three slopes in the rainfall simulator study.

6 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.004	0.036	0.038	0.017	0.017
Compost Berm	0.004		0.197	0.488	0.331	0.014
Compost Sock	0.036	0.197		0.278	0.156	0.193
Foam Berm	0.038	0.488	0.278		0.373	0.123
Plastic Dam	0.017	0.331	0.156	0.373		0.058
Riprap Berm	0.017	0.014	0.193	0.123	0.058	
9 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.004	0.026	0.043	0.001	0.019
Compost Berm	0.004		0.107	0.184	0.274	0.241
Compost Sock	0.026	0.107		0.474	0.084	0.292
Foam Berm	0.043	0.184	0.474		0.134	0.343
Plastic Dam	0.001	0.274	0.084	0.134		0.166
Riprap Berm	0.019	0.241	0.292	0.343	0.166	
12 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.048	0.101	0.040	0.251	0.020
Compost Berm	0.048		0.168	0.444	0.143	0.071
Compost Sock	0.101	0.168		0.137	0.365	0.193
Foam Berm	0.040	0.444	0.137		0.121	0.058
Plastic Dam	0.251	0.143	0.365	0.121		0.398
Riprap Berm	0.020	0.071	0.193	0.058	0.398	

Table 5.9. P-values for soil loss from the comparison of pairs to treatment from the three slopes in the rainfall simulator study.

6 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.011	0.202	0.026	0.002	0.002
Compost Berm	0.011		0.085	0.342	0.235	0.437
Compost Sock	0.202	0.085		0.104	0.054	0.079
Foam Berm	0.026	0.342	0.104		0.179	0.365
Plastic Dam	0.002	0.235	0.054	0.179		0.071
Riprap Berm	0.002	0.437	0.079	0.365	0.071	
9 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.006	0.027	0.004	0.001	0.006
Compost Berm	0.006		0.191	0.167	0.284	0.241
Compost Sock	0.027	0.191		0.222	0.138	0.184
Foam Berm	0.004	0.167	0.222		0.225	0.418
Plastic Dam	0.001	0.284	0.138	0.225		0.336
Riprap Berm	0.006	0.241	0.184	0.418	0.336	
12 to 1 Slope	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.001	0.005	0.001	0.002	0.002
Compost Berm	0.001		0.067	0.212	0.175	0.071
Compost Sock	0.005	0.067		0.036	0.159	0.294
Foam Berm	0.001	0.212	0.036		0.067	0.029
Plastic Dam	0.002	0.175	0.159	0.067		0.237
Riprap Berm	0.002	0.071	0.294	0.029	0.237	

5.3 Discussions of the Results, Plots, and Procedures

5.3.1 Comparison of the Check Dams and Their Analysis

The substantial amount of data collected accounted for several well-documented rainfall events. None of the events were repetitions due to changes in one or several variables. It is impossible to exactly match the temperature, moisture content, compaction, storm profile, and many other factors between experiments. This inherent property of soils makes comparison more general and less precise, although not moot.

The rainfall simulator studies had constant storm profiles and slopes but moisture content, temperature, and surface topologies were not necessarily constant between experiments. The field study was subject to real world conditions and storms; this data is more relevant.

Each run had its own set of variables so a universal statement of comparison could not be made but several trends were apparent. Due to the low confidence values all around, it is clearly seen that most check dam systems are comparable. This is likely due to the high degree of variance associated with soils and rainfall variability. The more flat the slope became the closer the products performed and less could be ascertained with statistical confidence. Any check dam setup was an improvement over a bare soil.

The data shows that check dams were quite well suited for reducing erosion compared to bare soil, however they are not as good as several of the products mentioned in the literature. Figure 5.7 reveals the percentage removal of sediment for the treatment plots compared to bare soil from the field study and Figure 5.8 reveals the same for the rainfall simulator experiments.

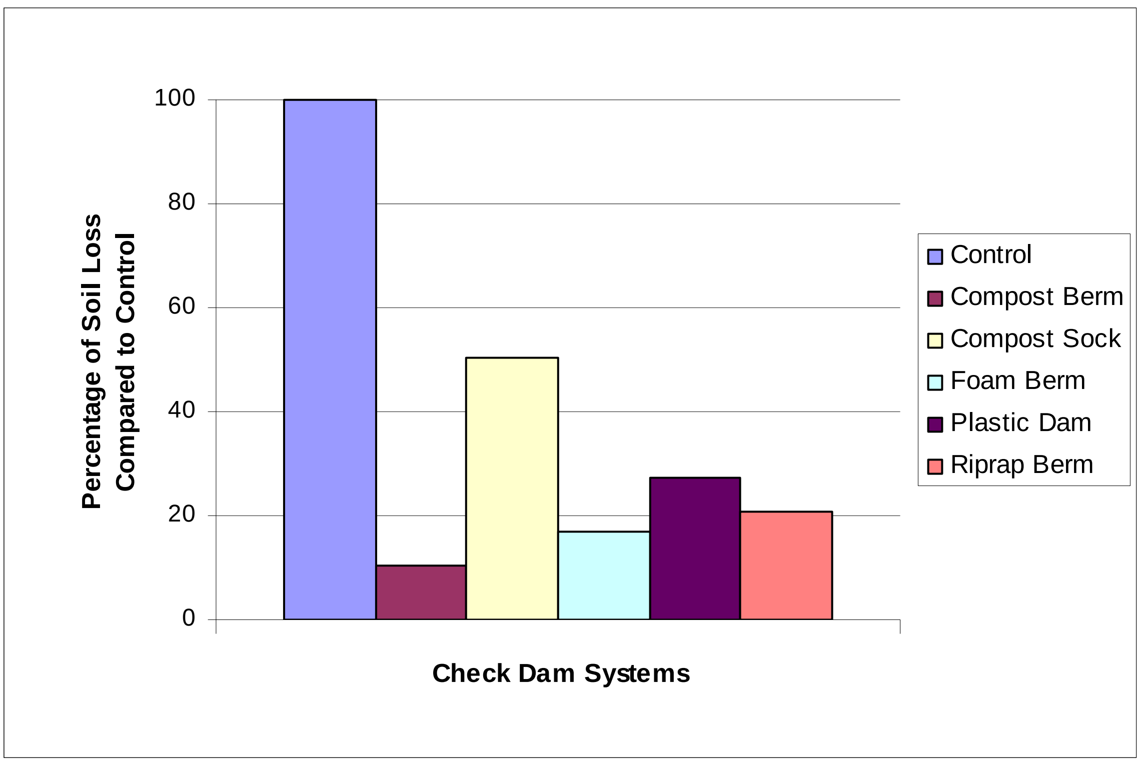

Figure 5.7. Percentage of soil loss compared to control on field plots.

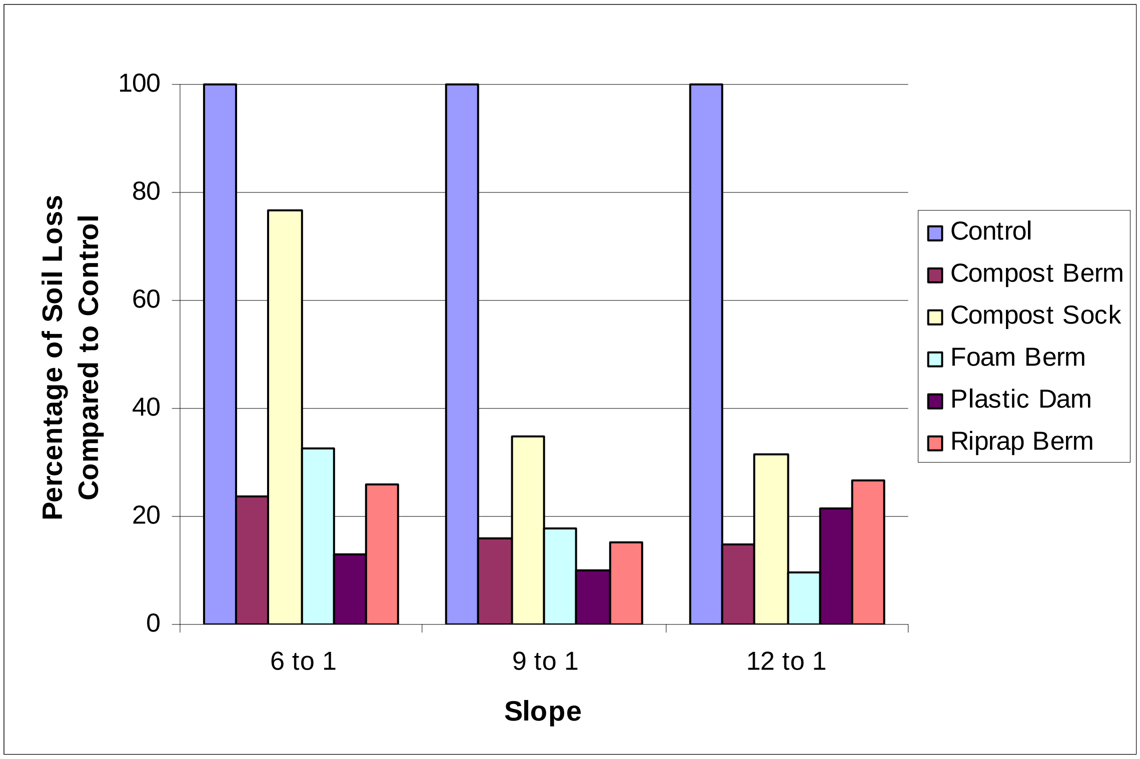

Figure 5.8. Percentage of soil loss compared to control in the rainfall simulator.

The two figures reveal one of the misleading fallacies of the experiment. Because check dams were placed a certain distance above the end of the plot even if the check dams were perfectly efficient at stopping sediment loss and runoff there would still have been measure amounts. This would have come from the bare soil between the end of the check dam and the termination of the plot. To accurately justify these percentages a bare plot of this short length should have been established to provide control data from this idealized 100% efficient case.

Nevertheless, the field study shows that all treatments had a notable decrease in erosion compared to bare soil. The compost berm looks to be the best option with almost an order of magnitude less erosion and less runoff. The product with least performance, according to measurements, would be the compost sock, with only a 50% decrease in sediment.

For the rainfall simulator the slope was an important factor. The compost berm, compost sock, and foam berm all performed better as the slope got flatter. Riprap was fairly consistent with its best sediment removal on the medium slope, while the plastic dam had its lowest removal on the flattest slope. This might be the case if the runoff was flowing through the compost at the flatter slopes and going over it at steeper slopes. The fact that some treatments had higher values on flatter slopes, was unforeseen, and is likely due to the variability in runs possibly from soil moisture content or other variables that were not measured.

The percentage of removal, however, still shows that compost tubes performed least well under all slopes: 25% reduction at steep slopes and 75% reduction at flat slopes; compost berm and plastic dam with a compost blanket are near the best at just over an 80-90% reduction on all slopes measured.

High variability between replications indicates the complex dynamics associated with such a study. More repetitions and replications would be useful in narrowing down the accuracy, if not the precision, in such experimental studies. The field study was limited by size but the rainfall simulator could have contained many more repetitions. This would have had the most impact on the control plots where only one repetition was present.

The sampling could also affect variability in values. During the first rainfall event, 3 samples were taken from each bucket and analyzed. This multiple sampling yielded nearly the same values each time. This practice was then not continued for the subsequent rainfall events. Continuing the multiple sampling would have provided additional validity to the values obtained.

Both studies were also dependant on the variability associated with the statistical confidence discussed earlier. After comparing measured results with previous studies mentioned in the literature review and in Appendix A, the results appear consistent. The compost socks used in this study matched the range of values that Kelsey (2007) presented in the study of tubular sediment control practices. The other check dams would fall on the better side of the ground covers used by Meyer et al. (1972) and would be slightly less effective than the compost blankets studied by Risse and Faucette (2003).

These results served as a small validation of the data and values obtained in this study, strict comparison between studies would be ill founded based on the differences between them such as soil type, slope, and plot size. Also the placement of the check dams in this study was above that in most other studies. This allowed observations of flow patterns through the check dams and resulting soil loss or deposition, however, it also led to higher sediment removal rates from the plots. A more extensive list of tabulated studies to which the results can be compared to is found in Appendix A.

5.3.2 Individual Plot Discussion

The graphs of the individual plots are included in Appendices F for the field study and Appendix H for the rainfall simulator study. They show the changes between runs and sets of runs. They were graphed with each other and inconsistencies between repetitions can be observed. Some change and fluctuation was expected as each set of experiments were run separately of the others. These differences were not determined to be caused directly by any measured phenomena or property and, thus, were attributed to external influences; such influences could have been temperature, humidity, soil moisture, or topographic conditions. Installation and human error were minimized to the best extent possible due to the fact that the same people followed the same procedure each time.

5.3.2.1 Field Plot Discussion

The average values for the check dams are useful and important to analyze. However, the averages can be skewed by outliers in the individual events. These points would not only affect averages and standard deviations but also the statistical confidence tests as well. Further investigation into these outliers should determine whether they should be kept with the data or discarded due to human error.

Several of the erosion plots were under suspicion of having extenuating factors affecting runoff and sediment yield from them. All plots showed similar fluctuations and changes between plots with several notable exceptions: the third compost sock plot, the third riprap berm plot, and the first foam berm plot. These plots showed a consistent major difference to the other plots of similar treatment. The discrepancy was consistent across all sampling times and indicates an issue within the check dam or plot and not an isolated occurrence within a rainfall event or sampling error.

The field study had the benefit of assuming the same environment and weather during event periods. The difference in the plots should have been minimal with the documented topography and soil chemistry being the only known differences; therefore, such large discrepancies must have been due to the installation procedure or the check dams, themselves. Rills or channels through, under, or around the check dams could cause this discrepancy in values but the data should not be discarded because regardless it is still a characteristic of the check dam.

Field observations and photographs revealed no discernable differences or errors within setup of the questioned plots and, thus, the variation in data were attributed to the check dam systems and variances therein. Figure 5.9 shows the questioned plots while Figure 5.10 shows normal plots. The photographs illustrating this conclusion were taken after a storm. Due to no apparent error, the outlying data was included in all analysis.

Figure 5.9. Plots under question with consistently imprecise data.

Figure 5.10. Plots with typical data.

The difference between the weirs and the flumes was evaluated but the data was inconclusive. The plots with weirs had not correlation to how they performed compared to similar check dam plots. The inconsistencies made it hard to determine if measured values were affected by the flow control structure or whether it was due to other factors.

It was noted that both structures were subject to scour and undercutting as the year went along. This was likely due in part to the hole containing the buckets was acting as a drain for subsurface slow. Figure 5.11 reveals the undercutting of both structures. To prevent this problem a better structure should be used either to collect runoff such as a keyed in container or metal trough leading into the collection apparatus.

Figure 5.11. Washout and scour occurring around both end structures used on plots.

5.3.2.2 Rainfall simulator discussion

The rainfall simulator study did not have the same issues as the field study. Each run in the simulator was supposed to be identical to all the others; therefore, any differences in the data are assumed to have been due to the variances in the runs themselves. The primary differences were the use of a new check dam for each event. Any minor change in preparing the beds through raking, smoothing, adding topsoil, and tamping of the soil surface to the actual installation of the check dams could also affect the results.

The only other documented factor that could have affected the results was the moisture content of the soil beds. This variable was measured and recorded for each run in the simulator. This factor was deemed important in effort to provide a comparison between runs; because the soil beds were allowed to air dry between runs. The moisture content recordings are included with results in Appendix H.

The averages for the check dam treatments reveal a much more consistent set of points than the field study. This should have been expected because the tighter controls over variables in the rainfall simulator study. Comparing the maximum and minimums on the average graphs clearly show the precise data from rainfall simulator at the expense of possible accuracy of the field study results.

The rainfall event chosen for the study was a short high intensity one. A more useful demonstration of a check dam’s ability would have been to test it under a variety of rainfall events, both longer and more intense as well as shorter and weaker and any combination there of. The presence of rills was lacking for most of the observed runs, thus, it can be assumed that a longer and/or more intense event should have been used to adequately test the check dams under extreme erosion conditions.

5.3.2.3 Treatment observations and discussion

The compost sock structure was prone to extreme performances both high and low. They also had a high amount of sediment lost relative to runoff. These could be due to its installation requirement that it needed to be installed in an arc shape with the direction of flow and anchored into the ground. This installation practice led to better stability and durability during high flows, but also led to higher amounts of runoff and sediment because it would cause an arc shape of settled or deposited sediment, which would funnel or focus the effluent flows. A series of photographs highlights this is shown in Figure 5.12.

The socks are also designed for a more trapezoidal shaped channel and not the rectangular one caused by the plot borders. The right angle formed at the border could allow water to flow around the compost sock and not through it. This would occur if the sock is not securely anchored up against the border.

The compost socks used in the study were themselves slightly faulty; a particle size analysis of the compost did not meet the manufacture's provided specifications. This difference, however minimal, could have been caused by poor samples or could have been constant through out all the socks; it is graphed in Figure 5.13. The standards only pertains to the points on the graph and the line is there merely as a reference. The socks were also stored indoors for about a month before being installed which may have affected the moisture content of the compost socks.

Figure 5.12. Compost sock in use and the resulting deposition pattern that could affect flow.

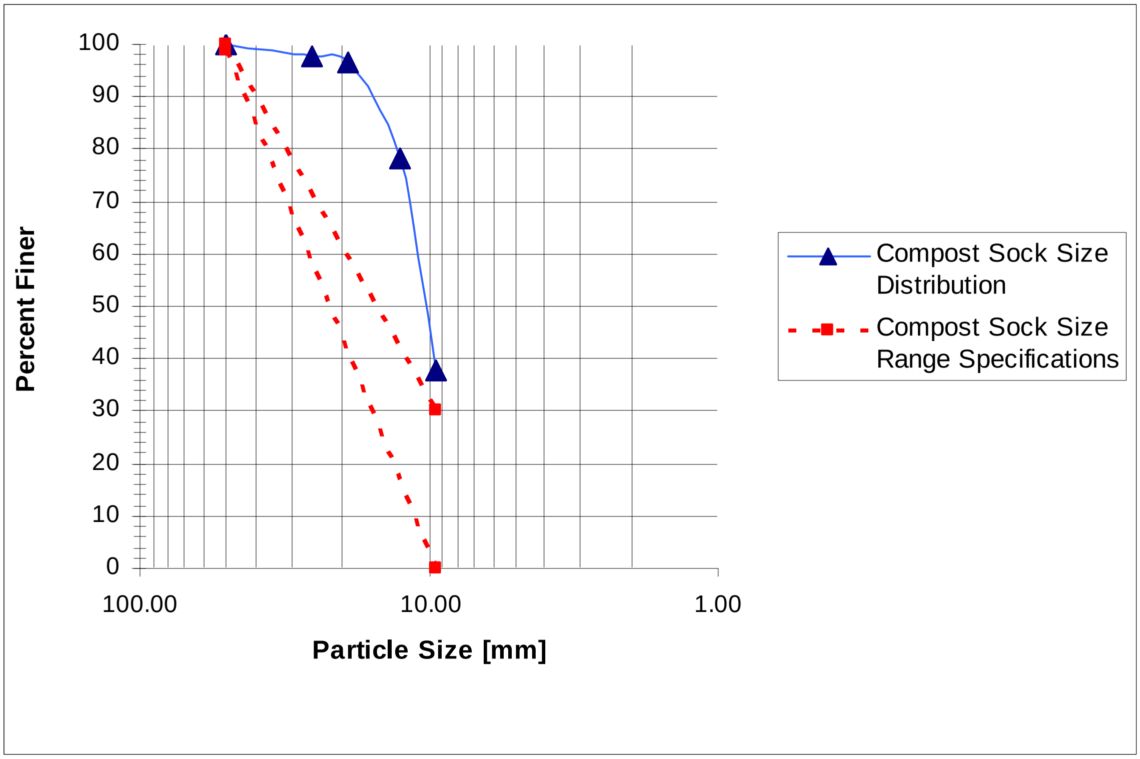

Figure 5.13. Comparison of the specified particle size of compost for the compost sock versus the actual compost size distribution measured.

Riprap berms also had the issue of focusing effluent flows. They would receive a sheet flow and turn it into several streams of water, thus concentrating the energy and volume of the flow. It was foreseeable that the rock size used in the berm is a major factor in this aspect, but the stone did meet the erosion control specification. Figure 5.14 shows this problem occurring in a rainfall event in the rainfall simulator. It can also be seen in Figure 5.14 that any gaps by the border did not lead to this same converging of flows and resulting rills.

Figure 5.14. The concentration of flows and the resulting rill formation in riprap berms.

Compost berms are made up of pieces or particles in a similar way to riprap berms. Compost berms with much smaller pieces were much more consistent in their performance. An additional factor that the compost berm had was the moisture content of the compost. Dry compost could hold lots of water but compost would take longer to dry out than the surrounding soil. Its moisture content likely affected the flow properties through the berm. No measurements of compost moisture content were taken during these studies.

The foam berm was highly unstable due to its light weight. Flow would routinely undercut and scour around the geotextile base; on certain occasions complete rills formed under the structure. This was probably due to the flexible geotextile being unable to control higher intensities of flow. This led to some of the variability with this type of check dam. The instillation is slightly to blame for this problem as a deeper keying in of the geotextile, deeper than the minimum recommended depth which was followed, would likely have avoided or reduced this problem considerably. Figure 5.15 shows several of these occurrences after a storm with rilling and moving of the geotextile by flowing water. The geotextile under the riprap berm was also subject to this problem but on a much smaller scale, due to the much smaller apron lengths.

Figure 5.15. Undercutting of the geotextile common with the foam berm.

The hard plastic dam was hard to qualify because it sat upon a compost blanket. If the rainfall events and subsequent runoff did not produce significant depth of flow the compost blanket, and not the plastic dam, would impeded the majority of the overland flow. If this occurred the results would likely be very similar to the compost berm, albeit they contain different types of compost. The results were similar but the high similarity between all treatments makes this a subjective judgment. It is hard to confidently state that the observed measurements obtained from these plots are due at all to the plastic dam but rather the underlying compost. Higher flow rates and intensities should be used to better assess this structure.

5.3.3 Cost and Installation

With comparable performance, cost and ease of installation were also investigated. All products cost about the same per unit length except for the compost being the cheapest by half. The local availability of the compost was a big asset in cost compared to paying for the shipping and freight of the various other products. Table 5.10 shows the costs of the materials for each structure without any associated shipping or installation costs.

Table 5.10. Cost analysis of the check dam structures.

Check Dam	Cost [$] per Linear Meter
Compost Berm	6.56
Compost Sock	13.94
Foam Berm	14.04
Plastic Dam	16.20
Riprap Berm	15.58

The installations of the check dams were straight forward with all products. Riprap was the hardest to work with due to the volume, weight, and the underlying geotextile. Heavy machinery was required to move large amounts of rock. The compost berm was easier to transport but still had the same volume per unit length as riprap. All three industrial made products were easy and fast to install. The installation of the compost sock was the fastest but somewhat awkward; it was heavy due to the length of the sock. The plastic dam was light and small since it came in sections but did have the underlying erosion control blanket or compost blanket to install first. Finally the geotextile wrapped foam berm was very light; this made it difficult due to the long sections it came in. Thus, the accurate placement of the structure and the long aprons of geotextile was difficult; it took time to lay the geotextile out and secure in even slightly windy conditions.

5.3.4 Pin Frame Analysis

The analysis of the pin frame pictures and data was much less useful than other data. The magnitude of points and variables led to the discarding of nearly all gathered data. The degree of precision desired was unobtainable with the initial set up. The length and thus area of the plots made the records useless for determining overall volume moved or lost. Measuring millimeter height increments every centimeter gave accurate soil surface profiles, but trying to extrapolate these profiles into a surface every half meter ro meter meter caused far too much error in the calculations. The two orders of magnitude difference was too vast to overcome when compounded during calculations.

Photoprocessing and measuring were time consuming and tedious processes to get accurate results to the millimeter; all of which was negated by the approximations used in generating the surface. Several plots were analyzed in such a manner. The results were vastly different than the recorded soil measurement. Some numbers were completely opposite of what was realistic, in that the surface was gaining mass and volume when it was being eroded. The rainfall alone should cause minor compaction that would lead to a net decrease in volume. Also the removed sediments gathered in the sample jars would only add to this decrease in volume. Figures 5.16 and 5.17 display a before and after of the computer generated surfaces. The approximated mass differences in grams are given in Table 5.11 and 5.12; the negative numbers indicate a gain in mass.

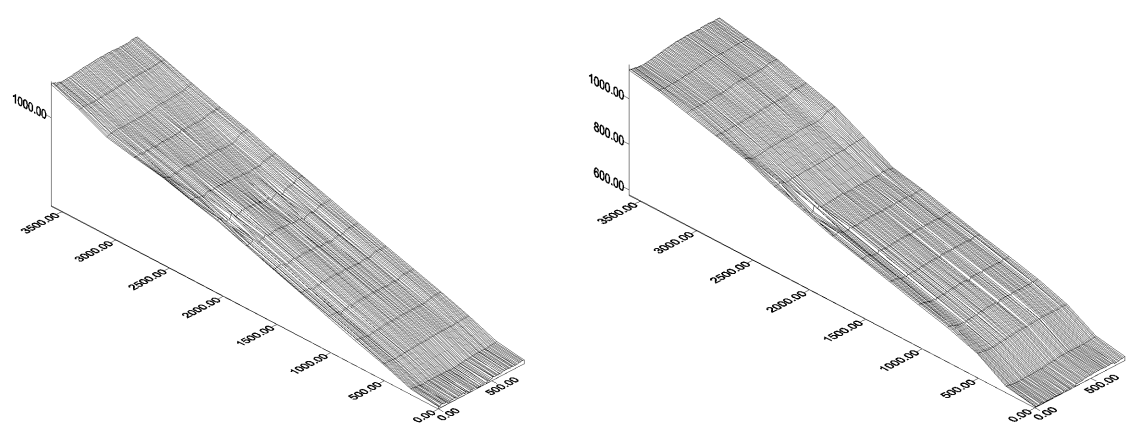

Figure 5.16. Before and after diagrams of the soil surface with a compost berm.

Table 5.11. Volume change of a compost berm plot according to pin frame analysis.

Volume Change	Grams
Soil lost calculated	-41114.0
Soil lost measured	431.2

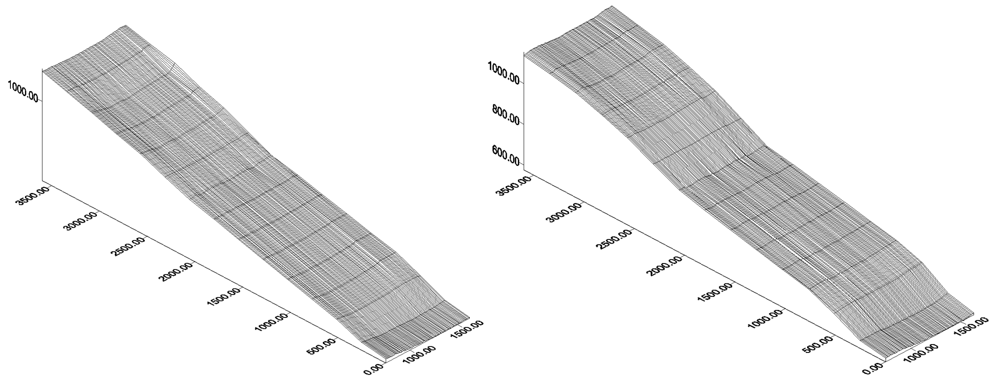

Figure 5.17. Before and after diagrams of the soil surface with a compost sock.

Table 5.12. Volume change of a compost sock plot according to pin frame analysis.

Volume Change	Grams
Soil lost calculated	-47685.8
Soil lost measured	1878.4

There are several hypotheses for how such calculation error occurred. This was most likely due to the factor of the interval of sampling along the length of the plot. Sedimentation and deposition patterns occur on a much smaller scale than the lateral sampling interval. This creates a dead space between the sampling cross-sections in which it is unknown what is occurring. Also the check dams themselves are neglected in the surface as their ability to hold or release sediment is not considered.

The surface-generating algorithm could have been at fault. A Kriging calculation was used; this algorithm uses a least squares estimation that will generate smooth lines. This estimation may eliminate small rills and thus overestimate the final volume. Fluctuations in the surface height caused by the flow were glossed over by rounding and extrapolation; by extrapolating any developed rills or depressions, as well as mounds, was ignored unless directly measured on.

It was however foreseeable that volume could increase in the rill meter measurements if the soil was be relocated from areas between the measured cross sections and deposited on them. This would result in the same amount of soil apparently gaining volume. The occurrence of this should have been vastly negated by the fact that being on a slope the overland flow should have removed the sediment from the plots to some degree. Any relocation of the soil would most likely have deposited it around the check dams and the termination of the plot.

For further studies, if such a set up was to be desired, a much smaller slope length increment should be used to more accurately model the surface of the plots. The smaller increment, however, would greatly increase the number of pictures that would be needed. To prevent issues with time of measurement and analysis an automated rill meter could be used or developed.

The rill meter works much better for giving a soil surface elevation cross-section or even a temporal scale of elevation changes and thus the development of topographical or erosion features can be seen. In this study most of the error would have been eliminated due to the similar scales, the lack of unknown areas and less extrapolation. Thus a pin frame is a useful tool as long as its limitations are known for its intended use.

5.4 RECOMMENDATIONS

The results of this study gathered indicate that check dams are a valid resource for erosion control. Despite varying levels of significance, compost berms were commonly the best at controlling runoff and mitigating sediment removal. Compost berms were also the cheapest check dam, due partially to local availability of compost. These factors suggest that the first and foremost check dam to consider for sheet and channel flow scenarios should be a compost filter berm. The other check dams had varying degrees of success and could be used to help mitigate erosion.

Different slopes did have different rankings of success and the confidence tables should be used to help make an informed decision. Riprap and compost socks had high variance and can even make erosion problems worse under some conditions. These should be considered as a last resort due to these potential problems.

According to the literature review there are other forms of erosion or sediment control that have shown better sediment retention. A thorough comparison of individual scenarios should be required before deciding on what type of erosion or sediment control practice to use. For most military applications, check dams seem to be a viable answer. They allow for much of the land to be used and only a fraction devoted to the actual controlling structures.

CHAPTER 6: CONCLUSIONS

The vast amount of data gathered during all parts of this study resulted in several main conclusions. Check dams are an effective erosion control technique causing anywhere from 25% reduction to 90% reduction in sediment lost. The field study saw a variety of conditions and the yearly performance for each check dam was better than a 50% reduction in sediment lost and similar for runoff.

The rainfall simulator study provided further insight into the abilities of each check dam. The change in slopes was the most useful variable measured and a major factor in performance of the check dam treatments; only riprap shows somewhat consistent performance despite slope. Most check dams are better at the flatter slopes. Runoff and erosion being inherently linked the ability to retain sediment was the most important factor.

Compost berms were consistent and often the most effective at controlling sediment with foam berms and plastic dams on compost blanket coming in next. Riprap was often suitable but allowed more sediment to pass, while compost socks were the least effective at retaining the sediment. Although compost socks were the least effective at erosion control, they were still substantially better than no treatment. All the products were all statistically comparable.

The compost berm is also the cheapest, due to the local availability of suitable compost, therefore, the best option for controlling erosion using check dams would be the compost filter berms.

CHAPTER 7: RECOMMENDATIONS FOR FURTHER STUDIES

Further research should be done to better understand how the various elements such as rainfall pattern, soil moisture content, and slope affect the individual performance of each check dam. Climactic and soil variables can be analyzed statistically to find dependency and correlation to erosion, sediment removal, and runoff. Many of these variables were recorded under this investigation, but the scope was not broad enough to delve into all facets.

The pin frame analysis turned out to be an ineffective investigation due to high variability and likely error. Further work with the accuracy and precision of a pin frame could make this a useful and viable option for measuring erosion. The faults in using such a device lie in the methods and not the device itself. The development of standards and a standard operating procedure for such a device can also greatly improve its use and reliability as a tool, as well as understand its limitations.

Check dams for use on military training lands can also be subject to other stressors in the environment. Tests of stability and durability of the structures will provide valuable information to their land managers. The placement on the landscape is important as well. Check dams can be used as sediment or erosion control practices and obtaining the desired placement for cost and effect should be analyzed.

Compost is a growing tool in combating soil loss in many forms. This was seen in the literature and through this study. Compost itself is a diverse media, rivaling that of soil in complexity; therefore, many other types of compost can be evaluated for erosion and sedimentation control.

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APPENDIX A: LITERATURE REVIEW STUDY DATA TABLES

A vast amount of research has been done in the areas of ground covers and composts used as erosion control. A sampling of significant studies was presented in the review of literature but the following tables detail a more extensive look at such studies.

Biocycle (2007) summarized a study done by several researchers that looked at compost erosion control practices. Table A.1 shows the findings.

Table A.1. Runoff and soil loss results for compost and ground covers (Biocycle, 2007).

	Runoff compared to bare soil [%]	Soil loss compared to bare soil [%]
Compost ECB	40.0	6.5
Wood mulch blankets	66.0	1.3
Straw with PAM	73.0	18.9

Birt et al. (2006) reviewed and studied the standards for compost blankets as an erosion control method. The experiment was conducted with a rainfall simulator at the Water Quality Laboratory at Texas A&M University. The pan dimensions were 0.33m by 0.45m and filled with a sandy loam soil. The pans were set on a 3 horizontal to 1 vertical slope. Table A.2 highlights the findings.

Table A.2. Runoff results for compost blankets (Birt et al., 2006).

		Runoff [mm/hr]	Runoff compared to control [%]
Compost Manufactured topsoil	75% topsoil, 25% compost 5 cm (2 inches)	65.96	112.8
Erosion Control Compost	50% untreated wood chips, 50% compost blend 5 cm (2 inches)	13.93	23.8
General Use Compost	100% Compost 5 cm (2 inches)	18.55	31.7
Dispersion Treatment of Erosion Control Compost	50% untreated wood chips, 50% compost blend <1.3 cm (1/2 inch)	18.87	32.3
Dispersion Treatment of Compost Manufactured topsoil	75% topsoil, 25% compost <1.3 cm (1/2 inch)	61.78	105.7
Hydroseeding	Paper mulch with fertilizer and Bermuda grass seeds 5 cm (2 inches)	2.44	4.2
Topsoil	100% topsoil 5 cm (2 inches)	58.47	100.0

Boix-Fayos et al. (2008) used computer molding to predict erosion yield from a 47.2 km^2 catchment in Spain. The model used the erosion model WATEM-SEDEM to compare not change to land use changes and check dam treatments. Table A.3 shows the predictions.

Table A.3. Soil loss results for check dam modeling (Boix-Fayos, 2008).

	Soil loss compared to control [%]
Control	100.0
Land Use Changes	46.0
Check Dams	23.0

Buchanan (2002) evaluated the size of woodchips as a variable in erosion control blankets. The plots had a 55% slope and had dimensions of 10m by 3m. Plots were subjected to natural rainfall events. The results are given in Table A.4.

Table A.4. Soil loss for various wood chip coverings (Buchanan, 2002).

	Soil loss [kg]	Soil loss compared to bare soil [%]
Zero cover	31.1	100.0
Small wood chips	24.2	77.9
Large wood chips	4.2	22.1
Mixture of chips	6.9	13.6

Codner (2003) studied composts effects on erosion at Story City, Iowa. Plots were at a 3 horizontal to 1 vertical slope. Rill plots of 3 ft by 26 feet were studied as well as interrill plots of 4 ft by 5ft. After the study it was concluded that unscreened garden compost was the best at reducing runoff. Table A.5 lists the other compost treatments studied.

Table A.5. List of ground coverings studied by Codner (2003).

Topsoil
Seeded Topsoil
Compacted subsoil
Compacted subsoil seeded
Bio-industrial byproducts compost
Municipal waste compost
Unscreened yard waste compost

Curtis (2007) studied compost as a soil amendment. The study used a 24% by volume mixture on a 2 horizontal to 1 vertical slope mountain road cut. The data shows that erosion was reduced by half.

Demars and Long (1998) studied compost for the Connecticut DOT. The plots had a slope of 2 horizontal to 1 vertical on a silty sand. Plot dimensions were 10 ft. by 30 ft. The study focused on the natural rainfall events that occurred. Table A.6 highlights the results.

Table A.6. Soil loss for compost from Demars and Long (1998).

	Soil loss compared to bare soil [%]
Manchester compost mulch	5.1
Hay and seed	8.2
Manchester compost seeded	5.7
Glastonbury wood mulch	7.5
Filter berm of Glastonbury wood mulch	6.5
Earthgro compost seeded	5.3

Demars et al. (2004) looked into the use of wood waste materials in controlling erosion. The study took place at Willington, Connecticut on a sandy silt soil. Each plot was 5 ft. by 30 ft. and on a 2 horizontal to 1 vertical slope. The erosion control results are included in Table A.7.

Table A.7. Soil loss from various erosion control practices (Demars et al., 2004).

	Soil loss compared to bare soil [%]
Geosynthetic Silt Fence	1.6
Hay Bale Berm	2.0
Wood Waste Filter Berm	0.2

Ettlin and Stewart (1993) examined the use of yard debris compost as an erosion control option. The study took place in Portland, Oregon and had slopes of 34% to 42%. Each plot was 9 ft by 32 ft and subject to 1.6 in. of rainfall. Table A.8 shows the results from the 34% slope study.

Table A.8. Soil loss from yard debris compost study (Ettlin and Stewart, 1993).

	Soil loss [mL/L]	Soil loss compared to bare soil [%]
Untreated bare soil	31000	100.0
Sediment fence	26000	83.9
Hydromulch	740	2.4
Mixed yard debris, compost, medium, uniform slope cover	280	0.9
Mixed yard debris, compost, coarse, uniform slope cover	690	2.2
Mixed yard debris compost barrier	1300	4.2
Leaf compost, uniform slope cover	740	2.4

Faucette et al. (2005) furthered the research from Risse and Faucette (2003). Plots were set up at Spring Valley Farm in Athens/Clarke County, Georgia and were 1.0 m wide and 4.8 m long containing disturbed Pacolet sandy loam. A rainfall event of 7.75 cm rainfall event for 1 hour was used for study. Rainfall events were chosen at 3 intervals throughout the year to measure the effect of revegetation on sediment removal. The results and comparison to bare soil is included in Table A.9.

Table A.9. Runoff and soil loss for various composts and conventional practices over time (Faucette et al., 2005).

1 Day	Runoff [mm]	Runoff compared to bare soil [%]	Soil loss [g/m2]	Soil loss compared to bare soil [%]
PLC/mulch/gypsum	32.0	75.7	158.9	2.5
Biosolids compost	38.1	90.1	105.8	1.6
MSW compost/mulch	22.5	53.2	191.9	3.0
Yardwaste compost	33.0	78.0	88.5	1.4
Hydroseed/mulch berm	36.7	86.8	265.1	4.1
Hydroseed/silt fence	30.0	70.9	307.9	4.8
bare soil	42.3	100.0	6428.1	100.0
3 months				
PLC/mulch/gypsum	5.0	10.9	14.6	0.3
Biosolids compost	6.9	15.0	18.9	0.3
MSW compost/mulch	1.8	3.9	6.0	0.1
Yardwaste compost	8.1	17.6	13.7	0.3
Hydroseed/mulch berm	20.2	44.0	78.1	1.4
Hydroseed/silt fence	32.3	70.4	219.6	4.0
bare soil	45.9	100.0	5464.2	100.0
12 months				
PLC/mulch/gypsum	15.9	39.0	10.8	1.0
Biosolids compost	21.6	52.9	8.8	0.8
MSW compost/mulch	21.9	53.7	17.8	1.6
Yardwaste compost	25.0	61.3	17.1	1.5
Hydroseed/mulch berm	34.2	83.8	10.9	1.0
Hydroseed/silt fence	27.6	67.6	14.5	1.3
bare soil	40.8	100.0	1109.7	100.0

Faucette et al. (2007) studied alternative erosion control methods in Athens, Georgia. Plots were 1m by 4.8m and at a 10% slope of Pacolet sandy clay loam. The rainfall event was 10 cm/hr for 1 hour. Their results are included in Table A.10.

Table A.10. Runoff and soil loss from compost mixes (Faucette et al., 2007).

	Runoff [L]	Runoff compared to bare soil [%]	Soil loss [kg/ha]	Soil loss compared to bare soil [%]
Bare Soil	478	100.0	6846	100.0
Straw w/ PAM	347	72.6	1110	16.2
100% Wood Mulch	317	66.3	96	1.4
1:2 blend	197	41.2	129	1.9
1:2 blend with clover	239	50.0	167	2.4
2:1 blend	159	33.3	208	3.0
100% compost	190	39.7	408	6.0

Faucette et al. (2009) studied the sediment removal efficiency of straw bales, mulch filter berms, compost filter socks, and compost filter socks and polymer at Spring Valley Farm in Athens/Clarke County, Georgia. Plots used were 1.0 m wide and 4.8 m long containing disturbed Pacolet sandy loam. The study modeled a 1.25 cm rainfall event over a area with maximum spacing for the given treatment. The results and comparison to bare soil is included in Table A.11.

Table A.11. Runoff and soil loss for compost socks from Faucette et al. (2009).

	Runoff [L/m2]	Runoff compared to bare soil [%]	Soil loss [mg/m2]	Soil loss compared to bare soil [%]
8 in. compost filter sock	157.9	66.5	226.8	15.7
12 in. compost filter sock	135.9	57.2	217.3	15.0
8 in. compost filter sock & polymer	149.8	63.1	198.3	13.7
12 in. compost filter sock & polymer	154.1	64.9	170.2	11.8
Mulch filter berm	205.4	86.5	526.9	36.5
Straw bale	199.8	84.2	414.6	28.7
Bare soil	237.4	100.0	1445.1	100.0

Foltz and Copeland (2009) detailed an extensive study evaluating wood shreds for erosion control. Plots were set up at the indoor rainfall simulator at the U.S. Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station and were 1.24m by 4.0m with a slope of 30%. Rainfall intensity was set at 50mm/hr, but added to additional flows from the top of the plot. Tables A.12 and A.13 detail many of the different runs contained within this study.

Table A.12. Runoff and soil loss for wood shred ground covers from sandy loam (Foltz and Copeland, 2009).

Rainfall	Runoff [mm]	Runoff compared to bare soil [%]	Soil loss [g]	Soil loss compared to bare soil [%]
Sandy Loam Cover 0%	3.1	100.0	780	100.0
Sandy Loam Cover 30%	0.2	6.5	20	2.6
Sandy Loam Cover 50%	x		x	
Sandy Loam Cover 70%	x		x	
Rainfall plus 1 L/min				
Sandy Loam Cover 0%	6.3	100.0	1310	100.0
Sandy Loam Cover 30%	1.8	28.6	170	13.0
Sandy Loam Cover 50%	0.4	6.3	20	1.5
Sandy Loam Cover 70%	0.01	0.2	0.01	0.0
Rainfall plus 4 L/min				
Sandy Loam Cover 0%	10.9	100.0	2330	100.0
Sandy Loam Cover 30%	5.7	52.3	480	20.6
Sandy Loam Cover 50%	3.4	31.2	190	8.2
Sandy Loam Cover 70%	1.3	11.9	50	2.1

Table A.13. Runoff and soil loss for wood shred ground covers on gravelly sand (Foltz and Copland, 2009).

Rainfall	Runoff [mm]	Runoff compared to bare soil [%]	Soil loss [g]	Soil loss compared to bare soil [%]
Gravelly Sand Cover 0%	0.01	100.0	4.0	100.0
Gravelly Sand Cover 30%	0.01	100.0	0.1	2.5
Gravelly Sand Cover 50%	x		x	
Gravelly Sand Cover 70%	x		x	
Rainfall plus 1 L/min				
Gravelly Sand Cover 0%	1.3	100.0	790	100.0
Gravelly Sand Cover 30%	0.9	69.2	160	20.3
Gravelly Sand Cover 50%	0.4	30.8	50	6.3
Gravelly Sand Cover 70%	0.2	15.4	20	2.5
Rainfall plus 4 L/min				
Gravelly Sand Cover 0%	4.2	100.0	3670	100.0
Gravelly Sand Cover 30%	3	71.4	1470	40.1
Gravelly Sand Cover 50%	2.7	64.3	460	12.5
Gravelly Sand Cover 70%	2.6	61.9	210	5.7

Glanville (2001) studied different composts at Ames, Iowa. The study plots measured 120 cm by 180 cm and set on a 3 horizontal to 1 vertical slope. Rainfall intensities simulated were 80-110 mm/hr. Results are given in Table A.14.

Table A.14. Runoff and soil loss for various composts (Glanville, 2001).

	Runoff [mm/hr]	Runoff compared to bare soil [%]	Soil loss [mg/m2s]	Soil loss compared to bare soil [%]
Biosolids (aggregated vegetated and non-vegetated)	36.0	66.2	1.5	90.9
Yard Waste	5.5	10.1	0.27	16.4
Bio-industrial	19.9	36.6	0.68	41.2
Control	54.4	100.0	1.65	100.0
Top Soil	48.9	89.9	3.19	193.3

Glanville (2003) also studied different composts at Ames, Iowa. Rainfall intensities simulated were 3.7 in/hr. Results are given in Table A.15.

Table A.15. Runoff and soil loss for various composts (Glanville, 2003).

Unvegetated	Runoff [mm]	Runoff compared to bare soil [%]	Soil loss [mg]	Soil loss compared to bare soil [%]
Biosolids	0.13	0.6	7.84	0.0
Yard Trimmings	0.01	0.0	0.02	0.0
Bio-industrial	0.08	0.3	2.52	0.0
Compacted Subsoil	23.22	100.0	45714	100.0
Topsoil	15.54	66.9	40046	87.6
Vegetated				
Biosolids			1.65	0.0
Yard Trimmings			0.01	0.0
Bio-industrial			0.06	0.0
Compacted Subsoil			7385	100.0
Topsoil			24867	336.7

Keener et al. (2006) studied the erosion control capabilities of silt fence and compost silt socks in Wooster, Ohio. Tests were run in a flume with dimensions of 2ft by 8 ft. with adjustable slope of 10% to 20%. The study dealt mainly with ponding depth but did determine that silt fence and compost socks are statistically similar with sediment removal from runoff around 30-50%.

Kelsey (2007) studied various best management practices, in Rice Lake, Wisconsin during 2005. Plots were 35.0 feet by 8.0 feet at an 12.5% slope and filled with a veneer of loam-textured soil. The simulated rainfall varied over time: 2 in/hr intensity for 20 minutes, 4 in/hr for

30 minutes, 6in/hr for 30 minutes. Table A.16 details her results. The first four points are based on data through the 4in/hr events while the last 3 data points are through all rainfall events.

Table A.16. Percent of soil retained for tubular erosion control practices (Kelsey, 2007).

	Percent of soil retained compared to bare plots
6" Excelsior Fiber Log	55.2
12" Excelsior Fiber Log	71.2
9" Straw Wattle	34.3
12" Straw Wattle	19.5
4' Excelsior Fiber Buffer Strip	63.9
8' Excelsior Fiber Buffer Strip	83.3
8' Straw Buffer Strip	53.9

Leib et al (2004) studied various erosion control methods in Washington State with a goal of reducing sediment loads in runoff. Study sites were a vineyard with a 1.2% slope and a cornfield with 0.2% slope. The study results indicated that grass-lined tail ditches were more effective than surge irrigation, tailwater drains, and tailwater check dams.

Meyer et al. (1972) studied a variety of ground covers. The study was conducted on a Wingate silt loam near Dayton, Indiana. The slope was a uniform 20% and the dimensions were 6 ft by 36 ft. The simulated rainfall event was 2.5 in/hr for one hour followed by 2 30-minute storms of the same intensity a day later. Results are tabulated in Table A.17.

Table A.17. Soil loss for various types and applications of ground cover (Meyer et al., 1972).

	Application rate	Soil loss [t/a]	Soil loss compared to bare soil [%]
Bare soil		39.6	100.0
Portland Cement		32.7	82.6
Woodchips	2 t/a	27.1	68.4
Stone	15 t/a	25.6	64.6
Gravel	70 t/a	14.7	37.1
Straw	2.3 t/a	12.1	30.6
Stone	60 t/a	11.4	28.8
Woodchips	4 t/a	8.5	21.5
Woodchips	7 t/a	5.5	13.9
Stone	135 t/a	3.5	8.8
Stone	240 t/a	2.0	5.1
Stone	375 t/a	2.0	5.1
Woodchips	12 t/a	2.0	5.1
Woodchips	25 t/a	2.0	5.1

Mukhtar et al. (2004) studied the use of dairy manure compost as an erosion control option. The setup was 1m by 2m and set on a 3 horizontal to 1 vertical slope on a highway right of way in Texas. A simulated rainfall event of 92 mm/hr for 30 minutes was studied. Table A.18 shows the data gathered from this study.

Table A.18. Runoff and soil loss for various composts (Mukhtar, 2004).

	Runoff [kg]	Runoff compared to bare soil [%]	Soil loss [kg]	Soil loss compared to bare soil [%]
Compost manufactured topsoil	49.85	69.0	2.48	24.3
Erosion control compost	47.33	65.6	0.09	0.9
Agronomic rate compost	58.43	80.9	4.31	42.3
Commercial fertilizer on soil (control)	72.2	100.0	10.20	100.0

Persyn et al. (2002) studied compost on highway right of ways. Plot sizes were 1.5m by 1.2 m for the first year and then 1.2m by 1.2m in the second year. Rainfall intensity was 63 mm/hr for the first run and then increased to 100mm/hr at year one. The slope of the study area was 3 horizontal to 1 vertical. Tables A.19 and A.20 show the data gathered, treatments are repeated with different depths of applications.

Table A.19. Runoff and soil loss for different depths of various composts on un-vegetated soil (Persyn et al., 2002).

Un-vegetated	Runoff [mm\hr]	Runoff compared to bare soil [%]	Soil loss [mg/m2s]	Soil loss compared to bare soil [%]
Biosolids Compost	41.55	63.5	28.82	24.8
Biosolids Compost	37.24	56.9	27.39	23.6
Yard waste compost	15.93	24.3	4.49	3.9
Yard waste compost	11.95	18.3	4.86	4.2
Bio-Industrial Compost	38.97	59.6	18.87	16.3
Bio-Industrial Compost	15.81	24.2	9.89	8.5
Compacted Subsoil (Control)	65.44	100.0	116.06	100.0
Topsoil	47.58	72.7	166.89	143.8

Table A.20. Runoff and soil loss for different depths of various composts on vegetated soil (Persyn et al., 2002).

Vegetated	Runoff [mm\hr]	Runoff compared to bare soil [%]	Soil loss [mg/m2s]	Soil loss compared to bare soil [%]
Biosolids Compost (veg.)	20.53	37.3	3.4	17.0
Biosolids Compost	19.5	35.4	8.57	42.8
Yard waste compost	5.53	10.0	0.12	0.6
Yard waste compost	1.25	2.3	0.08	0.4
Bio-Industrial Compost	24.53	44.5	3.69	18.4
Bio-Industrial Compost	5.54	10.1	4.36	21.8
Compacted Subsoil (Control)	55.1	100.0	20.01	100.0
Topsoil	56.35	102.3	83.63	417.9

Persyn et al. (2004) re-evaluates the study of compost on highway right of ways. Plot sizes were 1.5m by 1.2 m for the first year and then 1.2m by 1.2m in the second year. Rainfall intensity was 63 mm/hr for the first run and then increased to 100mm/hr at year one. The slope of the study area was 3 horizontal to 1 vertical. Table A.21 shows the data gathered. Data is averaged over all similar treatments.

Table A.21. Runoff and soil loss for various composts (Persyn et al., 2004).

Unvegetated	Runoff [mm\hr]	Runoff compared to bare soil [%]	Soil loss [mg/m2s]	Soil loss compared to bare soil [%]
Biosolids	39	60.0	28.0	23.3
Yard Waste	14	21.5	4.7	3.9
Bio-industrial	27	41.5	14.0	11.7
Control	65	100.0	120.0	100.0
Top Soil	48	73.8	170.0	141.7
Vegetated				
Biosolids	20	36.4	6.0	30.0
Yard Waste	3	6.2	0.1	0.5
Bio-industrial	15	27.3	4.0	20.0
Control	55	100.0	20.0	100.0
Top Soil	56	101.8	84.0	420.0

Risse and Faucette (2003) studied compost treatments based on local commercially availability. Plots used were 92 cm by 107 cm filled with Cecil sandy clay loam. Their apparatus was placed at a 10% slope and subjected to a 16cm/hr intensity event for 1 hour. Tables A.22 and A.23 show the recorded data and the comparison to bare soil.

Table A.22. Runoff and soil loss from various composts (Risse and Faucette, 2003).

	Runoff [L]	Runoff compared to bare soil [%]	Soil loss [g]	Soil loss compared to bare soil [%]
Poultry gold compost/Poultry litter	74	104.2	552	85.4
Sargents nutrients compost/Poultry Litter	44	62.0	208	32.2
Gro-mor compost/Poultry litter, vegetable waste, yard waste	52	73.2	168	26.0
Aged poultry littler/Layer manure from under-house storage	83	116.9	1221	189.0
Cobb Co. compost/Municipal solid waste and sludge	47	66.2	236	36.5
Erthfood compost/Municipal sludge, peanut hulls	53	74.6	154	23.8
Creative Earth Compost/Food residuals, ground wood waste	37	52.1	139	21.5
UGA compost/Yard waste, ground wood waste, some manure	63	88.7	111	17.2
Woodtech superfine mulch/Finely ground wood mulch	35	49.3	102	15.8
Woodtech medium hardwood mulch/Medium ground wood mulch	48	67.6	144	22.3
Rockdale Co. mulch/Coarse ground yard waste and waste wood	66	93.0	74	11.5
Bare soil/Control	71	100.0	646	100.0

Risse and Faucette (2003) also gave preliminary results for a study using the best performing composts from their previous study as filter berms and hydroseeding. Plots were 1m by 5m set up at Athens, Georgia with a slope of 10%. Results follow in Table A.23.

Table A.23. Runoff and soil loss from various composts and conventional practices (Risse and Faucette, 2003).

	Runoff [L]	Runoff compared to bare soil [%]	Soil loss [g]	Soil loss compared to bare soil [%]
Biosolid compost blanket and filter berm	170	89.9	471	1.6
Poultry litter compost blanket and wood mulch filter berm	143	75.7	708	2.5
Yardwaste compost blanket and filter berm	147	77.8	395	1.4
Municpal solid waste compost blanket and mulch filter berm	101	53.4	855	3.0
Hydroseed with silt fence	164	86.8	1182	4.1
Hydroseed with mulch filter berm	133	70.4	1372	4.8
Bare soil	189	100.0	28650	100.0

Storey et al. (1996) studied the performance of compost and woodchips with tackifier as erosion control materials. The experiment was set up in Texas on a 3 horizontal to 1 vertical slope in plots that measured 6.2 m by 21 m. Their findings are included in Table A.24.

Table A.24. Soil loss for various ground covers (Storey et al., 1996).

	Soil Loss [kg/10m2]	Soil loss compared to bare soil [%]
Compost Sand	3.88	13.6
Wood chips Granular PAM Tackifier Sand	11.27	39.4
Wood Chips Hydrophillic Colloid Tackifier Sand	10.97	38.4
Control Sand	28.58	100.0
Compost Clay	0.34	26.1
Wood chips Granular PAM Tackifier Clay	0.15	11.5
Wood Chips Hydrophillic Colloid Tackifier Clay	0.30	23.1
Control Clay	1.30	100.0

Tyler (2001) highlighted several field studies: most notably one in Richmond, Virginia where plots were set up on a roadside. All data gathered was visual with no quantitative values. All combinations preformed the same and no erosion was detectable. Table A.25 lists the erosion control treatments.

Table A.25. Compost arrangements studied by Tyler (2001).

Compost particle size	Blanket depth and berm
2 inch minus	2 inch and berm
0.5 inch minus	2 inch and berm
0.5 inch minus reground leaf compost	2 inch and berm
1 inch minus recycled and reground screen overs	2 inch and berm
2 inch minus	4 inch and berm
0.5 inch minus	4 inch and berm
0.5 inch minus reground leaf compost	4 inch and berm
1 inch minus recycled and reground screen overs	4 inch and berm

The USEPA, Solid Waste and Emergency Response, (1997) highlighted a study in Washington, DC. Two slopes were studied one was 2 horizontal to 1 vertical and the other was 3 horizontal to 1 vertical. They conclude that mature yard trimmings outperform hydromulch and fertilizer and yard trimmings and fertilizer for both reducing runoff and mitigating erosion.

APPENDIX B: WEATHER STATION SENSOR DETAILS

The weather station set up at the field study site measured many weather variables. Table B.1 presents sensors and their accuracy. The station was set up to gather once every 5 minutes in the field. Graphs of the entire readout are given in Appendix E.

Table B.1. Weather sensors and accuracy used on the weather station.

Sensor	Accuracy
Soil Moisture	±4%
Barometric Pressure	±1.5 mbar at 25ºC
Silicon Pyranometer	±5%
Tipping Bucket Rain Gauge	±1.0% at 1 inch per hour
Photosynthetically Active Radiation	±5%
Temperature and Relative Humidity	±0.7ºC at 25 ºC ±3%
Wind Speed and Direction	±0.5 m/s ±5 Degrees

APPENDIX C: SOIL CHEMISTRY RESULTS

Soil samples were taken from each plot and sent to a soil chemistry lab for analysis. Tables C.1 through C.3 detail the results.

Table C.1. Chemical properties of field study site soils: part 1.

	Organic Matter	Phosphorous		K	Mg	Ca	Na	pH		CEC
Plot	Percent	P1 ppm	P2 ppm	ppm	ppm	ppm	ppm	Soil pH	Buffer Index	meq/100g
1	2.6	26	42	123	176	1172	07	5.8	6.7	09.5
2	2.9	30	36	430	285	1701	17	5.8	6.6	14.9
3	3.0	26	40	292	267	1810	13	6.2	6.8	13.7
4	2.6	26	39	248	260	1644	10	6.0	6.7	13.1
5	2.7	25	36	245	253	1623	10	6.2	6.8	12.4
6	2.8	16	27	228	295	1702	11	6.9	6.7	13.6
7	2.5	18	31	229	250	1541	11	6.3	6.8	11.6
8	2.8	17	28	221	268	1613	10	6.2	6.8	12.4
9	2.7	19	29	267	174	1401	10	6.5	6.9	09.9
10	2.8	36	43	277	247	1633	12	6.2	6.8	12.5
11	2.6	19	31	200	250	1741	10	6.3	6.8	12.6
12	2.7	17	26	293	269	1648	11	6.5	6.9	12.2
13	2.6	14	23	220	258	1546	11	6.0	6.7	12.1
14	2.3	15	24	271	279	1849	13	6.4	6.8	13.5
15	2.4	14	19	182	235	1600	10	6.2	6.8	11.9
16	3.1	10	14	173	281	1656	11	6.2	6.8	12.6

Table C.2. Chemical properties of field study site soils: part 2.

	Percent Base Saturation					Nitrate-N		
Plot	%K	%Mg	%Ca	%H	%Na	ppm	lbs/A	depth (in)
1	3.3	15.4	61.7	19.3	0.3	6	11	0-6
2	7.4	15.9	57.1	19.1	0.5	8	14	0-6
3	5.5	16.2	66.1	11.8	0.4	3	05	0-6
4	4.9	16.5	62.7	15.6	0.3	8	14	0-6
5	5.1	17.4	65.4	11.7	0.4	9	16	0-6
6	4.3	18.1	62.6	14.6	0.4	4	07	0-6
7	5.1	18.0	66.4	10.1	0.4	9	16	0-6
8	4.6	18.0	65.0	12.0	0.4	2	04	0-6
9	6.9	14.6	70.8	07.3	0.4	7	13	0-6
10	5.7	16.5	65.3	12.1	0.4	9	16	0-6
11	4.1	16.5	69.1	10.0	0.3	7	13	0-6
12	6.2	18.4	67.5	07.5	0.4	6	11	0-6
13	4.5	17.3	62.3	15.5	0.4	6	11	0-6
14	5.1	17.2	68.5	8.8	0.4	7	13	0-6
15	3.9	16.5	67.2	12.0	0.4	7	13	0-6
16	3.5	18.6	65.7	11.8	0.4	7	13	0-6

Table C.3. Chemical properties of field study site soils: part 3.

	S	Zn	Mn	Fe	Cu	B	Soluble Salts
Plot	ppm	ppm	ppm	ppm	ppm	ppm	mmhos/cm
1	13	0.6	11	66	0.7	1.0	0.1
2	17	0.7	13	61	0.9	2.8	0.3
3	14	0.6	23	73	1.0	1.9	0.2
4	14	0.4	11	59	0.8	1.3	0.2
5	15	0.9	17	57	0.8	1.4	0.2
6	15	0.6	12	60	0.9	1.0	0.1
7	15	1.4	10	48	0.8	1.8	0.2
8	13	0.8	26	50	1.0	1.0	0.1
9	12	0.9	09	44	0.9	2.5	0.3
10	14	0.7	13	47	0.9	2.1	0.3
11	14	0.6	13	56	1.0	1.2	0.2
12	15	0.4	10	41	0.6	1.9	0.2
13	16	0.8	12	48	1.2	1.6	0.2
14	15	0.6	11	51	1.0	2.2	0.2
15	13	0.4	09	45	0.9	1.7	0.2
16	12	0.4	11	48	0.9	1.2	0.2

APPENDIX D: INDIVIDUAL STORM EVENT HYDROGRAPHS

Individual rainfall hydrographs are given in Figures D.1 through D.4 for the natural rainfall events that occurred in the field study. Any precipitation within 6 hours of the event is graphed in the hydrographs. The sampling rate for the data logger in the weather station was 15 minutes, thus, the points represent total collective rainfall during that period and not rainfall rates or trends. Return periods are estimated from the data points and the National Weather Service.

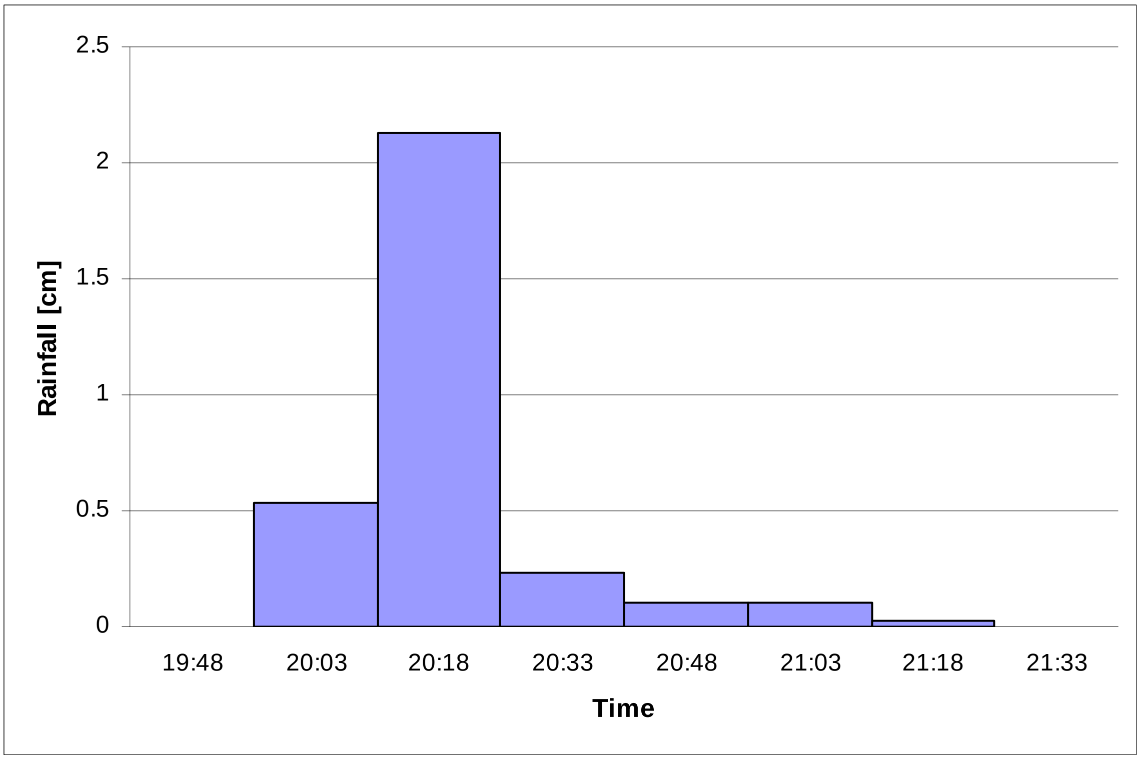

Figure D.1. Rainfall hydrograph for the rainfall event on 7/29/2008.

The July 29th and 30th rainfall event had a total of 3.12 cm of rainfall. During this event there was a return period of 2 years for a 15-minute rainfall at the peak of the storm.

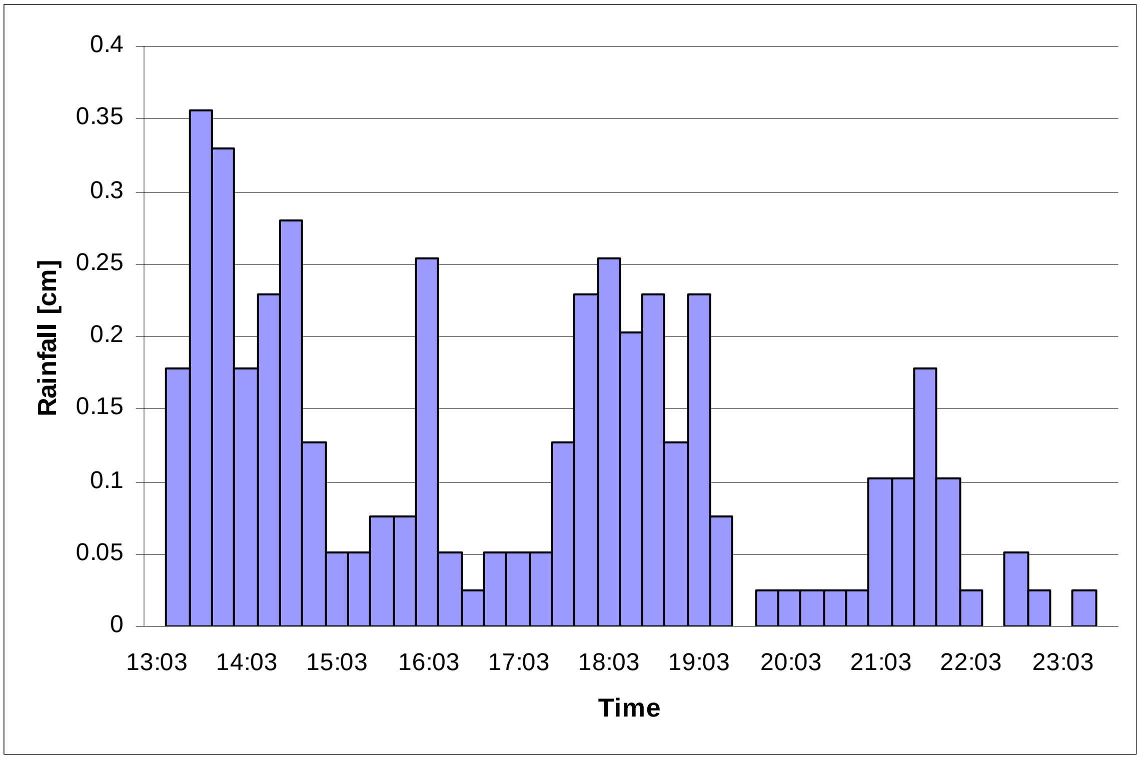

Figure D.2. Rainfall hydrograph for the rainfall event on 9/5/2008.

No significant return period was associated with this rain event on September 4th and 5th; even though there was a total rainfall of 4.62 cm it came over 11 hours.

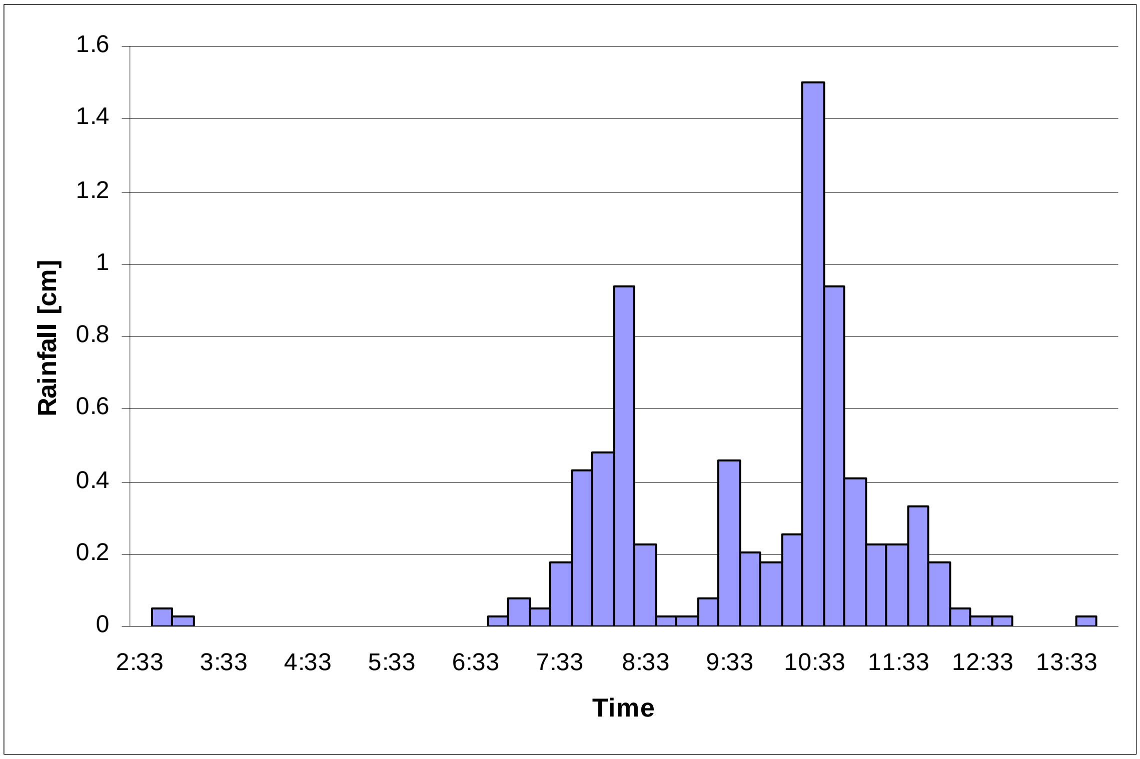

Figure D.3. Rainfall hydrograph for the rainfall event on 9/15/2008.

The rainfall event on September 14th and 15th had at total rainfall of 7.65 cm and had a return period of 9 years for the intensity from 7:00 till 12:00 on the graph.

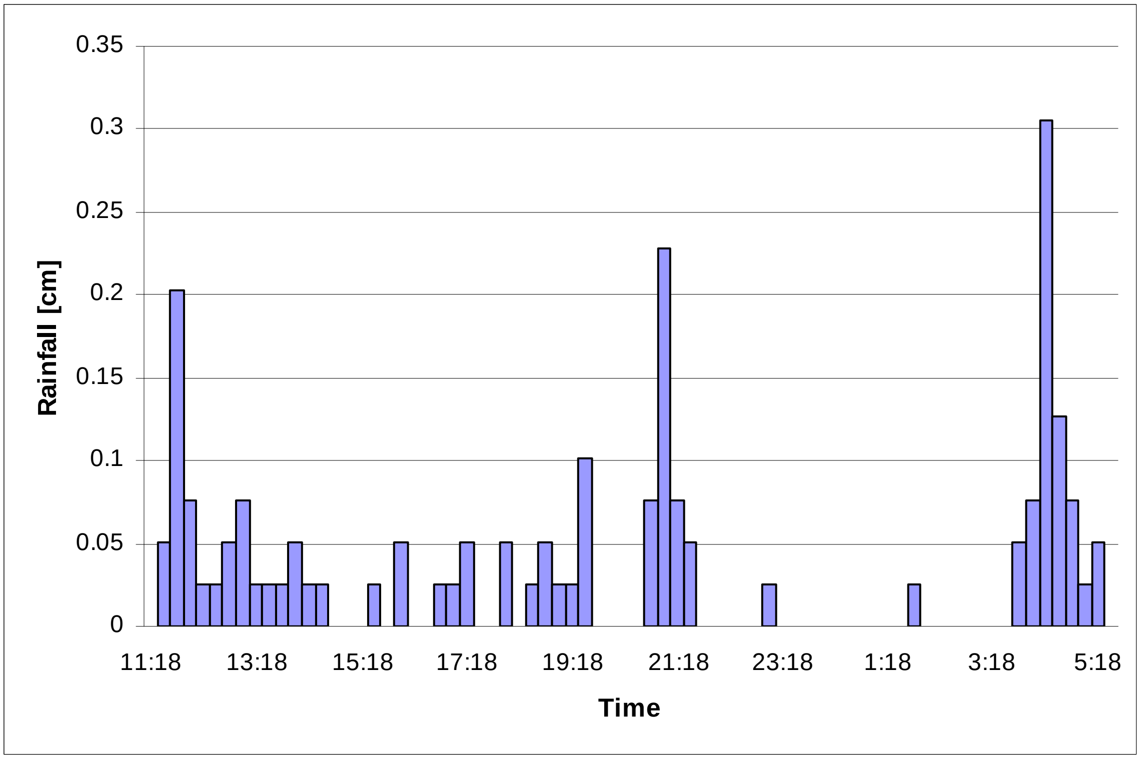

Figure D.4, Rainfall hydrograph for the rainfall event on 10/8/2008.

The last storm only had a total rainfall of 2.34 cm. No significant return period was associated with this storm that occurred on October 8th. Due to lab restrictions the samples did not make it to the lab till the 9th, therefore, this event is referred to as the October 9th storm.

APPENDIX E: COMPLETE WEATHER STATION READOUT

The weather station gathered data from July 15, 2008 through May 20, 2009. The field study period lasted only from July 15, 2008 through October 31, 2008; the rest of the data was included so as to provide a basis. Over 27,000 data points were recorded; therefore, the best display of the data is graphical; as shown in Figures E.1 through E.8.

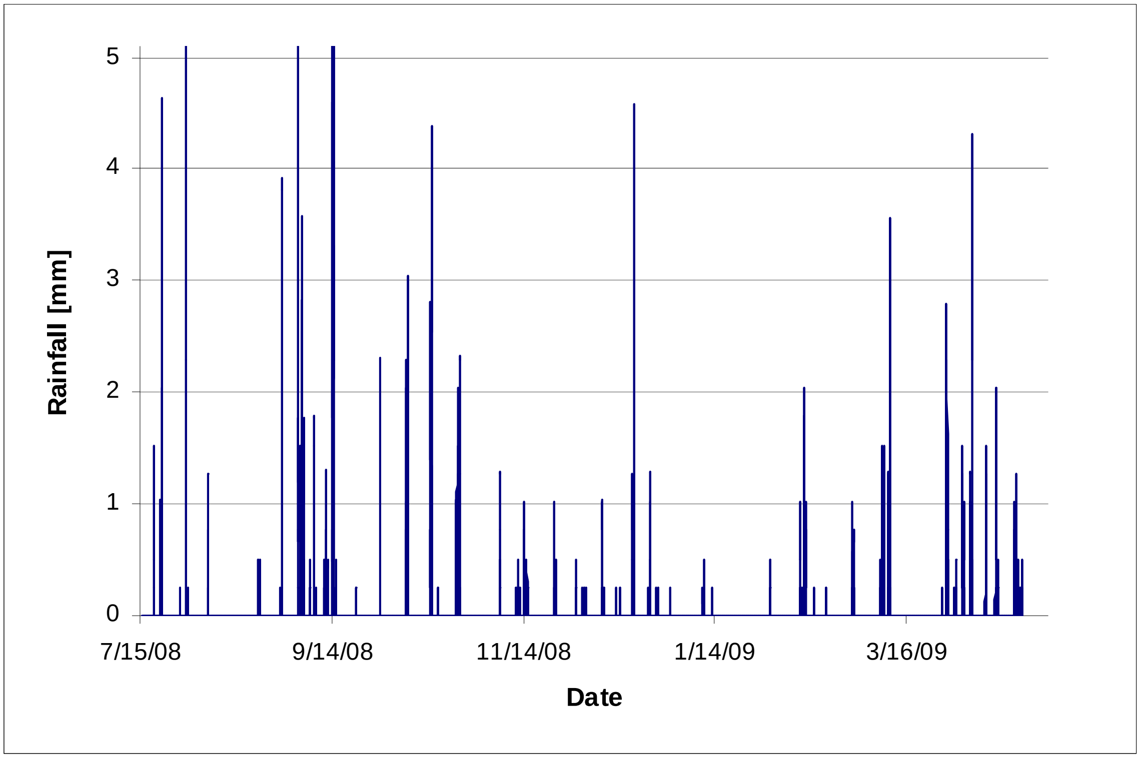

Figure E.1. Rainfall hydrograph over the entire recorded period.

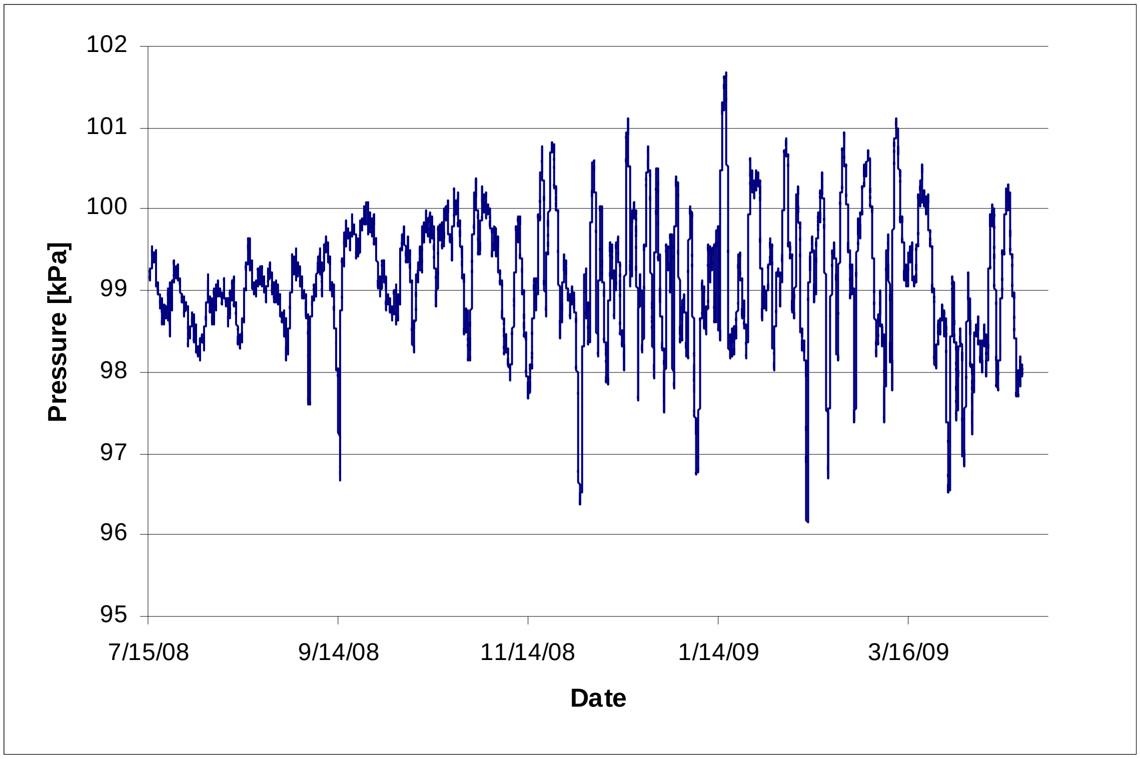

Figure E.2. Atmospheric pressure fluctuations over the entire recorded period.

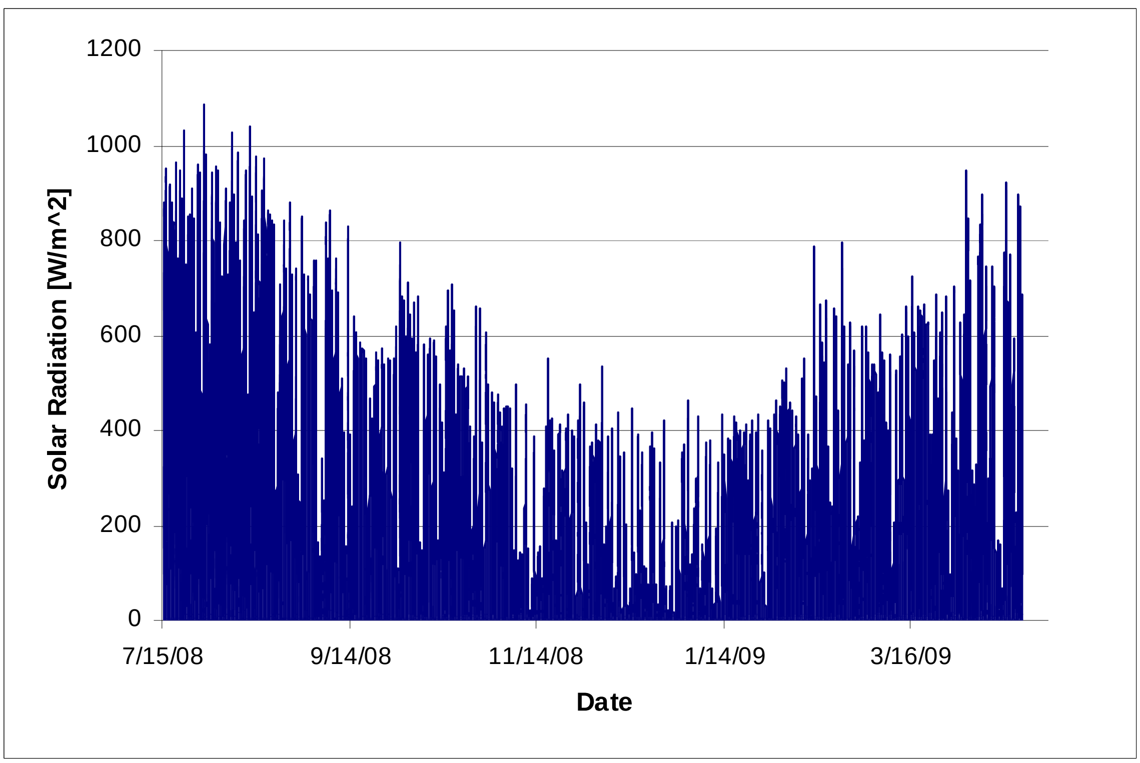

Figure E.3. Solar radiation fluctuations over the entire recorded period.

The wind sensor was knocked off of the weather station for a brief period during the later winter. The loss of data is clearly seen by the lack of data for a month long period in Figure E.4 and E.5. The lost data was not deemed vital because the field study had been concluded by that time.

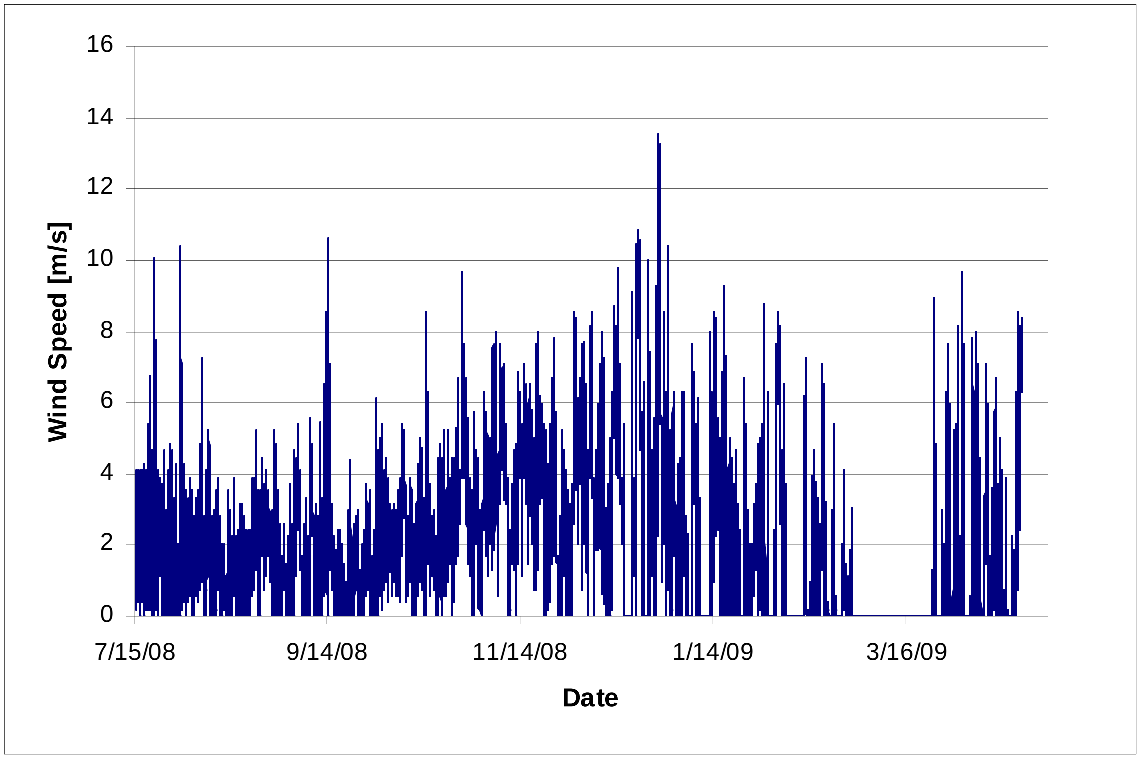

Figure E.4. Wind speed changes over the entire recorded period.

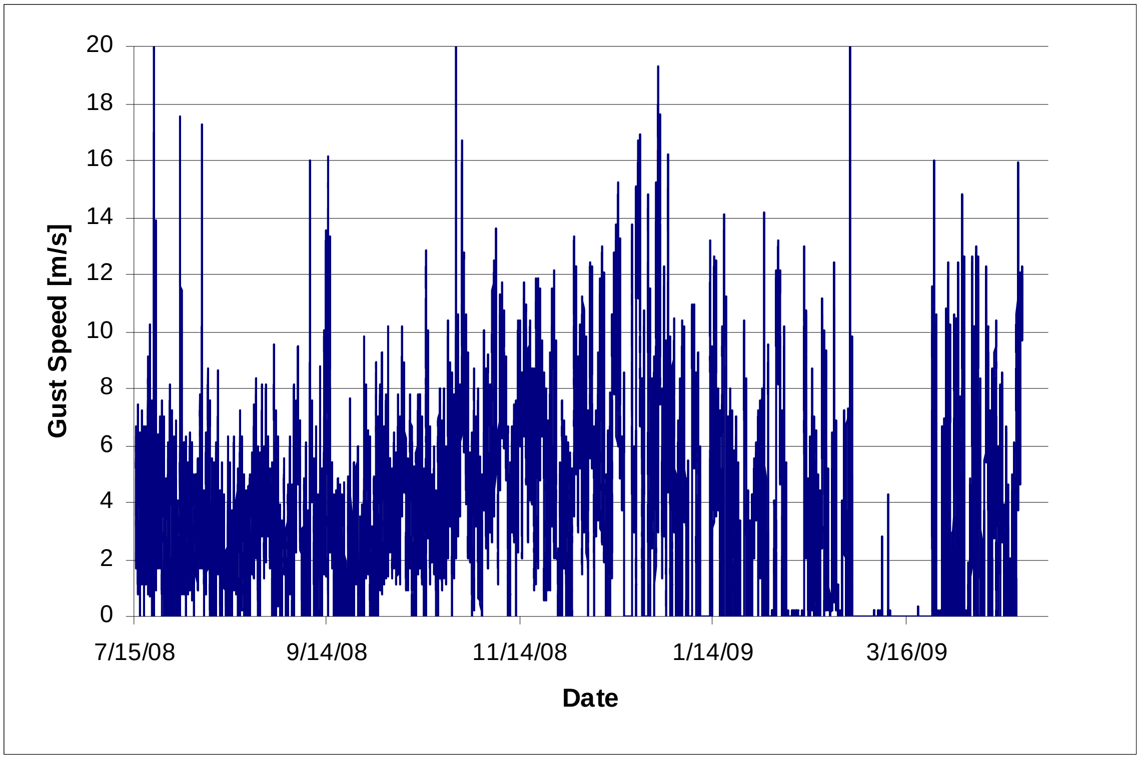

Figure E.5. Maximum gust speed per sampling interval over the entire recorded period.

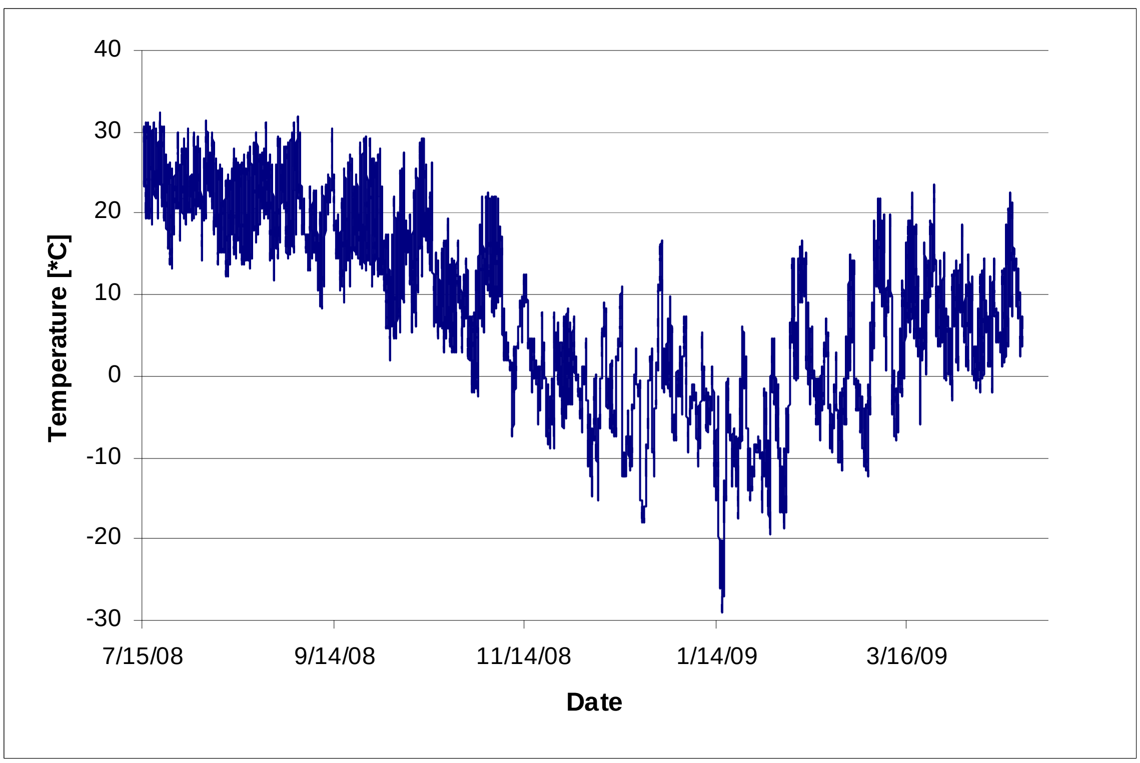

Figure E.6. Temperature readings over the entire recorded period.

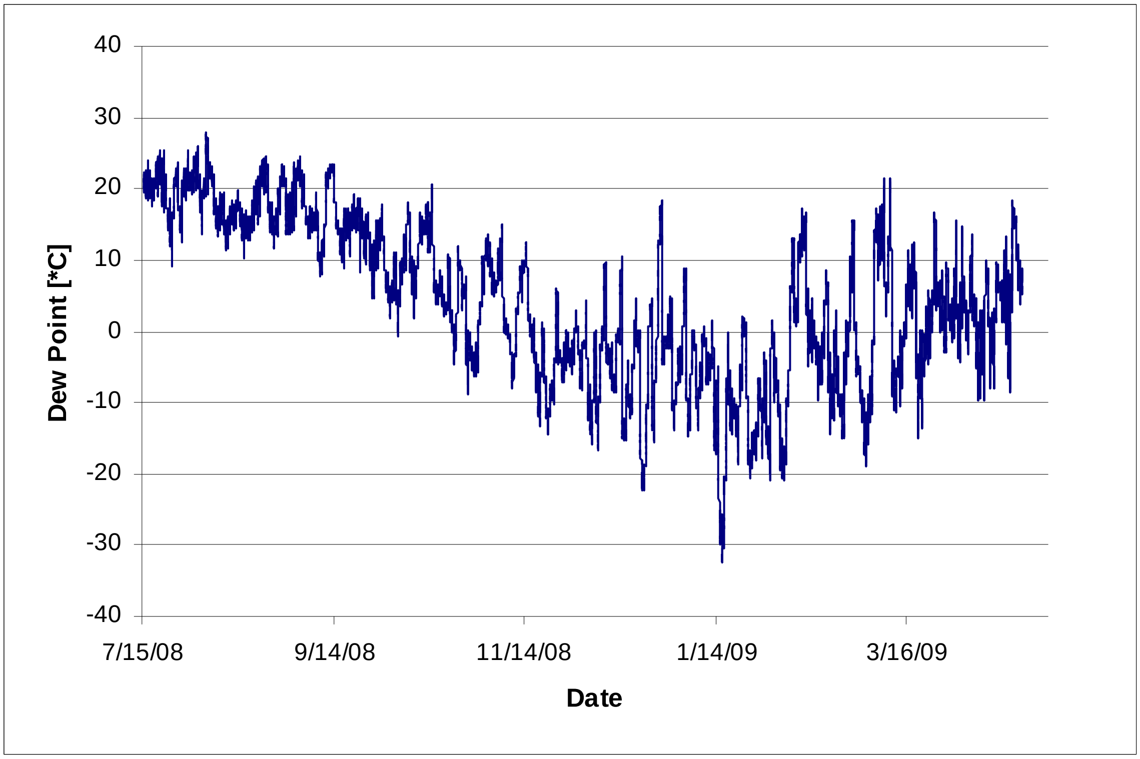

Figure E.7. Dew point readings for the entire recorded period.

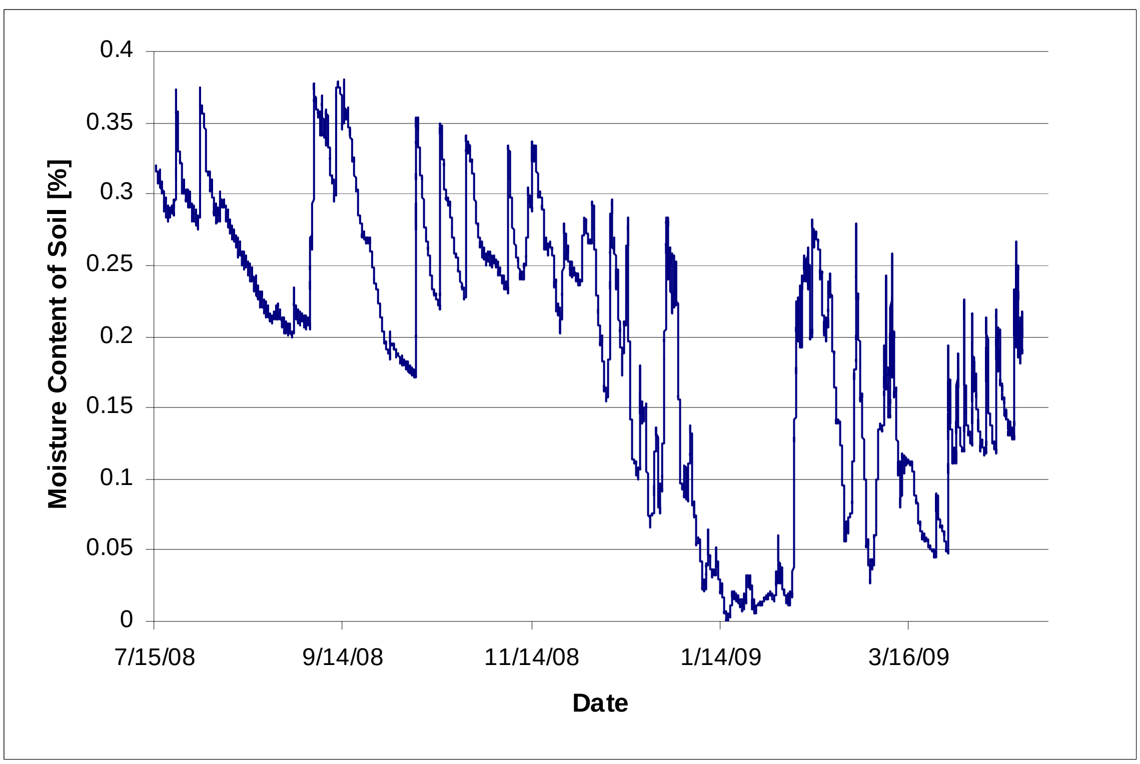

Figure E.8. Volumetric soil moisture content measurements for the entire recorded period.

APPENDIX F: FIELD STUDY INDIVIDUAL PLOT RESULTS

The individual storm events from the field study contain vast amounts of data. Each event could be a useful case study in check dam performance. The data is graphed below in Figures F.1 through F.10.

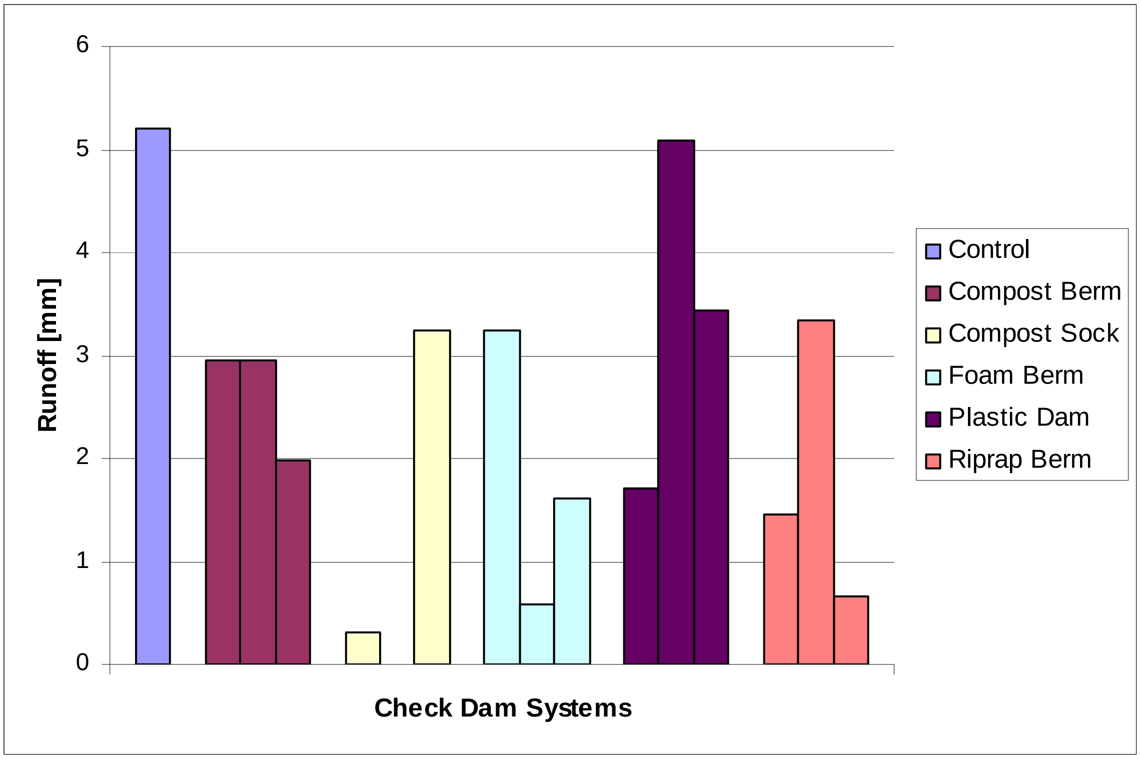

Figure F.1. Runoff from the field study plots for the rainfall event on 7/29/2008.

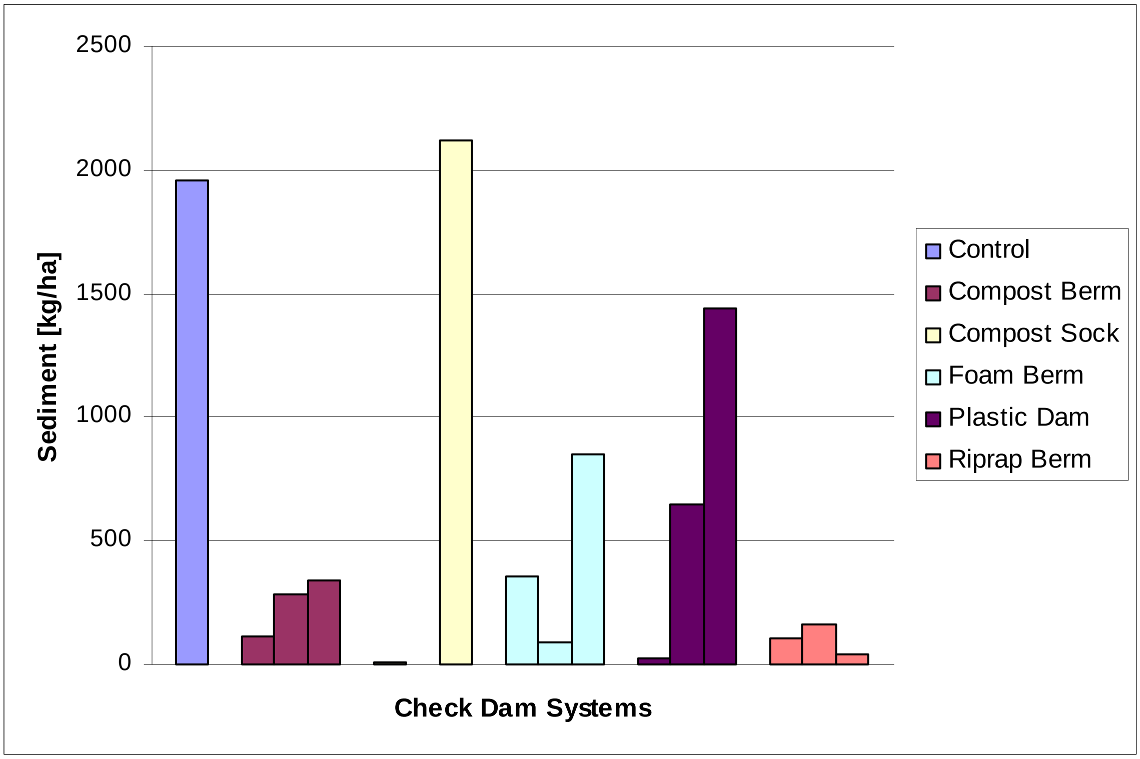

Figure F.2. Soil loss from the field study plot for the rainfall event on 7/29/2008.

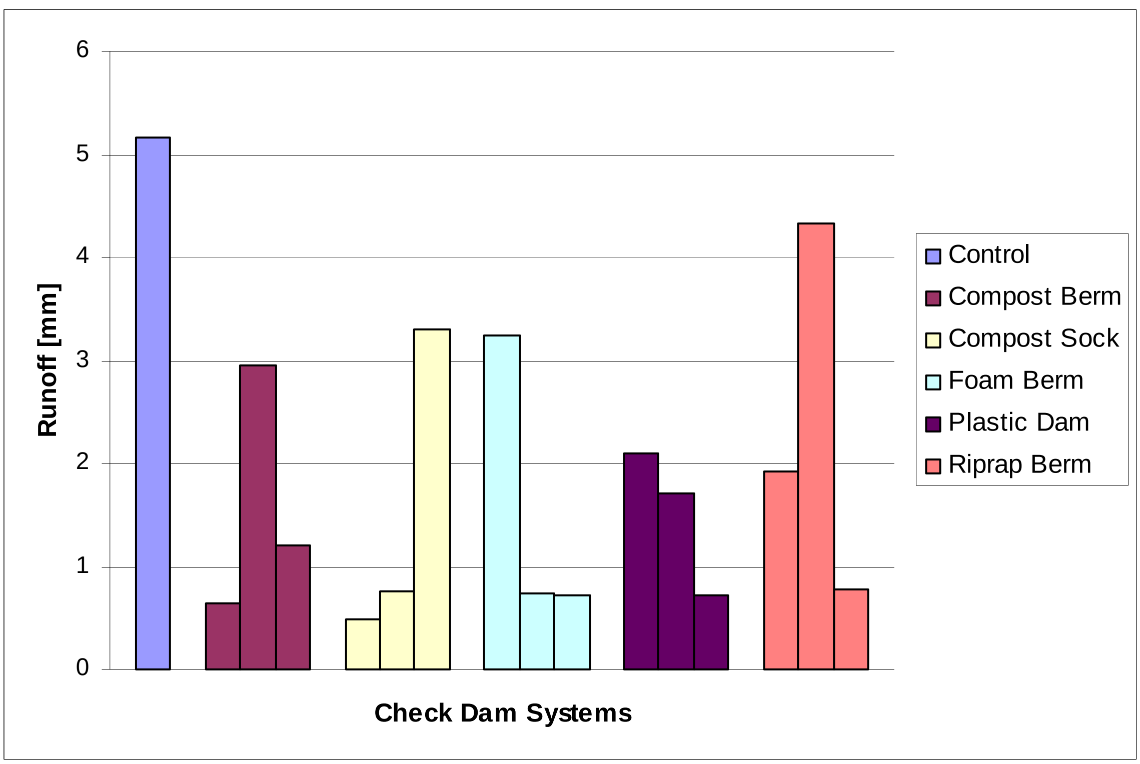

Figure F.3. Runoff from the field study plots for the rainfall event on 9/5/2008.

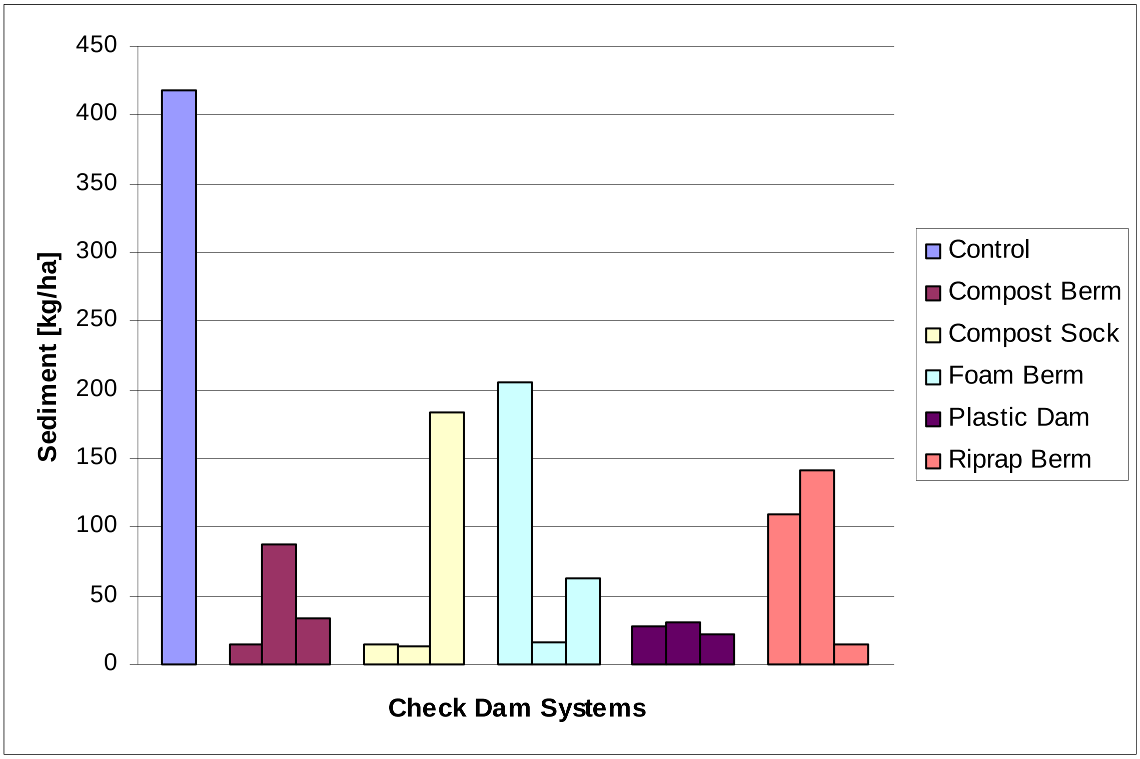

Figure F.4. Soil loss from the field study plot for the rainfall event on 9/5/2008.

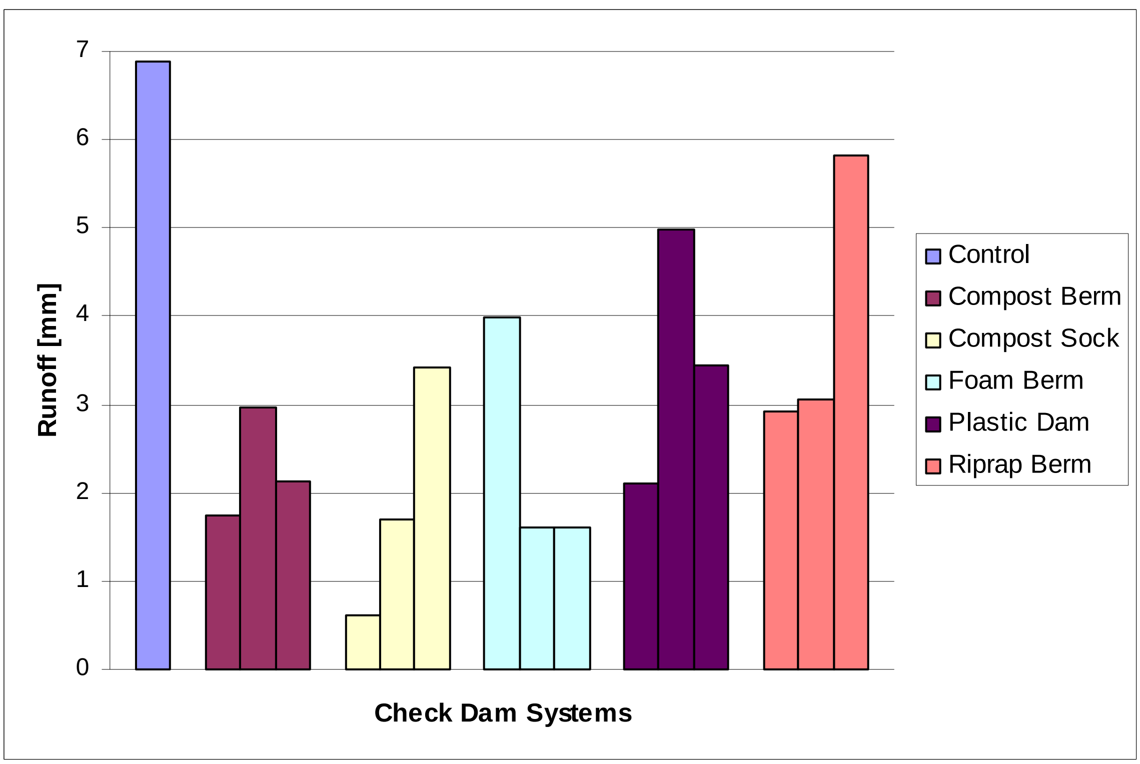

Figure F.5. Runoff from the field study plots for the rainfall event 9/15/2008.

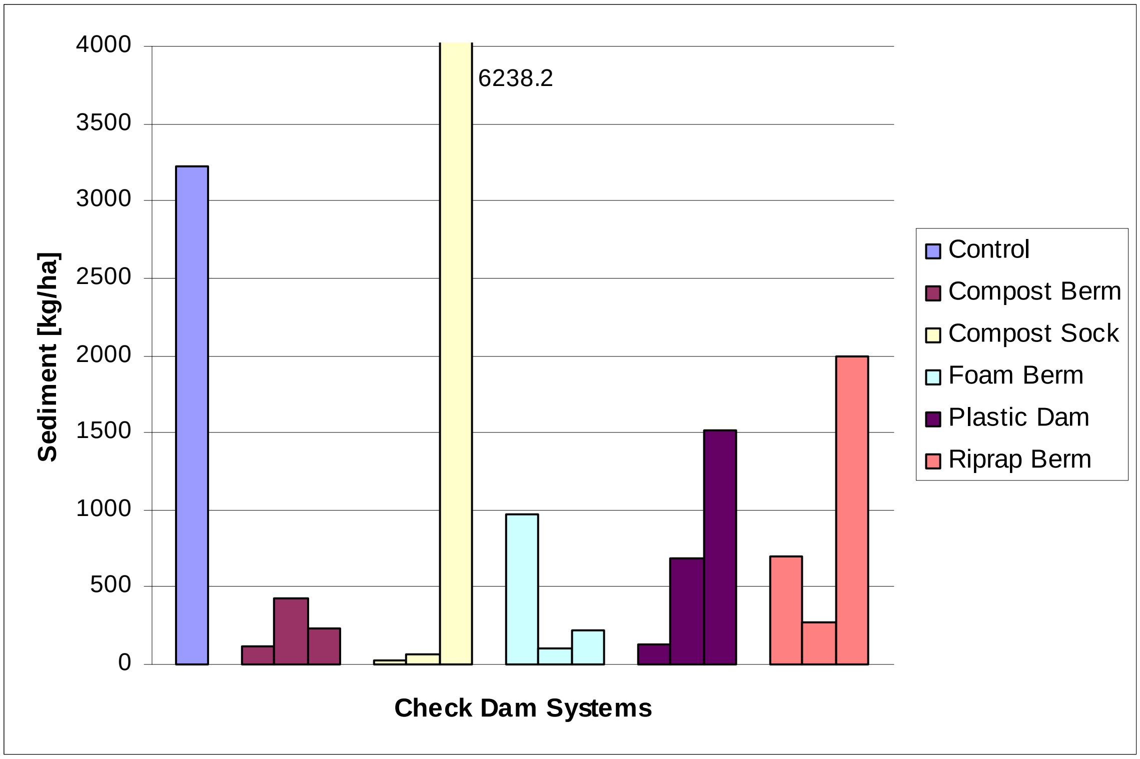

Figure F.6. Soil loss from the field study plot for the rainfall event on 9/15/2008.

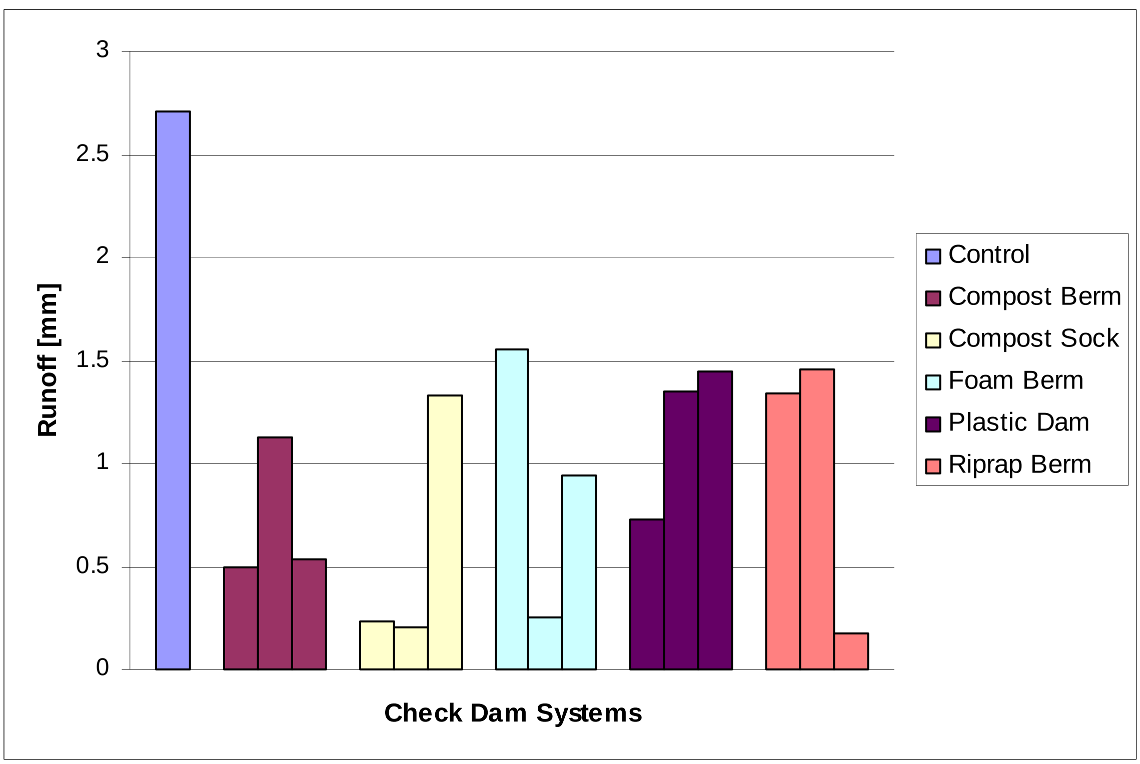

Figure F.7. Runoff from the field study plots for the rainfall event on 10/9/2008.

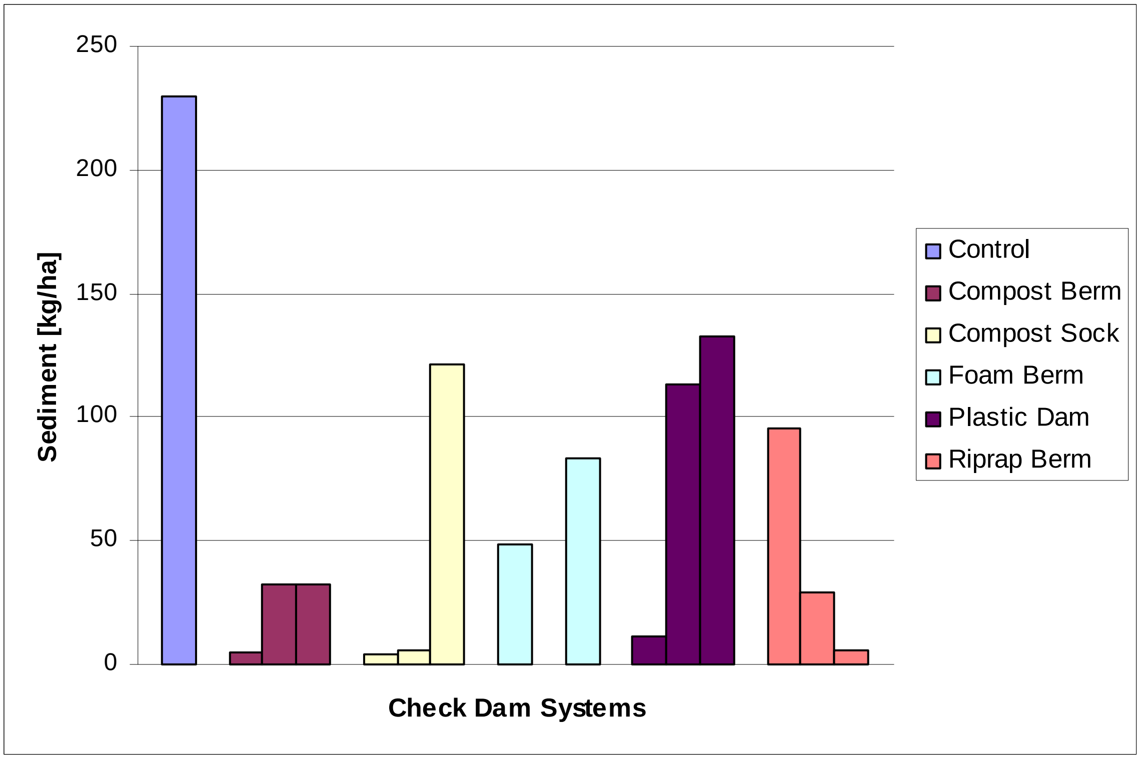

Figure F.8. Soil loss from the field study plot for the rainfall event on 10/9/2008.

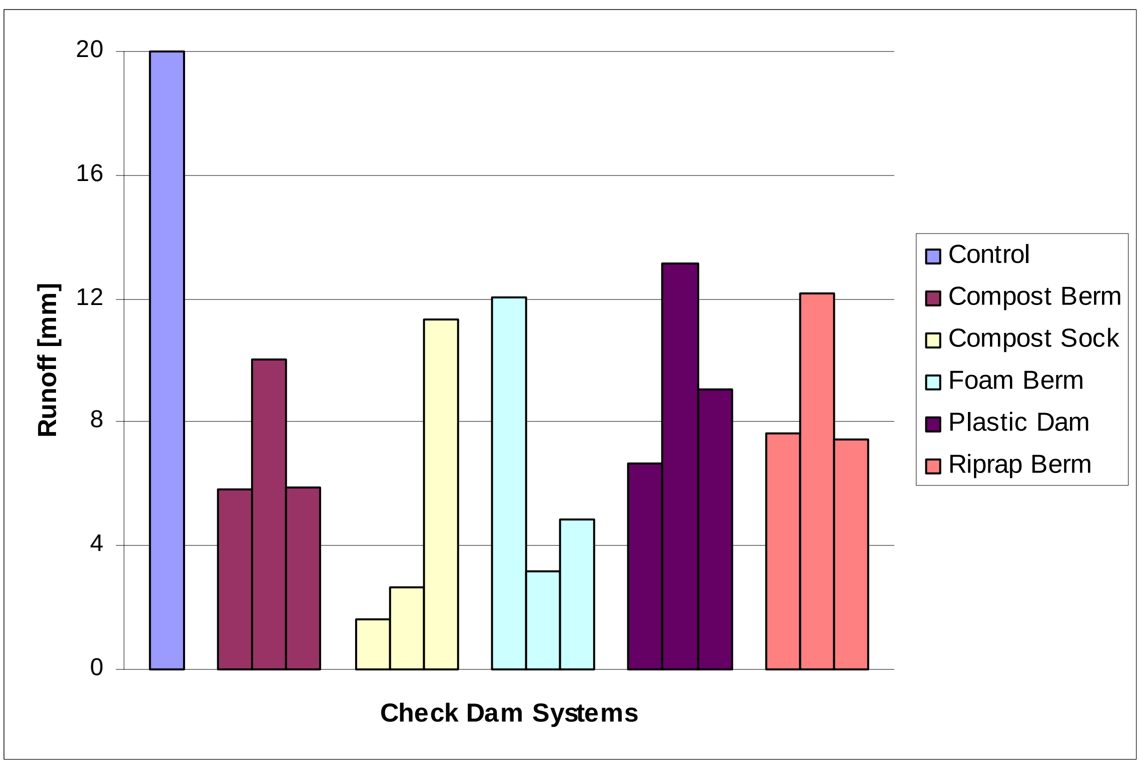

Figure F.9. Runoff from the field study plots for the entire study period.

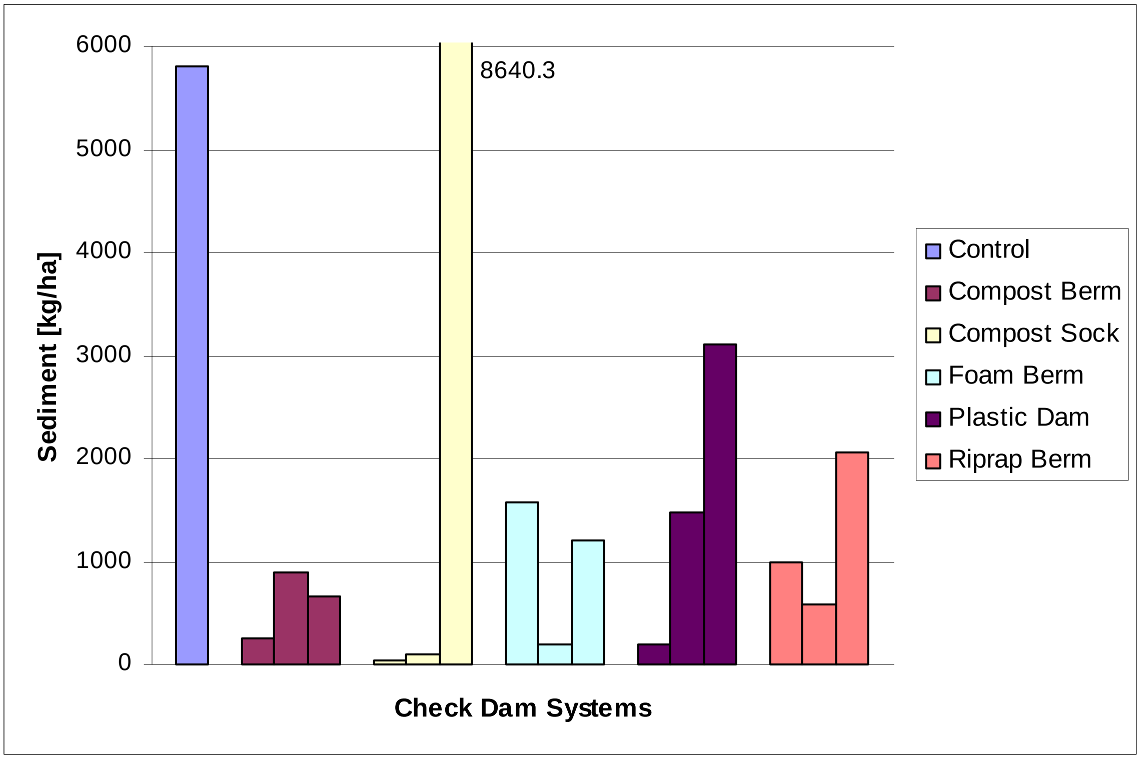

Figure F.10. Soil loss from the field study plots for the entire study period.

APPENDIX G: CONFIDENCE FOR THE FIELD STUDY

Figures G.1 through G.4 denote statistical measurement of standard deviation for each treatment. The error bars denote the individual check dam erosion control treatments' confidence interval and not the statistical comparison between treatments as in the tables shown in the results section. Each bar denotes that check dams distribution and assuming a normal distribution would imply around a 68% confidence interval.

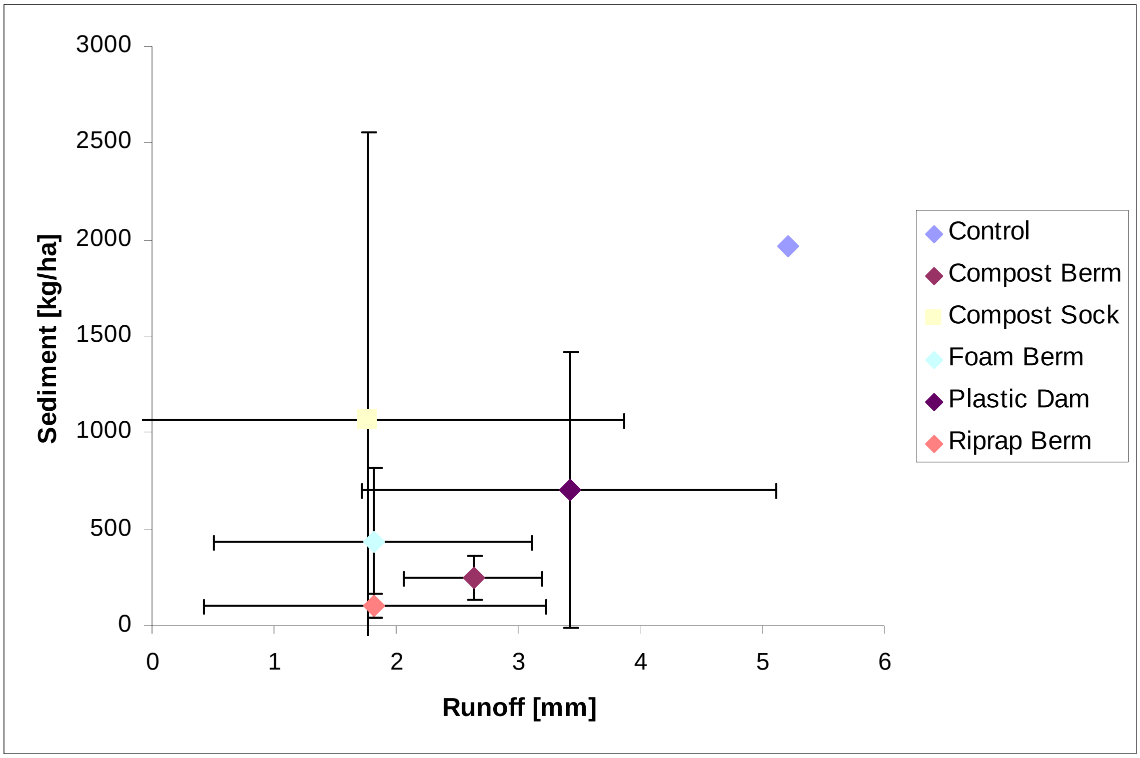

Figure G.1. Standard deviation of the data from the rainfall event on 7/29/2008.

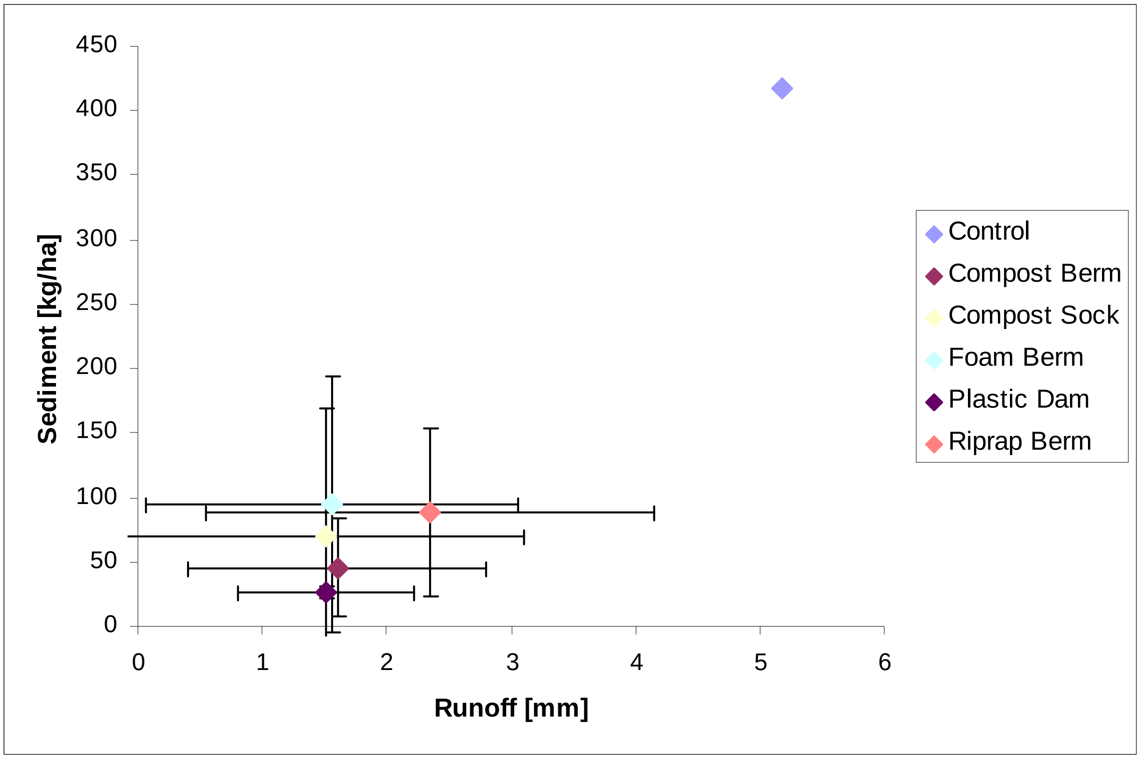

Figure G.2. Standard deviation of the data from the rainfall event on 9/5/2008.

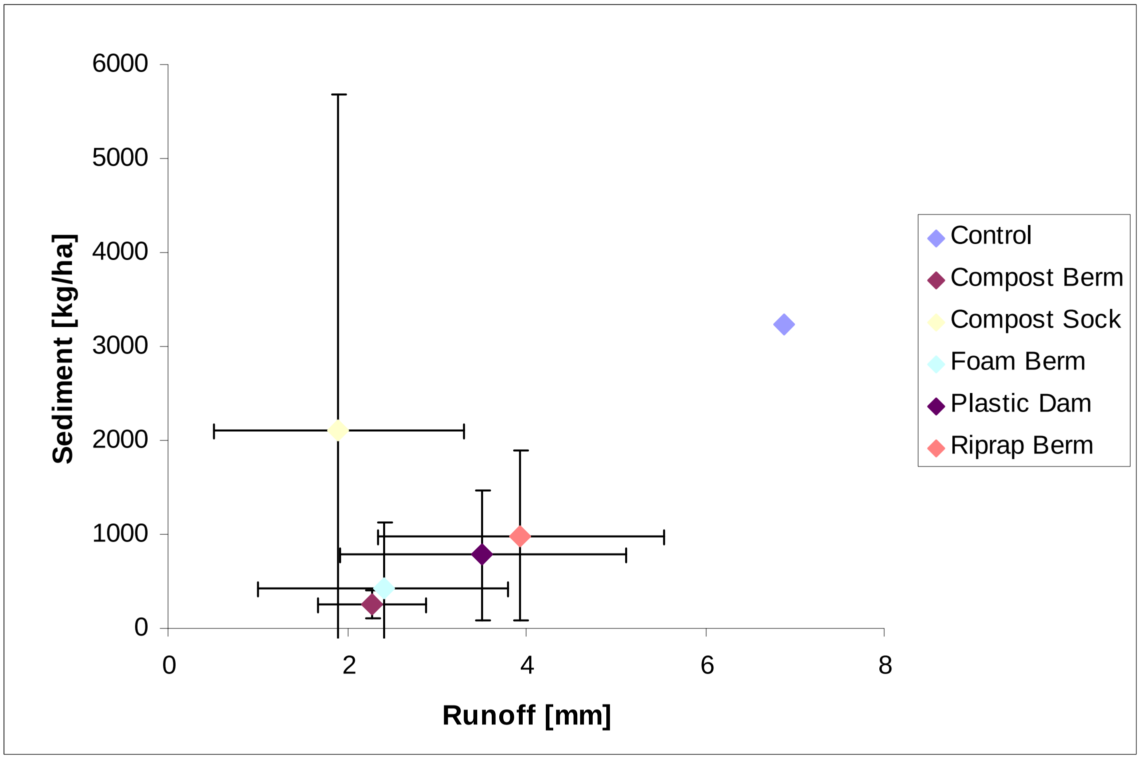

Figure G.3. Standard deviation of the data from the rainfall event on 9/15/2008.

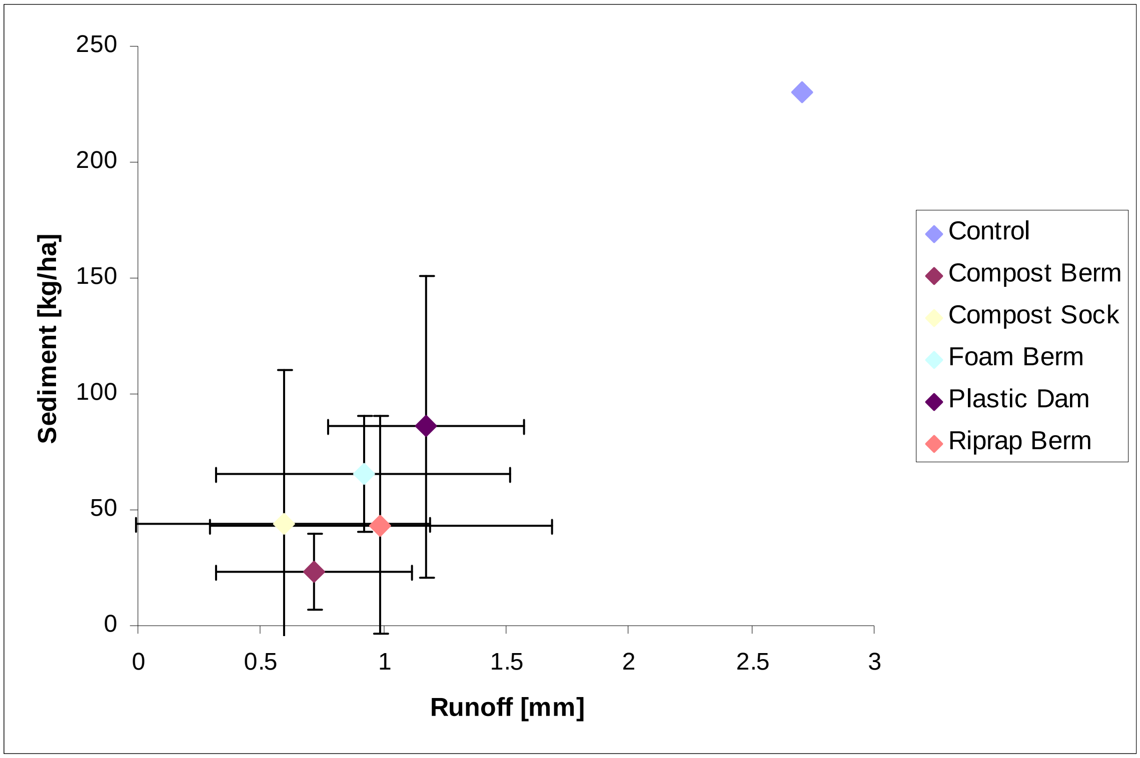

Figure G.4. Standard deviation of the data from the rainfall event on 10/9/2008.

There was a low amount of statistical confidence for the field study. The data may not be very precise but is derived from a field study so it's accuracy makes whatever conclusions that can be drawn from it important.

The comparison table included in the results are quite hard to read and follow due to the amount of information so Tables G.1 and G.2 contain the actual confidence intervals for each check dam at both 90% (α=0.10) and 67% (α=0.33) for comparison. The p-values for the individual rainfall events are tabulated in the matrices in Tables G.3 and G.4.

Table G.1. Confidence intervals for runoff, in millimeter, from the field study plots.

	July 29th Average α=0.10 α=0.33	Sept. 5th Average α=0.10 α=0.33	Sept. 15th Average α=0.10 α=0.33	Oct. 9th Average α=0.10 α=0.33	Yearly Plot Average α=0.10 α=0.33
Control	5.2	5.2	6.9	2.7	20.0
Compost Berm	2.6 (2.1, 3.2) (2.3, 3.0)	1.6 (0.5, 2.8) (0.9, 2.3)	2.3 (1.7, 2.9) (1.9, 2.6)	0.7 (0.4, 1.1) (0.5, 0.9)	7.2 (5.0, 9.5) (5.9, 8.6)
Compost Sock	1.8 (-0.6, 4.2) (0.3, 3.2)	1.5 (0.0, 3.0) (0.6, 2.4)	1.9 (0.6, 3.3) (1.1, 2.7)	0.6 (0.0, 1.2) (0.2, 1.0)	5.2 (0.2, 10.2) (2.2, 8.2)
Foam Berm	1.8 (0.5, 3.1) (1.1, 2.6)	1.6 (0.2, 2.9) (0.7, 2.4)	2.4 (1.1, 3.7) (1.6, 3.2)	0.9 (0.3, 1.5) (0.6, 1.3)	6.7 (2.3, 11.1) (4.1, 9.3)
Plastic Dam	3.4 (1.8, 5.0) (2.5, 4.4)	1.5 (0.8, 2.2) (1.1, 1.9)	3.5 (2.1, 4.9) (2.7, 4.3)	1.2 (0.8, 1.5) (1.0, 1.4)	9.6 (6.5, 12.7) (7.8, 11.5)
Riprap Berm	1.8 (0.5, 3.1) (1.0, 2.6)	2.3 (0.6, 4.1) (1.3, 3.4)	3.9 (2.4, 5.5) (3.0, 4.9)	1.0 (0.2, 1.8) (0.5, 1.5)	9.1 (6.5, 11.7) (7.6, 10.6)

Table G.2. Confidence intervals for soil loss, in kilograms per hectare, from the field study plots.

	July 29th Average α=0.10 α=0.33	Sept. 5th Average α=0.10 α=0.33	Sept. 15th Average α=0.10 α=0.33	Oct. 9th Average α=0.10 α=0.33	Yearly Plot Average α=0.10 α=0.33
Control	1961	417	3224	230	5801
Compost Berm	248 (136, 361) (182, 315)	45 (9, 82) (24, 67)	261 (118, 405) (176, 347)	23 (8, 38) (14, 32)	597 (295, 900) (418, 776)
Compost Sock	1064 (-673, 2800) (35, 2092)	71 (-23, 164) (15, 126)	2110 (-1285, 5505) (99, 4120)	44 (-20, 107) (163, 695)	2929 (-1768, 7626) (147, 5710)
Foam Berm	430 (63, 798) (213, 648)	95 (1, 188) (39, 150)	429 (-20, 878) (163, 695)	66 (42, 89) (52, 80)	990 (315, 1664) (590, 1389)
Plastic Dam	703 (29, 1378) (304, 1103)	27 (22, 31) (24, 29)	779 (119, 1439) (389, 1170)	86 (24, 148) (50, 123)	1590 (205, 2975) (770, 2410)
Riprap Berm	103 (48, 159) (70, 136)	88 (26, 150) (52, 125)	989 (137, 1842) (484, 1494)	43 (-11, 98) (11, 76)	1208 (485, 1931) (779, 1636)

Table G.3. P-values for runoff from the comparison of pairs to treatment during individual rainfall events at the field study site.

7/29/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.008	0.129	0.024	0.103	0.025
Compost Berm	0.008		0.335	0.216	0.262	0.223
Compost Sock	0.129	0.335		0.493	0.261	0.491
Foam Berm	0.024	0.216	0.493		0.144	0.496
Plastic Dam	0.103	0.262	0.261	0.144		0.147
Riprap Berm	0.025	0.223	0.491	0.496	0.147	
9/5/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.018	0.028	0.025	0.006	0.057
Compost Berm	0.018		0.469	0.486	0.457	0.298
Compost Sock	0.028	0.469		0.484	0.499	0.294
Foam Berm	0.025	0.486	0.484		0.480	0.300
Plastic Dam	0.006	0.457	0.499	0.480		0.267
Riprap Berm	0.057	0.298	0.294	0.300	0.267	
9/15/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.003	0.013	0.015	0.028	0.045
Compost Berm	0.003		0.359	0.450	0.154	0.122
Compost Sock	0.013	0.359		0.346	0.132	0.102
Foam Berm	0.015	0.450	0.346		0.203	0.151
Plastic Dam	0.028	0.154	0.132	0.203		0.380
Riprap Berm	0.045	0.122	0.102	0.151	0.380	
10/9/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.005	0.015	0.080	0.010	0.026
Compost Berm	0.005		0.392	0.380	0.115	0.306
Compost Sock	0.015	0.392		0.318	0.136	0.261
Foam Berm	0.080	0.380	0.318		0.353	0.458
Plastic Dam	0.010	0.115	0.136	0.353		0.360
Riprap Berm	0.026	0.306	0.261	0.458	0.360	

Table G.4. P-values for soil loss from the comparison of pairs to treatment during individual rainfall events at the field study site.

7/29/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.001	0.276	0.010	0.046	0.000
Compost Berm	0.001		0.291	0.259	0.194	0.099
Compost Sock	0.276	0.291		0.331	0.402	0.265
Foam Berm	0.010	0.259	0.331		0.300	0.142
Plastic Dam	0.046	0.194	0.402	0.300		0.141
Riprap Berm	0.000	0.099	0.265	0.142	0.141	
9/5/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.002	0.013	0.015	0.000	0.006
Compost Berm	0.002		0.359	0.252	0.243	0.199
Compost Sock	0.013	0.359		0.392	0.259	0.405
Foam Berm	0.015	0.252	0.392		0.177	0.466
Plastic Dam	0.000	0.243	0.259	0.177		0.122
Riprap Berm	0.006	0.199	0.405	0.466	0.122	
9/15/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.000	0.322	0.005	0.013	0.025
Compost Berm	0.000		0.233	0.309	0.167	0.150
Compost Sock	0.322	0.233		0.252	0.296	0.325
Foam Berm	0.005	0.309	0.252		0.261	0.205
Plastic Dam	0.013	0.167	0.296	0.261		0.385
Riprap Berm	0.025	0.150	0.325	0.205	0.385	
10/9/2008	Control	Compost Berm	Compost Sock	Foam Berm	Plastic Dam	Riprap Berm
Control		0.001	0.020	0.034	0.031	0.056
Compost Berm	0.001		0.329	0.138	0.123	0.277
Compost Sock	0.020	0.329		0.328	0.245	0.497
Foam Berm	0.034	0.138	0.328		0.336	0.279
Plastic Dam	0.031	0.123	0.245	0.336		0.242
Riprap Berm	0.056	0.277	0.497	0.279	0.242	

APPENDIX H: RAINFALL SIMULATOR STUDY INDIVIDUAL REPLICATION RESULTS

The individual runs from the rainfall simulator study contain vast amounts of data. Each event could be a useful case study in check dam performance, given the tighter control over certain variables. The data is graphed below in Figures H.1 through H.6. Tables H.1 through H.6 include the moisture content readings taken for each run.

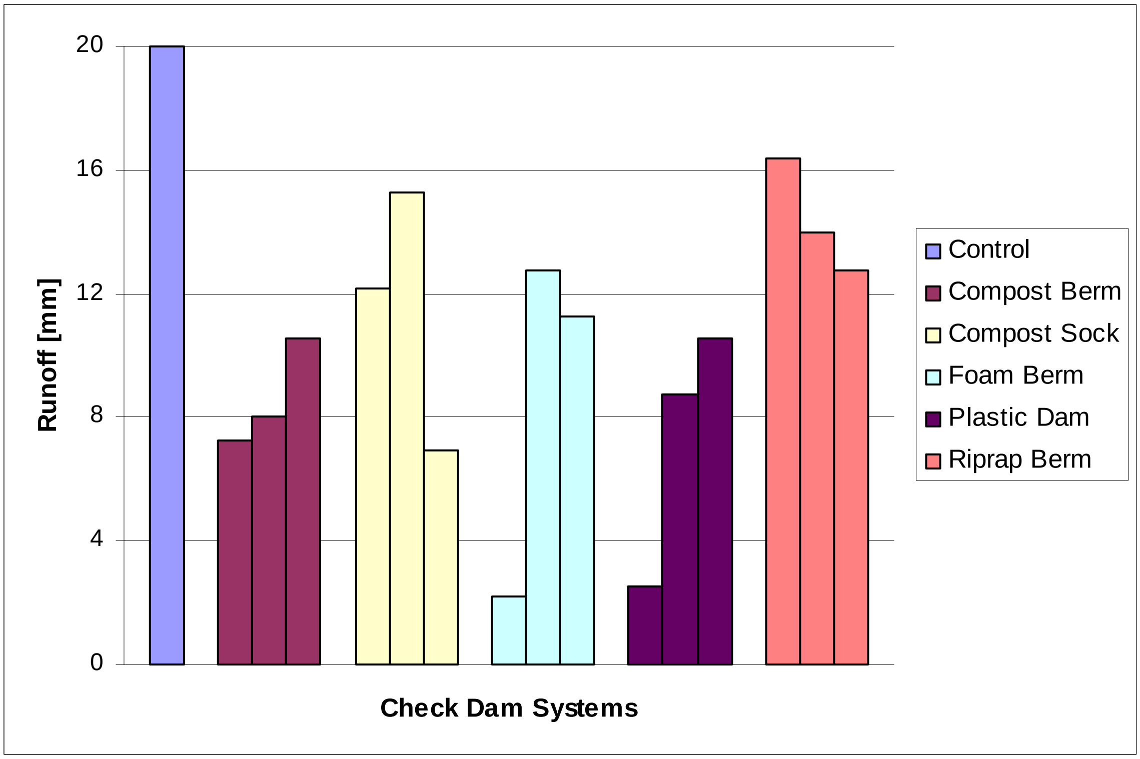

Figure H.1. Runoff from the rainfall simulator plots for a 6 to 1 slope.

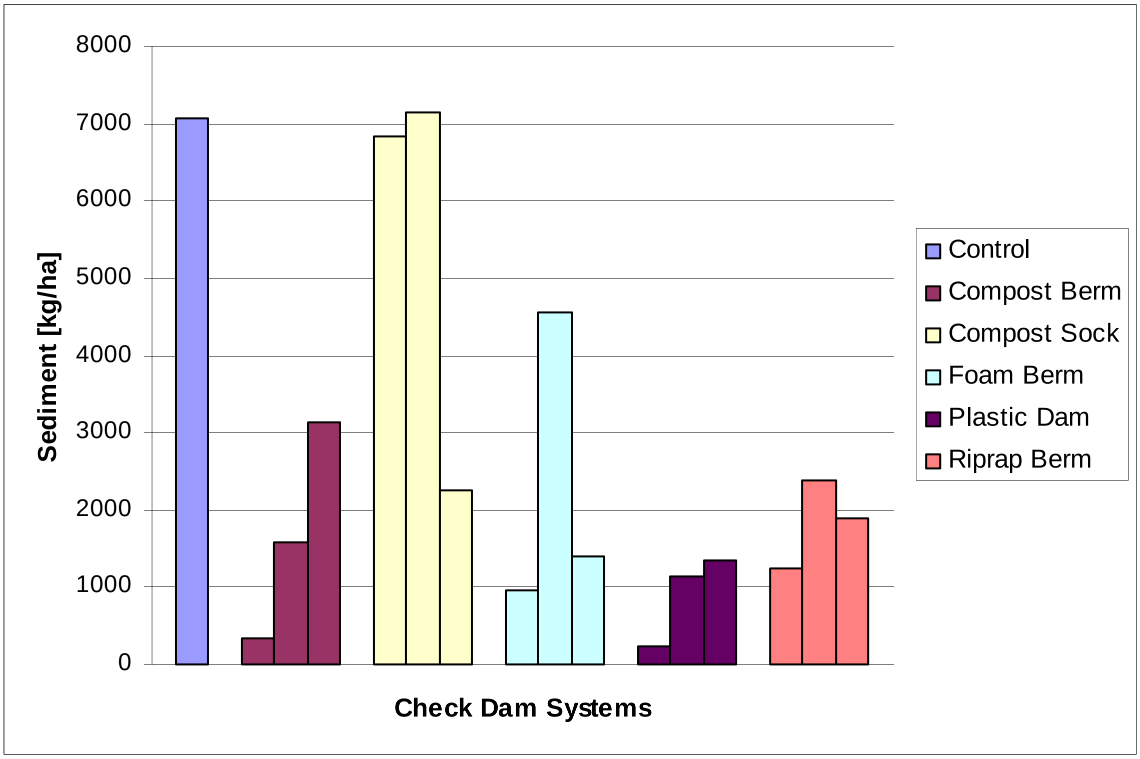

Figure H.2. Soil loss from the rainfall simulator plots for a 6 to 1 slope.

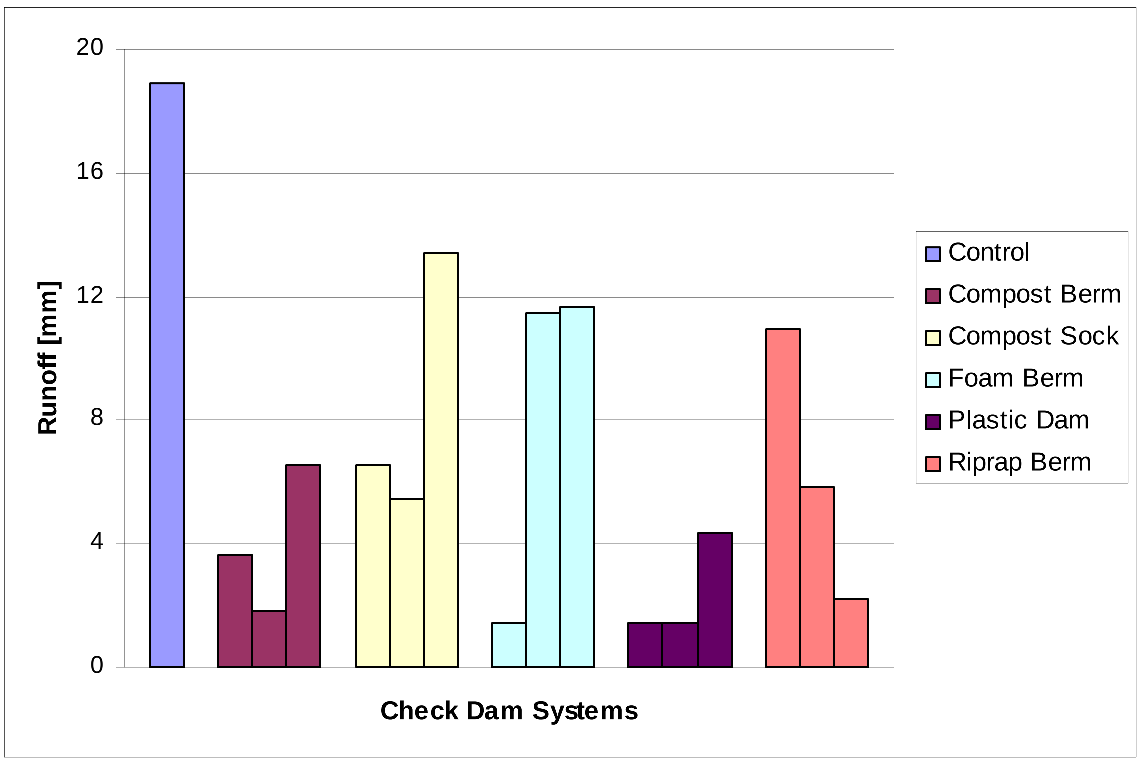

Figure H.3. Runoff from the rainfall simulator plots for a 9 to 1 slope.

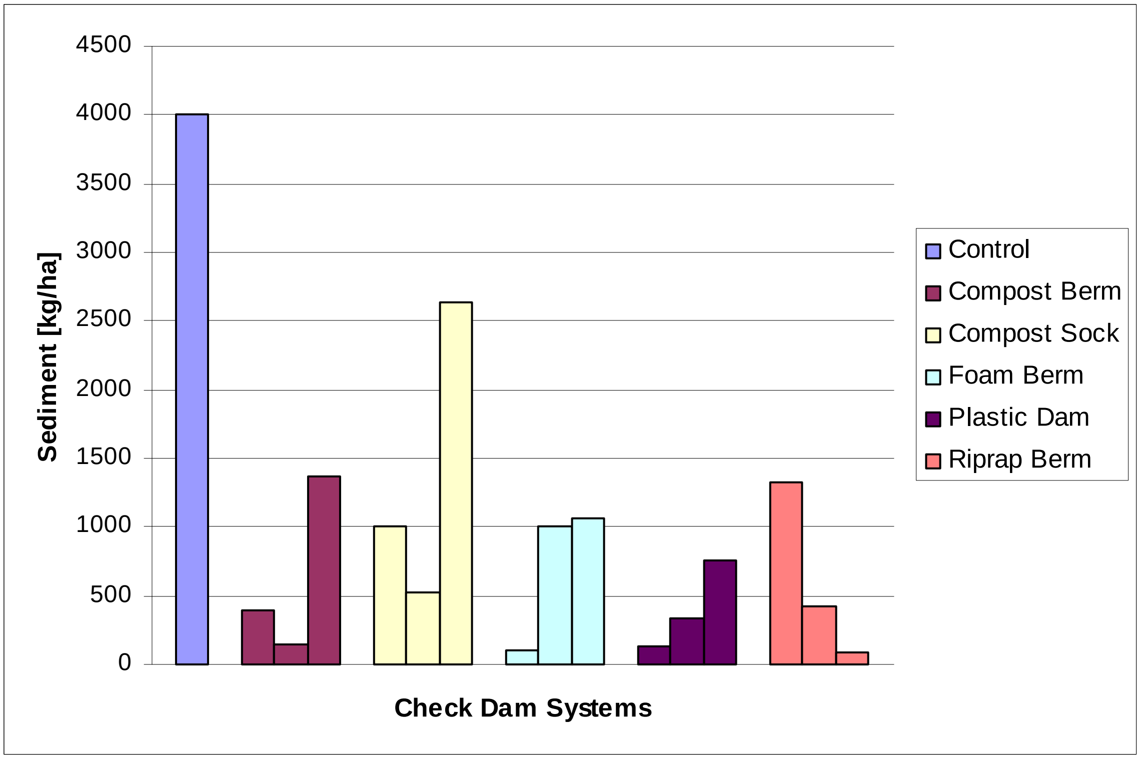

Figure H.4. Soil loss from the rainfall simulator plots for a 9 to 1 slope.

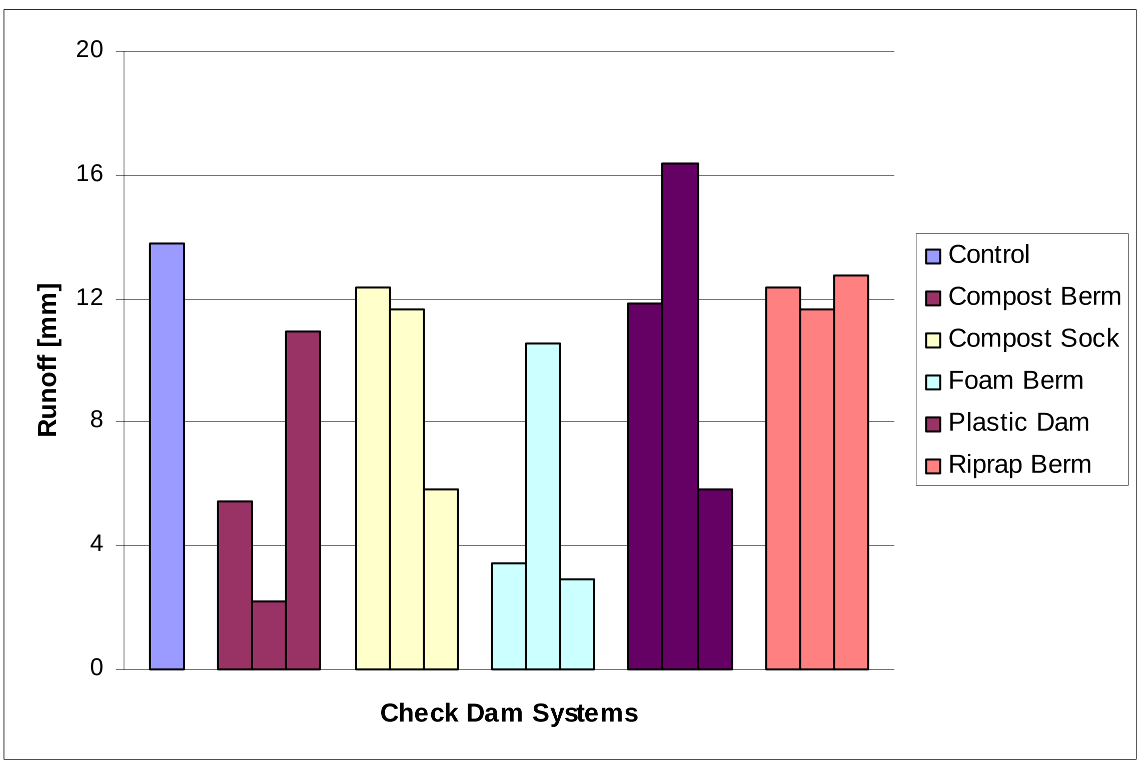

Figure H.5. Runoff from the rainfall simulator plots for a 12 to 1 slope.

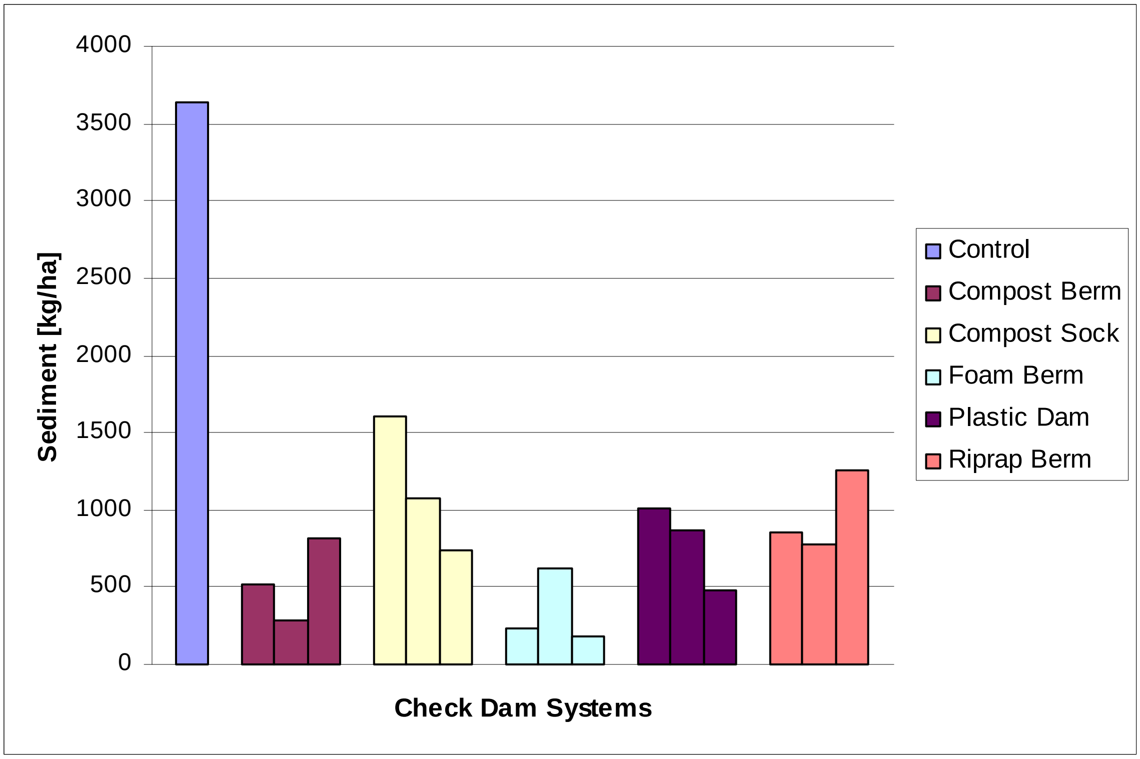

Figure H.6. Soil loss from the rainfall simulator plots for a 12 to 1 slope.

Table H.1. Slope, moisture content, runoff, and soil loss for the bare soil plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.23	20.0	7074
9:1	0.32	18.9	4012
12:1	0.13	13.8	3634

Table H.2. Slope, moisture content, runoff, and soil loss for the compost berm plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.19	7.3	343
6:1	0.22	8.0	1568
6:1	0.28	10.5	3141
9:1	0.21	3.6	391
9:1	0.15	1.8	142
9:1	0.27	6.5	1368
12:1	0.29	5.5	512
12:1	0.25	2.2	291
12:1	0.31	10.9	814

Table H.3. Slope, moisture content, runoff, and soil loss for the compost sock plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.22	12.1	6830
6:1	0.23	15.3	7149
6:1	0.18	6.9	2258
9:1	0.24	6.5	1009
9:1	0.22	5.5	527
9:1	0.33	13.4	2635
12:1	0.22	12.4	1610
12:1	0.18	11.6	1080
12:1	0.20	5.8	735

Table H.4. Slope, moisture content, runoff, and soil loss for the foam berm plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.07	2.2	967
6:1	0.22	12.7	4565
6:1	0.14	11.3	1397
9:1	0.16	1.5	103
9:1	0.27	11.5	999
9:1	0.28	11.6	1056
12:1	0.13	3.5	233
12:1	0.32	10.5	627
12:1	0.10	2.9	185

Table H.5. Slope, moisture content, runoff, and soil loss for the plastic dam plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.07	2.5	241
6:1	0.29	8.7	1130
6:1	0.18	10.5	1352
9:1	0.18	1.5	125
9:1	0.22	2.9	341
9:1	0.28	4.4	756
12:1	0.29	11.8	1013
12:1	0.32	16.4	863
12:1	0.20	5.8	473

Table H.6. Slope, moisture content, runoff, and soil loss for the riprap berm plots in the rainfall simulator.

Slope [L:H]	VMC [%]	Runoff [mm]	Sediment [kg/ha]
6:1	0.19	16.4	1248
6:1	0.22	14.0	2371
6:1	0.27	12.7	1901
9:1	0.21	10.9	1326
9:1	0.18	5.8	423
9:1	0.15	2.2	83
12:1	0.30	12.4	848
12:1	0.25	11.6	780
12:1	0.32	12.7	1261

APPENDIX I: CONFIDENCE FOR THE RAINFALL SIMULATOR STUDY

Figures I.1 through I.3 denote statistical measurement of standard deviation for each treatment. The error bars denote the individual check dam erosion control treatments' confidence interval and not the statistical comparison between treatments as in the tables shown in the results section. Each bar denotes that check dams distribution and assuming a normal distribution would imply around a 68% confidence interval.

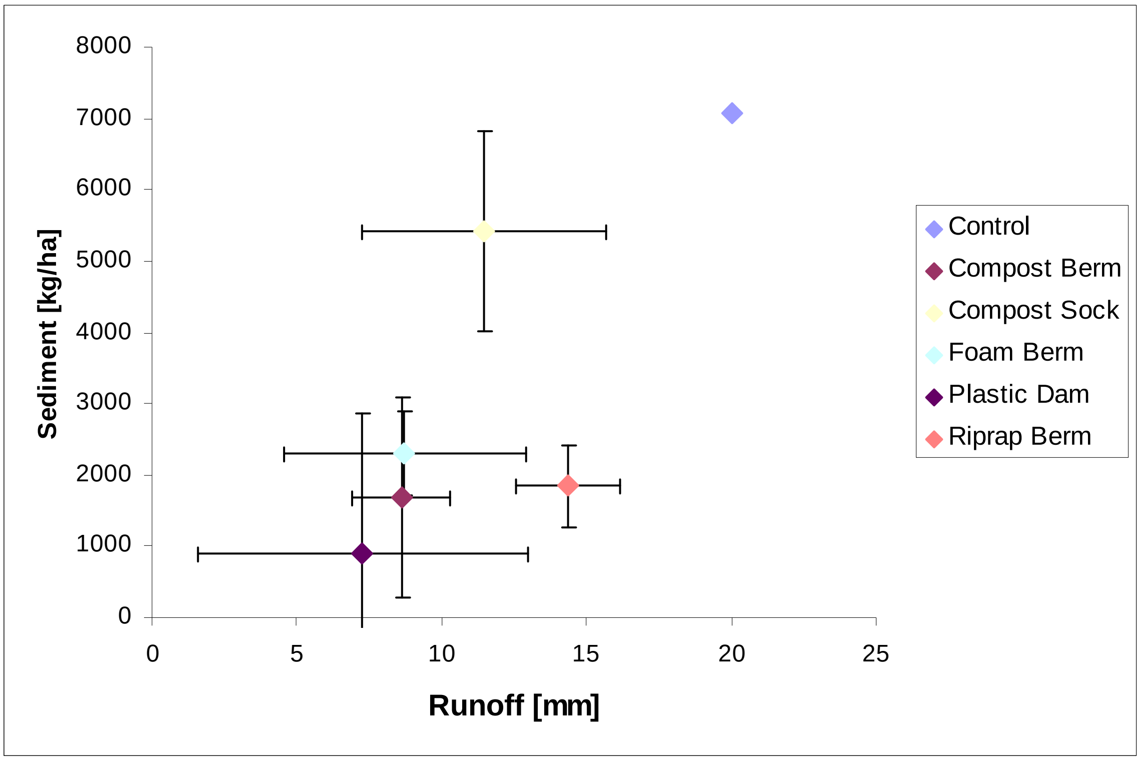

Figure I.1. Standard deviation of the data for rainfall simulator experiments ran at a 6 to 1 slope.

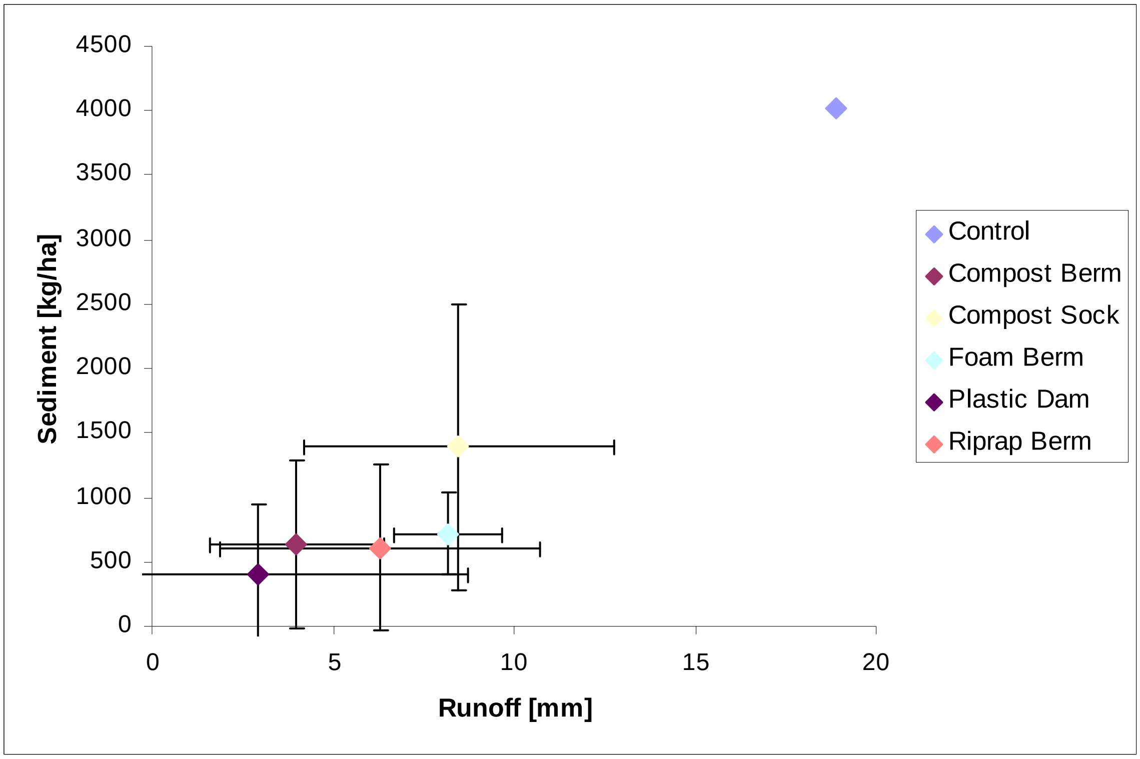

Figure I.2. Standard deviation of the data for rainfall simulator experiments ran at a 9 to 1 slope.

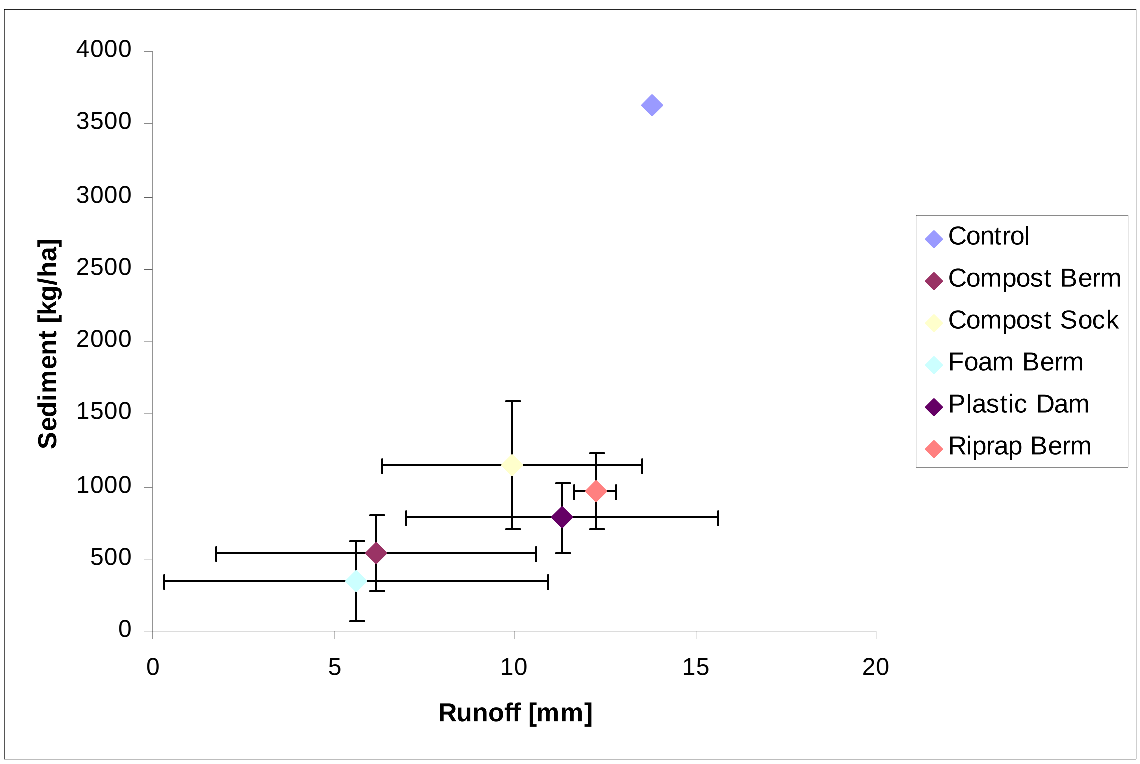

Figure I.3. Standard deviation of the data for rainfall simulator experiments ran at a 12 to 1 slope.

There was a low amount of statistical confidence for the rainfall simulator study. The data is more precise than the field study but still heavily similar. The comparison table in the results section is quite hard to read and follow due to the amount of information implied so Tables I.1 and I.2 contain the actual confidence intervals for each check dam at both 90% (α=0.10) and 67% (α=0.33).

Table I.1. Confidence intervals for sediment removed, in kilograms per hectare, from the rainfall simulator study.

	6 to 1 Average α=0.10 α=0.33	9 to 1 Average α=0.10 α=0.33	12 to 1 Average α=0.10 α=0.33
Control	7074	4012	3634
Compost Berm	1684 (352, 3016) (895, 2473)	633 (18, 1249) (269, 998)	539 (290, 788) (391, 686)
Compost Sock	5412 (2813, 8011) (3873, 6951)	1390 (342, 2439) (769, 2012)	1142 (723, 1560) (894, 1390)
Foam Berm	2310 (444, 4175) (1204, 3415)	719 (211, 1227) (418, 1020)	348 (118, 579) (212, 485)
Plastic Dam	908 (349, 1466) (577, 1239)	407 (103, 712) (227, 587)	1142 (519, 1047) (624, 940)
Riprap Berm	1840 (1305, 2375) (1523, 2157)	610 (0, 1220) (249, 972)	963 (716, 1210) (817, 1109)

Table I.2. Confidence intervals for runoff, in millimeters, from the rainfall simulator study.

	6 to 1 Average α=0.10 α=0.33	9 to 1 Average α=0.10 α=0.33	12 to 1 Average α=0.10 α=0.33
Control	6.2	4.7	4.0
Compost Berm	8.6 (7.0, 10.2) (7.6, 9.6)	4.0 (1.7, 6.3) (2.7, 5.3)	6.2 (2.0, 10.4) (3.7, 8.7)
Compost Sock	11.4 (7.4, 15.5) (9.1, 13.8)	8.5 (4.4, 12.6) (6.0, 10.9)	9.9 (6.5, 13.3) (7.9, 12.0)
Foam Berm	8.7 (3.3, 14.2) (5.5, 11.9)	8.2 (2.6, 13.7) (4.9, 11.5)	5.6 (1.6, 9.7) (3.2, 8.0)
Plastic Dam	7.3 (3.3, 11.3) (4.9, 9.6)	2.9 (2.6, 13.7) (4.9, 11.5)	11.3 (1.6, 9.7) (3.2, 8.0)
Riprap Berm	14.4 (12.6, 16.1) (13.3, 15.4)	6.3 (2.1, 10.5) (3.8, 8.8)	12.2 (11.7, 12.8) (11.9, 12.6)