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EVALUATION OF CHECK DAM SYSTEMS FOR EROSION AND SEDIMENT CONTROL AT MILITARY FACILITIES

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EVALUATION OF CHECK DAM SYSTEMS FOR EROSION AND SEDIMENT CONTROL AT MILITARY FACILITIES

1. Purpose.

a. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit information and provide guidance for the selection and use of check dam structures for erosion control. The information is based on data collected from field and laboratory evaluations done by the Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) and the University of Illinois. Since many land managers commonly use a variety of check dam systems in conjunction with other best management practices (BMP) for comprehensive erosion control programs, there is a need for independent evaluation. Current data on check dam system performance is lacking. This PWTB will help land managers select suitable check dam structures for certain conditions. This information will help reduce product failure due to misapplication and provide results based on side-by-side comparisons of commonly used check dam systems found on military lands.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences Whole Building Design Guide (WBDG) webpage, which is accessible through the following link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army facilities and associated training lands in both Continental United States (CONUS) and Outside Continental United States (OCONUS) locations that want to use check dam systems for erosion and sediment control.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 13 December 2007.

b. Other references used in the Appendixes are listed in Appendix D.

4. Discussion.

a. AR 200-1, implemented in 2007, contains policy for environmental protection and enhancement, implementation of pollution prevention, conservation of natural resources, sustainable practices, compliance with environmental laws, and restoration of previously damaged or contaminated sites. AR 200-1 requires that installations be good stewards of land resources by controlling sources of erosion to prevent damage from facilities to the land, water resources, and equipment. Additionally, hydrologic erosion is associated with multiple laws and regulations (Clean Air Act, Clean Water Act, etc.), which all affect how Army training lands are managed.

b. This PWTB reports the results of laboratory studies investigating the effectiveness of five types of check dams (rip-rap berm, compost filter berm, plastic grid dam, triangular foam berm, and compost sock) under three different slope conditions (6:1, 9:1, and 12:1). Additionally, results from a 24:1 slope field evaluation are documented. Quantitative analysis was conducted by comparing the runoff volume and sediment load from the check dams in both laboratory and field conditions. Overall, check dam treatments resulted in lower runoff volumes and sediment loads when compared to no check dam treatment "control." There was little difference between check dam treatments with the exception of the compost filter sock. It was found later that the compost filter sock material did not meet manufacture specification which may have contributed to the lack of performance compared with the other check dam structures.

c. Appendix A contains an introduction explaining the importance of the check dam study to the Army's environmental program.

d. Appendix B contains the methods used in the laboratory and field studies.

e. Appendix C contains the results and conclusions from the studies. Additional recommendations for future use of check dam structures are also given in Appendix C.

f. Appendix D includes references cited in the previous appendices.

g. Appendix E lists acronyms and abbreviations used throughout this document, along with their spellouts.

5. Points of Contact.

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Appendix A:

EROSION PROCESSES AND CHECK DAMS

Sediment in surface waters that comes from erosion of soils is one of the leading causes of water pollution. Land used for military training is particularly prone to erosion due to its associated high level of human activities, including foot and off-road vehicle traffic, which disturb the soil and its vegetative cover (Whitecotton et al. 2000; Wang et al. 2006). The Department of Defense (DoD) controls more than 25 million acres of federally owned land in the United States with 15 million acres of that land available for a variety of military training activities (Ayers et al. 2000). Installations are required to maintain a healthy, no net loss environment by several legal sources: the Sikes Act, Army Regulation (AR) 200-3, Executive Order (EO) 13112, the Clean Air Act, and the Clean Water Act. Thus, it is vital to determine when and where negative impacts on soil, water, plant, and animal communities are occurring and to develop practices to eliminate them.

Due to the nature and intensity of military training activities, many Army training lands and trail shoulders are severely degraded and need repair. Degraded landscapes jeopardize effective training as well as troop safety. As a result of these concerns, it is imperative to mitigate and rehabilitate critical areas of Army training lands. Exposed soils that result from training and construction activities can contribute to environmental and compliance issues for Army installations. Training and construction without BMPs for erosion control will form rills and gullies in the soil, leading to a loss of training area, lower troop safety, and a negative environmental impact.

One common BMP is the installation of check dams on training lands to help mitigate erosion from exposed soil. Check dams systems are structures that can be placed directly in the path of water flow. Check dams alleviate the potential for erosion by reducing the shear stress and energy in the flowing water. Check dams also reduce sediment load by trapping and containing sediment in the structure and by allowing sediment deposition in ponded water behind the structure.

These structures can be either temporary or permanent. Each check dam will require varying levels of management and maintenance depending upon the type of structure. There are three general categories of check dams: rock, natural, and engineered products. Traditional check dams are often made out of rock or rip-rap. These structures are hard to work with due to their weight, but they are very durable. Other check dam systems being deployed are more temporary in nature than rip-rap/rock check dams. Materials used in these new check dam structures range from foam triangles to ridged plastic to fiber-filled logs to compost-filled filter socks. These structures offer the benefit of being lighter, increasing their ease of installation. They also commonly allow the establishment of vegetation which improves the environmental benefit. Other common check dam systems often use straw bales and silt fencing. While this type is easy to install, they often lack the durability and performance of other check dams.

The objectives of this study were to:

1. Identify the types of commonly used and available check dam systems.

2. Evaluate each structure in two places: a field setting and a controlled rainfall simulator.

3. Investigate the performance, durability, and installation ease of the dams to increase land managers' understanding of the types of check dams available and the characteristics of each.

4. Provide costs associated with the check dam structures evaluated, and the pros and cons of those structures.

Appendix B:

STUDY METHODS

Methods

Laboratory Experiments

Two horizontal tilting soil chambers (measuring 3.6 m long, 1.5 m wide, and 0.3 m deep) were used to investigate soil erosion from soil beds with check dams installed. Each soil chamber was divided into two separate compartments with a steel plate divider placed at the center of the 1.5-m-wide chamber across its 3.6-m length and then sealed. Similarly, the bottom and edges of each compartment were sealed completely. The chambers were filled with Dana silt loam series soil which is predominantly found on slopes (from 2–5%) in Central Illinois. The clay content of this soil series ranges from 11%–22%. The soil bulk density ranges from 1.40–1.55 g/cc, soil permeability ranges from 0.6–2.0 in/hr, and the soils contain 4% organic matter.

The top 0.3 m of soil were collected in two separate layers (0–0.15 m and 0.15–0.3 m) then packed in the chamber. The beds were then saturated, re-saturated, and allowed to sit for a few weeks which allowed natural compaction to occur. The edges of each compartment were compacted tightly to eliminate preferential flow of water along the edges of the bed. The check dam treatments were installed on each compartment of the soil chambers, allowing for side-by-side comparison of the different treatments.

Five different check dams were tested (rip-rap berm, compost filter berm, plastic grid dam, triangular foam berm, and compost sock) under three different slopes for the study. Slopes of 6:1, 9:1, and 12:1 were used to measure the performance of the check dam systems. Rip-rap was used as a traditional permanent dam. Compost is less widely used, but possibly more environmentally friendly than other structures. The three industrial products were chosen due to their popularity and variety, but they were evaluated to determine if they could hold up to the conditions despite their small size and lightweight build. Each check dam system has very specific installation standards and specifications. These specifications were met as closely as possible during installation and maintenance.

Rainfall was applied to the soil chamber using a computer-controlled laboratory rainfall simulator. The simulator was situated 10 m from the floor to ensure the rainfall attained the terminal velocity required for erosion studies (Hirschi et al. 1990). A rainfall intensity of 43.4 mm/hr (1.71 in/hr) for 30 min was chosen, representing a 10-yr, 30-min rainfall event in Central Illinois. The entire runoff volume was collected. A sample volume was dried and the sediment load was calculated (ASTM D 3977).

Field Experiments

The site selected for this study is located south of Urbana, IL. The soil is classified as Dana Silt Loam (NRCS 2008) with a slope of approximately 24:1 or 4.2%, as determined by a field survey. Sixteen field plots (1.5 x 8.9 m) were designed in accordance with Lal's (1994) Universal Soil Loss Equation (USLE) style plots (Figure B-1). Plots were lined with metal borders. The plots terminated in a 90-degree V-notch weir flow collection structure (Figure B-2). Runoff was collected in a series of buckets.

Figure B-1. Field plot layout at start of study.

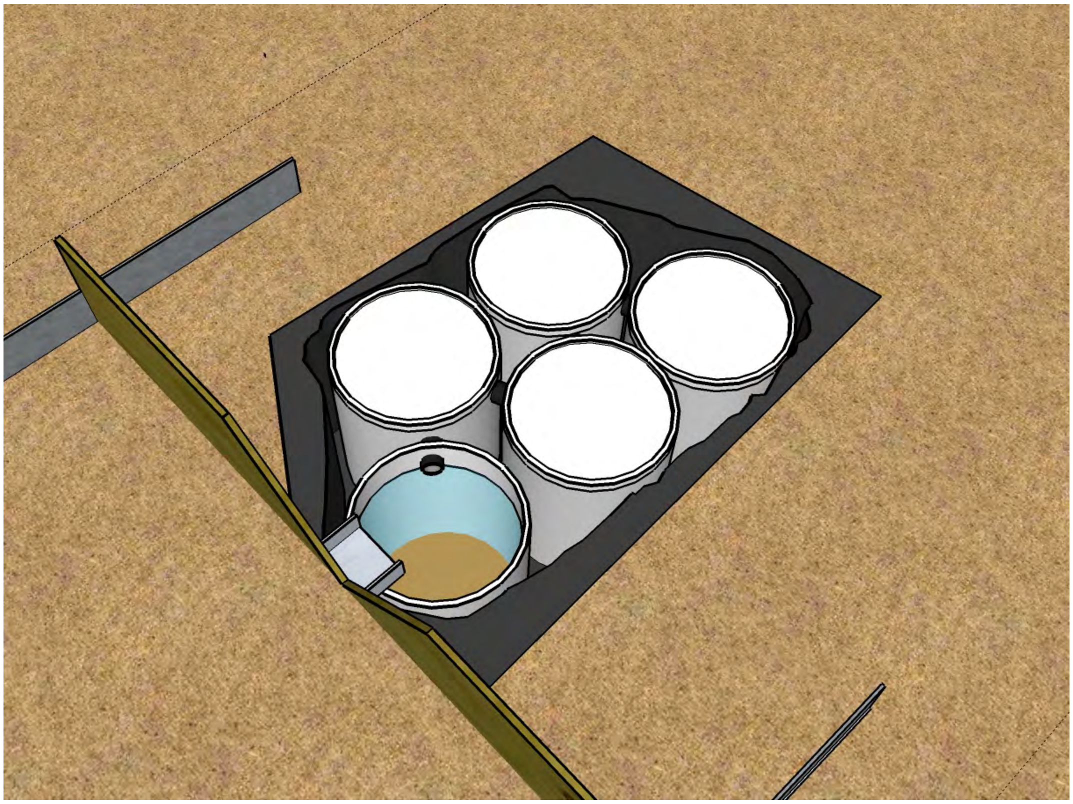

Figure B-2. Plot runoff collection structure.

The five check dam structures mentioned previously (rip-rap berm, compost filter berm, plastic grid dam, triangular foam berm, and compost sock) were installed according to their specific standards and specifications 5 m from the beginning of the plots (Figure B-3). Three repetitions for each treatment were installed. A single bare plot was installed as a control for all of the replications (since this was a comparison study and space was limited, only one control plot was used). Additional plywood borders were placed along the sides of the check dams to improve stability and runoff containment. A weather station monitored rainfall, temperature, soil moisture levels, relative humidity, barometric pressure, and wind speed.

Following rainfall events, runoff volume was collected and measured. Representative samples were analyzed for sediment load according to ASTM D3977-97 (2007). Additionally, sediment loss and deposition were measured three times throughout the study period using a pin frame adapted from McCool et al. (1981).

Figure B-3. Check dam and runoff collection structures used are arranged clockwise from top left: (A) rip-rap berm, (B) compost berm, (C) plastic grid dam, (D) triangular foam berm, (E) compost sock, and (F) runoff collection device .

Appendix C:

STUDY RESULTS AND LESSONS LEARNED

Laboratory Experiments

The measured runoff volumes and resulting sediment load for each check dam and slope condition are given in the graphs reproduced in Figure C-1. In every case, the control yielded higher runoff and sediment loads than the treatments. Despite the high variability between experiments, some trends become apparent. With the exception of the runoff volumes observed in the 12:1 slope condition, as slope increased, runoff volumes and sediment loads also increased. Compared to the other dams tested, the compost sock yielded higher runoff and sediment values.

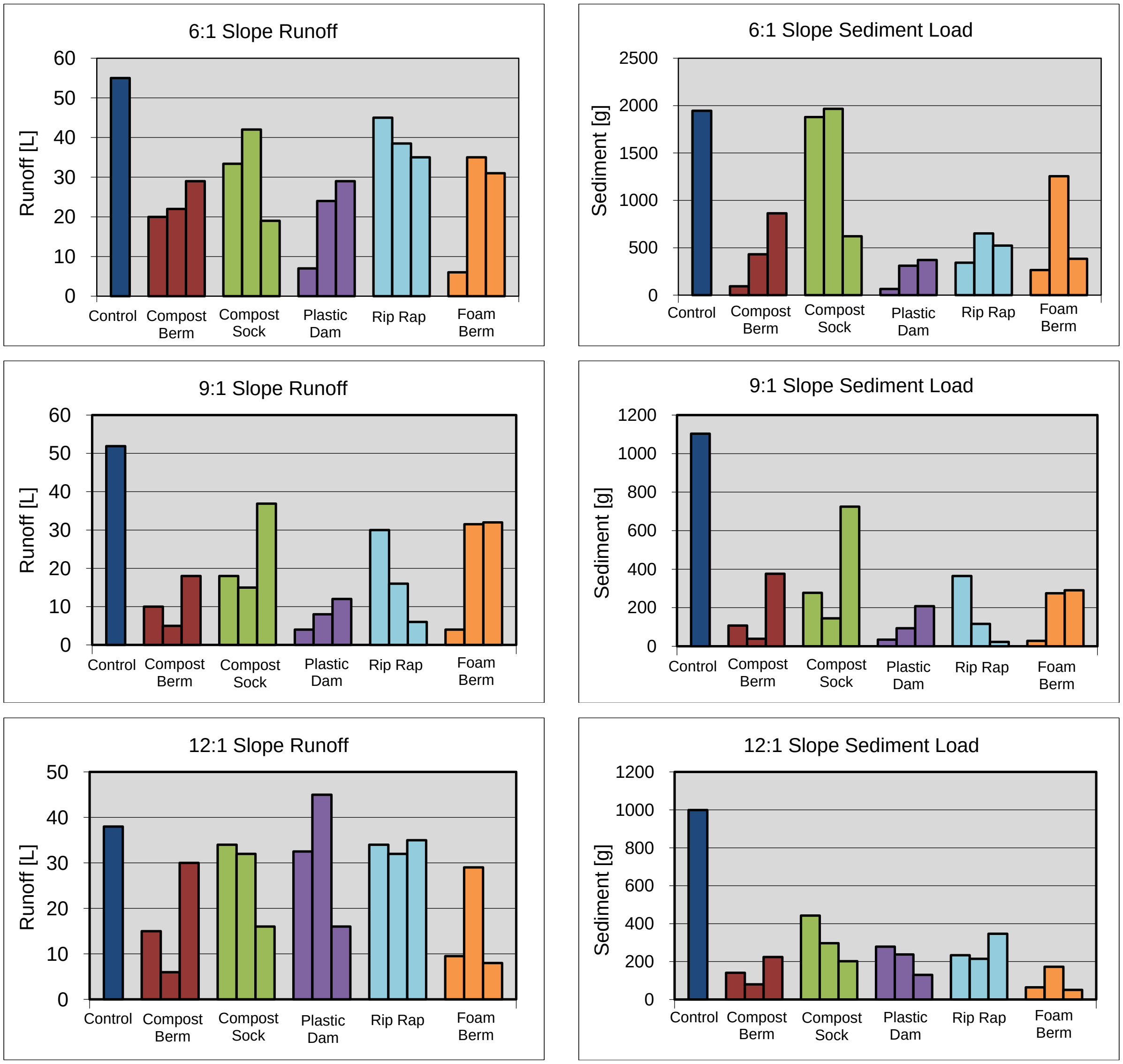

Figure C-1. Runoff volumes and resulting sediment loads.

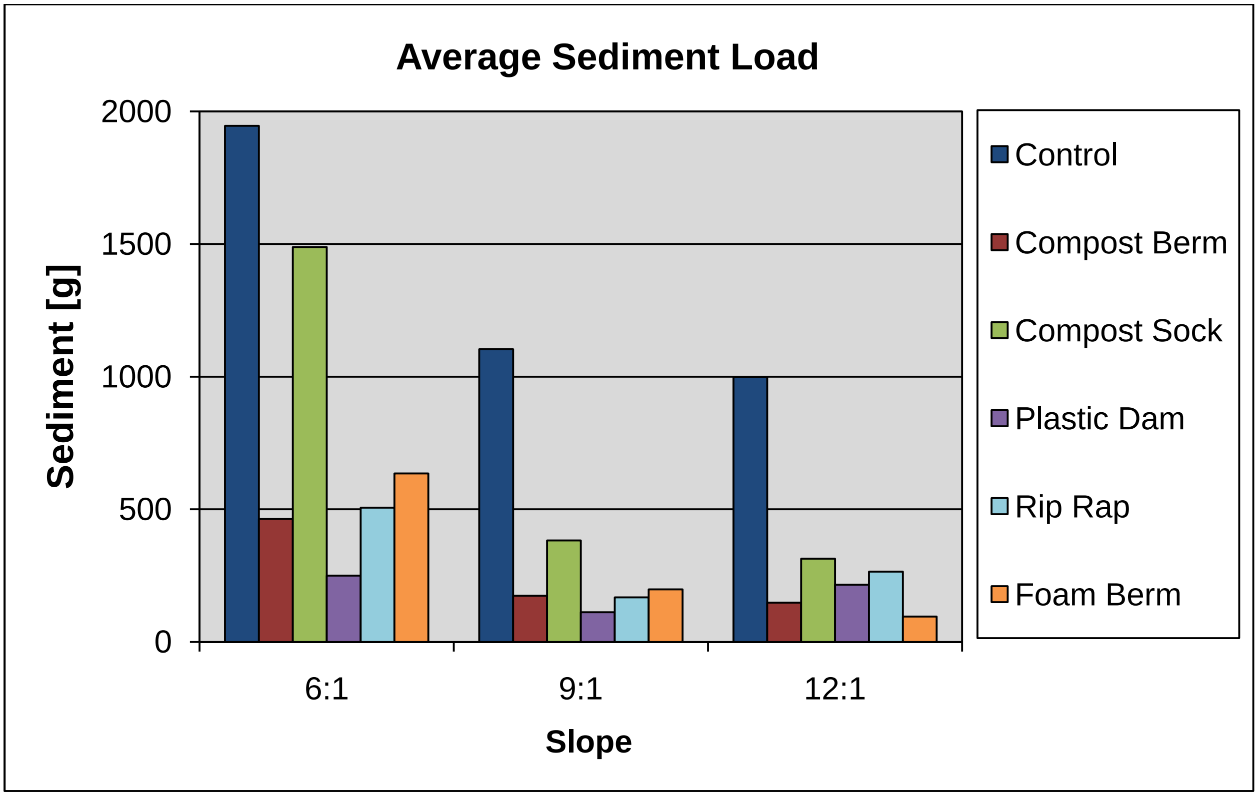

Figure C-2 illustrates the average sediment collected from the five types of check dams and control across the three treatment repetitions for each slope condition. Again, the same trends are observed. The control (no check dam) resulted in the highest sediment load while the compost sock was outperformed by the rest of the check dam treatments. The plastic dam and compost berm consistently performed well at all slope conditions tested. The foam berm seemed to perform better relative to the other treatments at lower slopes. As slope increased, its performance relative to the other check dams was lacking. The rip-rap berm performance was adequate for all slopes tested.

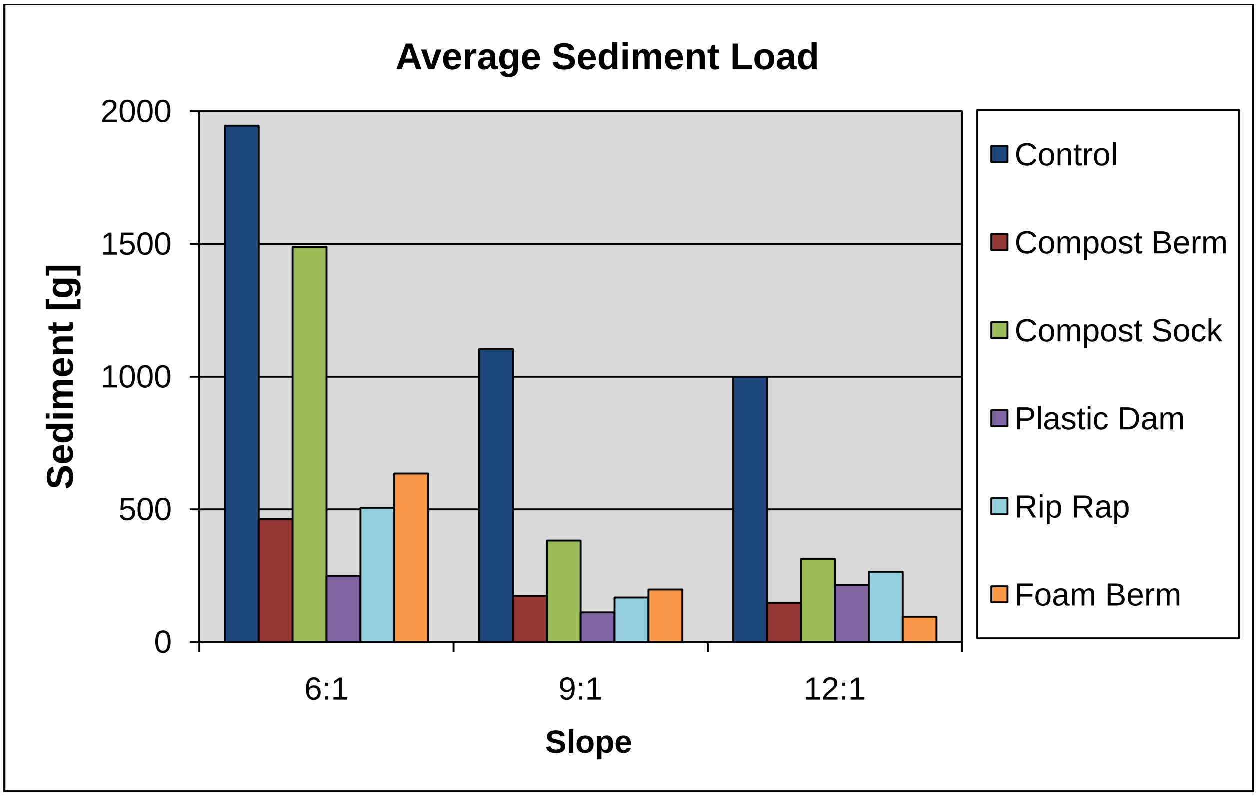

Figure C-2. Average sediment load in runoff from laboratory experiments.

While the data appears to show some trends in runoff volume and sediment removed, the high degree of variability makes it difficult to draw statistically significant differences. 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; (i.e, whether the treatments statistically are performed the same). Averages and a 67% confidence interval for all check dams are given in Table C-1. Superscripts denote statistical similarity (i.e., if two numbers both have the superscript letter, there is statistically no difference between the two numbers at a 67% confidence interval).

Table C-1. Laboratory experiment 67% confidence analysis for sediment load at various slopes (Note: subscripts denote statistical similarity for each slope).

Check Dam Type	Slope		
	6:1	9:1	12:1
Control	1946.0 1103.0		999.4
Compost	$463.1^{a,b}$	174.2^{c}	148.2
Compost Sock	1489.0	382.4	314.0
Plastic Dam	249.6	112.0^{b}	215.3
Rip-Rap	$506.0^{a,c}$	$167.8^{b,c}$	264.8
Foam Berm	$635.2^{b,c}$	197.8^{c}	95.8

The statistical analysis confirms the observations previously discussed. All check dams significantly reduced the sediment load in the runoff. The compost sock system performed the poorest of the check dam treatments at all slopes tested. At the highest slope condition (6:1), the plastic dam performed the best followed by the compost, rip-rap, and foam berm. The plastic dam and rip-rap reduced the most sediment at the 9:1 slope condition, followed by the compost and foam berm. At the 12:1 slope, the foam berm removed the most sediment followed by the compost berm, plastic dam, and rip-rap.

Both the graph and statistical analysis show that every treatment removed statistically more sediment than the control. Also, the compost sock performed the poorest of the check dams tested. Of the remaining check dams, the foam berm performed well at lower slopes while the plastic dam performed well at higher slopes. The compost and rip-rap berm performance was consistent and adequate on all slopes tested.

Field Experiments

During the field study, six storm events were experienced. Of those, only four were large to provide sufficient runoff and sediment load data. The storm events that did not produce more than 2 cm of rainfall did not result in significant runoff volumes. The resulting runoff volumes and sediment loads for each check dam are given in Figure C-3. The average sediment loads are illustrated in Figure C-4.

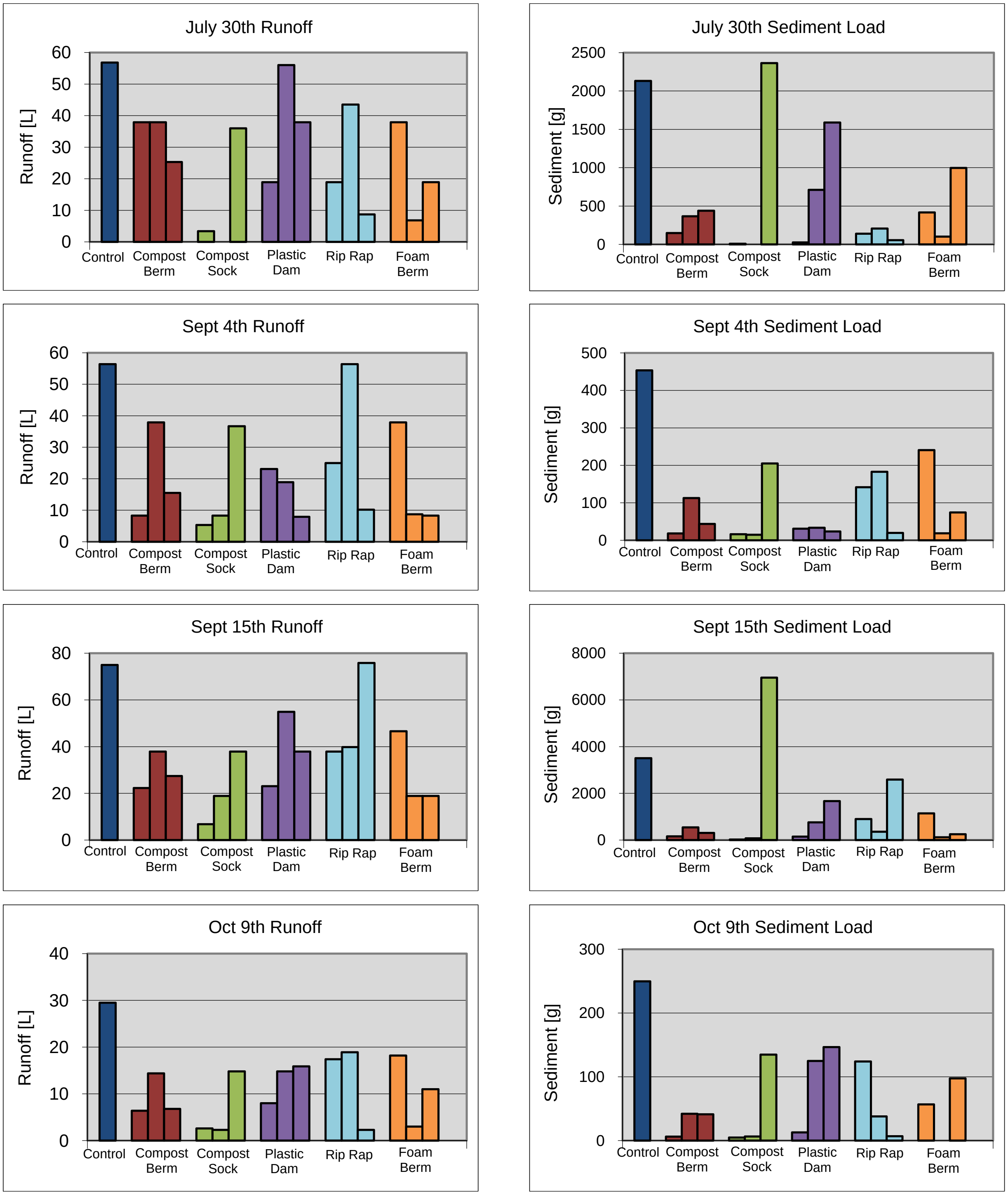

Figure C-3. Runoff volumes and sediment loads from the field study.

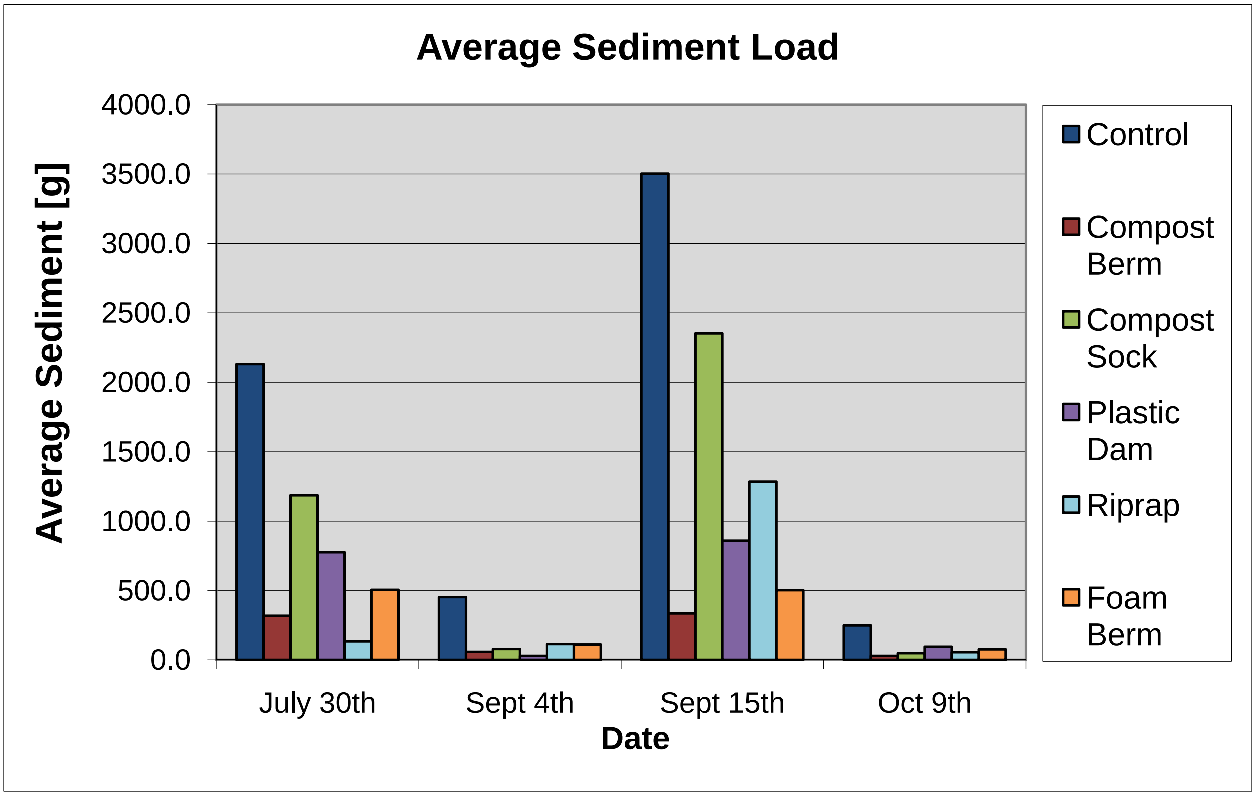

Figure C-4. Average sediment load for each treatment, over four storm events.

The observations from the laboratory experiments were generally confirmed in the results from the field experiments. In all but two cases, every treatment resulted in lower runoff and sediment loads compared to the control plot (no treatment). Figures 16-24 confirm that the compost sock treatment resulted in higher sediment and runoff loads than the other treatments. The compost berm consistently removed the sediment even in the high rainfall event (Sept 15th). The foam berm also performed well in all events. The rip-rap berm performance was excellent for three of the events but was not as effective for the high flow event. The plastic dam was consistently on the higher side of the treatments. A Welch's T-Test was performed as before on a 67% significance level (Table C-2) to determine statistical differences in the data. The rainfall depth observed is given for each storm. Superscripts indicate statistical similarity at the tested confidence level.

Table C-2. Field study sediment load 67% confidence intervals (subscripts denote statistical similarity for each event).

Check Dam Type	July 30th 3.1 cm	Sept. 4th 4.6 cm	Sept. 15th 7.6 cm	Oct. 9th 2.3 cm	Yearly Plot Total
Control	2130.9	453.5	3503.3^{a}	249.7	18907.2
Compost	318.5	58.2^{a}	335.6^{b}	29.8^{a}	2300.1
Compost Sock	$1186.0^{a,b}$	$78.7^{a,b,c}$	$2352.6^{a,c}$	$48.8^{a,b}$	9797.5^{a}
Plastic Dam	$775.8f^{a}$	29.2	859.6	94.8^{c}	$5261.8^{a,b}$
Rip-Rap	134.3	$114.7^{b,d}$	1284.1^{c}	56.3^{b}	4703.2^{b}
Foam Berm	505.1^{b}	$111.2^{c,d}$	503.5^{b}	77.1^{c}	3485.6

The statistical analysis again indicates that all check dam systems tested are better than no treatment for mitigation of runoff and sediment trapping during the varying storm intensities observed. Comparison between systems is not very precise and although general trends can be found, statistically they are too similar to have any confidence in their differences. Across the entire year, the compost berm removed the most sediment, followed by the foam berm, rip-rap, plastic dam, and compost sock. The compost berm removed the most sediment in every case except for the Sept. 4th storm event. The rip-rap performance was good except for the high-flow event. The foam berm and plastic dam performances were consistent throughout the entire year. As observed in the laboratory tests, the compost sock performed the poorest of all treatments tested. However, it removed statistically more sediment than the control situation except for the Sept. 15th high-flow event.

General Observations

The compost sock treatment was installed in an arc shape going with the direction of flow, and it was anchored into the ground per the company's recommendations. This installation practice led to better stability and durability during high flows but also led to higher amounts of runoff and sediment as the arc shape would funnel or focus the flows.

Rip-Rap berms also had the issue of taking a sheet flow and turning it into several streams of water and thus concentrating the energy and volume of the original flow. It is likely that the rock size used in the berm is a major factor in this aspect.

The triangular foam berm was highly unstable due to its light weight. Flow would routinely undercut and scour around the geo-textile base and, on certain occasions, flow went completely under the structure. This outcome led to some of the variability observed in the data.

The plastic grid dam was hard to qualify because it sat on a compost blanket. The rainfall events and subsequent runoff did not obtain significant depth of flow, so the majority of the overland flow was filtered by this compost blanket. Higher flow rates and intensities should be used to better assess this structure.

Cost and Installation

The cost and ease of installation was also investigated for each type of check dam. The cost of every product except for the compost berm was approximately the same. Table C-3 illustrates the cost of the materials for each structure. Note that these costs do not include any shipping costs, which should be taken into account when determining the best product for the situation.

Table C-3. Check dam costs per linear foot

Check Dam Type	Cost ($) per Linear Foot
Rip-rap Berm	4.75
Compost Berm	2.00
Triangular Foam Berm	4.28
Plastic Grid Dam	4.94
Compost Sock	4.25

Installation

Rip-rap berm

The rip-rap berm was the most difficult to install due to its volume and weight. Heavy machinery is required for the installation of rip-rap check dams. A woven geo-textile is required as an underlayment and should be installed on the soil surface to prevent erosion from preferential flow through the check dam. The rip-rap size specifications vary by the local NRCS should be consulted for further recommendations. Rip-rap berms should not exceed 3 ft in height and the center of the dam should at least 9 in. lower than the sides to prevent flow from eroding the edges.

Compost Berm

Compost berms can be created using locally available materials. In this study, compost was used to create a trapezoidal berm roughly 1 ft tall and 5 ft wide at the base. This large volume of material makes installation difficult without the necessary equipment. However, installation was easier than for the rip-rap berm. For long-term success, it is recommended that the compost berm be seeded and vegetated.

Triangular Foam Berm

The triangular foam berms were installed according to manufacturer specifications. The berms are pre-wrapped with geo-textile and have a front and back geo-textile "apron." The berms were placed perpendicular to the flow of water with geo-textile aprons extending 2-3 ft on both sides of the berm. Staples of No. 11 gauge wire 6-8 in. long were used to secure the berm and geo-textile aprons. The installation was fairly easy due to its light weight and the pre-wrapped geo-textile.

Plastic Grid Dam

The manufacturer recommends that plastic grid dams be installed on an erosion control blanket that is properly installed in the ditch. A number of commercially available products are adequate. For the purpose of this demonstration, locally available compost was used to create a erosion control cover. At least a 4 ft width blanket is recommended. The plastic grid dam is installed in the middle of the blanket (perpendicular to flow) and secured with 10 in. spiral stakes. At least 3 stakes must be used on the upstream side of the dam and 2 stakes on the downstream side. Once the erosion cover was installed, the installation of the grid dam was extremely easy.

Compost Sock

The compost sock is installed forming a U-shaped figure towards the incoming water to create a ponding effect. The berm must be staked with 2 x 2 in. wooden stakes at least every 5 ft to a depth of 1 ft. Stakes should not be installed in the center of the sock but on the "downstream" side at a 45-degree angle. The socks can be bought pre-filled with compost or filled on site with compost meeting manufacturer specifications. Also, the socks can be stacked if greater heights are needed, and the socks are highly malleable allowing for conformation to non-uniform surfaces. The compost sock was the fastest to install of all the berms tested.

Comparison and Conclusions of Check Dams Tested

The purpose of this study was to demonstrate and evaluate the performance of five different check dam systems under field and laboratory conditions. A summary of these findings is presented in Table C-4.

The main take-home message from the demonstration is that every check dam reduced both the runoff volume and sediment load when compared with the control (doing nothing). We also saw from the laboratory demonstration that as slope increases, the amount of sediment lost in the control case increases. This means that as the slope increases, it becomes much more important to slow down the runoff by using a check dam to allow for sedimentation.

The rip-rap berm was effective and very durable. However, volume and weight of the rip-rap material requires heavy machinery to construct the berm. If the berm is required to be in place for extended periods (months to years) a rip-rap berm is a great choice due to its durability. However, the geo-textile and edges should be inspected occasionally to ensure undercutting and scour is not taking place after a long period of time. Also, the price of the material may vary by location. If the materials are available locally, the cost to install a check dam of this type may be more economical than other options.

The compost berm performed consistently and was the most economical of all the berms tested. The nature of this type of dam also makes it a great option if compost is widely available. Due to the large volume of compost required, equipment with a loader will make the construction much easier. If the compost berm is in place for an extended period of time, it should be vegetated and routinely inspected and maintained to ensure its continued performance.

The triangular foam berm is recommended for temporary use (weeks to a few months) on low slopes. It is lightweight and very easy to install. It is not as durable as the other berms tested so it should be considered only for temporary use. It performed well at lower slopes but was one of the poorer performers at higher slopes so this finding should be kept in mind when determining which berm to use.

The plastic grid dam was the most expensive product tested. However, it is lightweight and easy to install. If a check dam needs to be installed quickly, it would be simple to spread out a compost blanket or geo-textile and stake the dam in place. Due to its construction, the dam could likely be re-used. The dam performed much better for lower flows. Higher flow rates, in which the dam was overtopped, were not tested and may not be recommended. This means it should not be used where a large area is contributing to a small outlet without further research.

The compost sock was economical, very easy to install, and has the potential for reuse. However, its ability to remove sediment and reduce runoff volumes was lower than the rest of the check dams evaluated in this study. Although the socks were prefilled with compost by the manufacturer, a particle-size analysis of the compost material found that the contained compost did not meet the manufacturer’s guidelines. This possibly contributed to the limited success of this product. Additionally, product success may be improved if a very small trench was dug (1-2 in. deep), with the check dam installed in the trench, and then backfilled and packed around the sock. While this would increase the installation time overall, it would reduce the effect of undercutting and scouring under the check dam. If compost is readily available, this check dam also is attractive due to lower costs.

Table C-4. Summary of check dam assessment and performance.

Check Dam Type	Summary of Assessment and Performance
Rip-rap Berm	• Cost similar to commercial products • Very durable • Variable performance observed in lab • Heavy, requires heavy machinery to work with • Needs geo-textile • Subject to undercutting and scour
Compost Berm	• Very efficient sediment control • Consistent performance • Most economical • Durable • Easy to install • Large volume of material
Triangular Foam Berm	• Cost similar to other products • Lightweight • Easy to install • Adequate performance • Poor durability • Subject to undercutting
Plastic Grid Dam	• Cost slightly higher than other commercial products • Lightweight • Efficient sediment control • Slightly more difficult to install due to compost blanket • Higher flow rates not tested
Compost Sock	• Cost similar to other products • Easy to install • Fast installation • Requires specific compost • Poorer performance compared with other treatments

Appendix D:

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Appendix E

ACRONYMS AND ABBREVIATIONS

Term	Spellout
AR	Army Regulation
BMP	best management practices
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
CONUS	Continental United States
DA	Department of the Army
DPW	Directorate of Public Works
DoD	Department of Defense
EO	Executive Order
EPA	Environmental Protection Agency; also USEPA
ERDC	Engineer Research and Development Center
HQUSACE	Headquarters, U.S. Army Corps of Engineers
OCONUS	outside Continental United States
PDF	portable document file
POC	point of contact
PWTB	Public Works Technical Bulletin
URL	universal resource locator
USACE	U.S. Army Corps of Engineers
WBDG	Whole Building Design Guide
WWW	World Wide Web